Virtual Reality Simulations in Web-Based Science Education

YOUNG-SUK SHIN
Division of Electronics and Information Engineering, Chonbuk National University, 7320-ho, 664-14 Duckjin-Dong, Jeonju Chonbuk, 561-756, Korea

Received 25 October 2001; accepted 1 May 2002

ABSTRACT: This article presents the educational possibilities of Web-based science education using a desktop virtual reality (VR) system. A Web site devoted to science education for middle school students has been designed and developed in the areas of earth sciences: meteorology, geophysics, geology, oceanography, and astronomy. Learners can establish by themselves the pace of their lessons using learning contents considered learner level and they can experiment in real time with the concepts they have learned, interacting with VR environments that we provide. A VR simulation program developed has been evaluated with a questionnaire from learners after learning freely on the Web. This study shows that Web-based science education using VR can be effectively used as a virtual class. When we consider the rapid development of VR technology and lowering of cost, the study can construct more immersive environments for the education in the near future.

© 2002 Wiley Periodicals, Inc. Comput Appl Eng Educ 10: 18–25, 2002; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.10014

Keywords: virtual reality simulations; interactive learning environments; Web-based learning; computer assisted instruction; science education

INTRODUCTION
Currently there is an increasing number of educators abandoning predominantly didactic, lecture-based modes of instruction, and moving towards more learner-centered models in which students are engaged in problem solving and inquiry [1].

Current technological advances make it possible to use new types of learning experiences, moving from transmission models where technology functions like books, films, or broadcasts to environments in which the technology functions like studios and laboratories in which students immerse themselves within interactive contexts that challenge and extend their understanding [2,3]. Many such technologies have been discussed in the literature [4–7]. One exciting technology that has much potential in which to ground learning in rich environments is virtual reality [3,7–9].

Virtual reality (VR) is one of the technologies that will bring dramatic changes in the educational process and environments. The ability of VR to help learners learn in a virtual class that transcends geographical boundaries facilitates constructivist
learning activity. Although the evaluation study for the educational benefits of using VR are insufficient, it has been reported that VR is a new challenging technology that increases student interests, understanding, and creative learning [3,7–9]. At first, VR meant fully immersive worlds created by computers, but more recently it has been extended to semi-immersive and desktop VR. In spite of the disadvantage of desktop VR systems, desktop VR systems are by far the most common not only because they are cost effective but also because they can be used in network environments.

Owing to the fast development of communication technology and the spreading Internet connectivity, learning on the Web has been popularized in recent years. One of the major restrictions for science education on the Web is the difficulty of laboratory activities. These problems can be overcome using simulation programs running on the Web instead of requiring hands-on experiments. Moreover, dangerous, high cost, and complicated experiments can be realized in a VR system for learners on the Web.

In this study, we investigated the educational effects of Web-based earth science education using a desktop VR system. In the first place, we describe VR as an educational tool in the area of earth science. Secondly, the Virtual Reality Simulation Program (VRSP) based on the Web for middle school students has been designed and developed. At this point, we introduce an instruction design in order to select learning levels by themselves according to the degree of the learner’s understanding or interest. Finally, the VRSP has been evaluated based on the reactions of learners who learned in VR on the Web.

VIRTUAL REALITY AS AN EDUCATIONAL TOOL ON THE WEB

Due to the spreading Internet and the fast development of computer systems, learning on the Web allows learners to establish by themselves the pace of their lessons without constraint of time and space. But one of the restrictions for science education on the Web is that it cannot support the laboratory activities. A VR simulation program can offer a virtual hands-on experimentation running on a Web browser instead of requiring hands-on physical experiments.

VR is defined as a highly interactive, computer-based multimedia environment in which the user becomes a participant in a computer-generated world. A key feature of VR is real-time interactivity where the computer is able to detect user inputs and instantaneously modify the virtual world in accordance with user interactions. Virtual reality technology may offer strong benefits in science education and engineering education not only by facilitating constructivist learning activities, but also by supporting different types of learners such as those who are visually oriented.

There are several reasons why the area of earth science is an appropriate choice for learning system using VR on the Web. In the science education, the area of earth science has many educational contents that are hard to observe and measure in real situations. Moreover, the ability to perceive and envision the spatial configuration is required.

VR learning environments can support the notion of situated learning where students learn in the actual context where that learning is to be applied. For example, the astronomical phenomena, such as exploration of the solar system, the direct and indirect motion of Mars, and the phase change of moon, are the most attractive subjects that can be taught when the learners are actively involved in the virtual environments.

Furthermore, VR has an additional benefit to support the enhancement of spatial behavior. Durlach and his colleagues reported that the use of virtual environment technology helps in training spatial behavior in the real world [10]. One of the areas of earth science that require spatial abilities in particular is structural geology. This branch deals with deformational structures of the earth’s crust and their relation to internal forces of the earth. To understand these relations, spatial abilities play a fundamental role [11,12]. This branch of the earth science is neither easy to perceive nor to measure with two-dimensional traditional textbooks. But VRSP can be viewed in many different perspectives on 3-D and so can support to perceive the spatial configuration of various structures and the shapes of different cross-sections. Therefore, VR as an educational tool on the Web will bring a dramatic changes in the educational process and environments.

VIRTUAL REALITY SIMULATION PROGRAM (VRSP) IN EARTH SCIENCE EDUCATION

Development Procedure

The development process of VR simulation program using VR technique consists of three steps. First, an instruction design to introduce new knowledge to students is provided. Second, the learning contents have been organized into three levels according to the
degree of difficulty and have been devised to put the learning subjects in a hierarchical structure. Finally, VRSP has been developed to open at our homepage for the free access by anyone including middle school students on the Web. Figure 1 shows a model about developing process of VR simulation program.

Instruction Design. Until now, Karplus’s cycle is widely accepted as a strategy to introduce new knowledge to learner [13]. It consists of three steps: First, the learners are given some environment where they can explore a given environment. They make their own observations and draw some first conclusions. Second, these preliminary conclusions are discussed with the teacher and incorrect interpretations are removed. Finally, once the new and correct explanation is acquired, new concepts are used in the exploration of a new situation, and the learning cycle repeats itself.

Our instruction design is similar to Karplus’s learning cycle model. Learners can explore a given phenomenon using VRSP and make their own observations. VRSP allows learners to develop their own reasoned interpretations through interaction with artifacts in the virtual environments without teacher’s advice and is compatible with the constructivist theory [14]. Learners can select the level of learning (regular, advanced, and remedial courses) according to the degree of the learner’s ability by Kim [15]. See Figure 2.

Educational Content. Once the educational method has been defined, our second approach is to put the contents of learning in the learner level-based learning structure for learner-centered learning. To this aim, a learner level-based learning structure has been devised with analysis methods of the inquiry level by Wood and the concept level provided by National Committee on Science Curriculum Revision about the contents of learning [16,17].

After analyzing both inquiry level and concept level about the contents of learning, the levels of learning contents can be built to regular, advanced, and remedial courses. Specially, a selection of educational contents using virtual reality was considered by mainly experimental attributes and enactive representation among the learning types (e.g., enactive representation, iconic representation, and symbolic representation) by Bruner [19]. Table 1 shows an example wherein specific contents of learning were analyzed by both inquiry level and concept level. The learning subjects such as radiation balance, earthquake waves, the earth’s crust balance, the movement of ocean, and the solar system were developed by VR. Each of these topics indicates learning subjects in the five parts in the earth science education: meteorology, geophysics, geology, oceanography, and astronomy.

The subjects of learning are also to put in a hierarchical structure in order to identify which concepts are prior to the others, and conceptual pyramids can be built. We referenced the results of an official announcement by the Department of Education to analyze a hierarchical structure [18].

Development. We have used the 3D Webmaster software for developing VR simulation programs. 3D Webmaster is a multifunctional tool to create, manipulate, texture, and animate shapes, group and ungroup objects.

It also creates various viewpoints to view VR worlds among other features. This software is the virtual reality modeling language (VRML) editing tool. VRML is the WWW standard for VR and is a language similar to HTML in that it establishes a
common standard for making VR easily distributed over the Internet. The world created from this software can be displayed on the Web as fully interactive environments, or embedded in 2D HTML pages on a PC.

Worlds created in 3D Webmaster are fast, realistic, and highly interactive. URLs can be linked to objects so that it can link directly from one virtual world to any other 2D or 3D page on the WWW. A script language for desktop computers, the Superscape Control Language (SCL), helps to create realistic and useful worlds to assign behaviors to objects in the world, perform complex actions, and modify virtual worlds based on user’s actions in the HTML documents. 3D Webmaster’s point-and-click interface can control all movement, interaction, and object manipulation in the virtual worlds by using mouse and keyboard, or a peripheral device such as a space-mouse or joystick.

A Web site for five virtual experiment laboratories is shown in Figure 3. In the following, we introduce briefly each of the virtual experiment laboratories. 

**Meteorology VRSP: e.g., The Radiation Balance.**
A virtual experiment set-up for the radiation balance of the sun is shown in Figure 4. Learners can understand concepts of the radiation balance of the sun using a temperature variation of a cup with the color in proportion to the distance from a light source. Learners can move by dragging mouse if they want to move a cup with a thermometer. If a button on the left of the display screen is clicked after moving each cup, a display screen in front will show increasing temperature according to each cup.

After exploring and interacting with the artifacts on the virtual environment, learners can have a result data of experiment, make their own observations and understand a science concept or a tendency involved in experimental data that the relation of a distance of a light source and the color of cup (light of a light source) reflects a cause of increasing temperature.

**Geophysics VRSP: e.g., The Earthquake Waves.**
A virtual experiment set-up for the earthquake waves inside the earth is shown in Figure 5. The waves and a value of velocity have been selected from the students, then they can explore features of each wave selected in the 3D. The topic of earthquake waves is a good example of abstract learning subjects that are difficult to learn.

In the virtual experiment environments, learners can experience the abstract concepts taking shape in concrete forms. Theoretically, this enables them to build a concrete mental model about the abstract concepts.
information that the waves of earthquake have certain shape and a vibrating direction of medium.

**Geology VRSP: e.g., The Earth’s Crust Balance.**

A virtual experimental set-up for learning of the earth’s crust balance is shown in Figure 6. This VRSP was designed to explore the earth’s crust floating on the mantle. Learners can drop by dragging optional blocks in a water tank with a mouse button and observe the length of blocks in the water tank according to the scale and density of blocks on the 3D. We designed a visual symbol as blocks of tree floating in a water tank in order to create concrete metaphor of the earth’s crust structure floating on the mantle. As Johnson points out, “small-scale models of reality need neither be wholly
accurate nor correspond completely with what they model in order to be useful” [20]. VRSP can represent models that highlight the information deemed appropriate by an instructor.

**Oceanography VRSP:** e.g., *The Movement of Ocean.* A virtual experiment set-up for learning of the ocean’s movement is shown in Figure 7. This VRSP was designed to explore the causes of generating an ocean current through water observed in a water tank. Learners can observe the water in a water tank by controlling a weathercock. The weathercock is a visual symbol in order to create concrete metaphor of the wind.

**Astronomy VRSP:** e.g., *The Solar System.* A virtual experiment set-up for the solar system is shown in Figure 8. Astronomical phenomena, such as the exploration of the solar system, can be taught when learners are actively involved in the virtual environments. Learners can not only simulate the 3-D relative motion of nine planets and other families of the solar system, but also explore more closely the characteristics of the solar system by the capacity of zoom. Learners can also explore the relative size and distance among the families of the solar system.

**PEDAGOGICAL EFFECTIVENESS**

The VRSP developed has been evaluated to the reactions of learners taught in virtual reality on the Web. Upon learning the VRSP, each learner completed a questionnaire which featured three-point scales that asked learners to rate such things as their achievement of learning object, their satisfaction of learning contents, whether or not they were interested in or enjoyed the virtual environment, and whether it was easy to move around and interact with objects in the virtual environment.

We directly investigated the reactions of learners on the Web without limitations about sex, age, and the style of job. After completing the questionnaire, applicants were to write their personal information (e.g., sex, age, job, etc.), but many applicants did not give their personal information. Applicants who gave their personal information were 231 (56.4%) secondary school students, 132 (32.4%) university students and secondary school teachers, and 47 (11.2%) others. The distribution of sex was 210 (51.2%) male and 200 (48.8%) female.

The survey results of learners’ responses are shown in Table 2 and Figure 9. We asked learners the following questions. (A) Were the teaching materials

<table>
<thead>
<tr>
<th>Question</th>
<th>Agree (response)</th>
<th>Common (response)</th>
<th>Disagree (response)</th>
<th>Total No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>54% (381)</td>
<td>32% (218)</td>
<td>14% (102)</td>
<td>701</td>
</tr>
<tr>
<td>(B)</td>
<td>54% (347)</td>
<td>32% (201)</td>
<td>14% (87)</td>
<td>635</td>
</tr>
<tr>
<td>(C)</td>
<td>50% (313)</td>
<td>39% (244)</td>
<td>11% (70)</td>
<td>627</td>
</tr>
<tr>
<td>(D)</td>
<td>42% (257)</td>
<td>35% (218)</td>
<td>23% (141)</td>
<td>616</td>
</tr>
<tr>
<td>(E)</td>
<td>44% (277)</td>
<td>37% (231)</td>
<td>19% (117)</td>
<td>625</td>
</tr>
<tr>
<td>(F)</td>
<td>50% (311)</td>
<td>34% (207)</td>
<td>16% (98)</td>
<td>616</td>
</tr>
<tr>
<td>(G)</td>
<td>51% (309)</td>
<td>32% (193)</td>
<td>17% (102)</td>
<td>604</td>
</tr>
</tbody>
</table>
useful in helping learners to understand the subject? (B) Could learners easily understand the subject? (C) Were the contents of learning described clearly? (D) Did learners enjoy their experience in the VRSP? (E) Could learners participate actively in the VRSP? (F) Was the screen composition well designed? (G) Could learners easily move around and interact with objects in the virtual environment? The total number of responses to each question is different. With 701, largest number of the applicants participated in the first question; the lowest number of applicants was 604.

The results of survey indicated that learners reported positively more than 50% over (A), (B), (C), (F), and (G) questions asking about desktop VR environment on the Web. However, (D) and (E) were reported negatively less than 50%. It seems that learners understand the learning subjects well in desktop VR, while they do not enjoy the experience of VR. This suggests that the desktop VR environment did not support immersion or the full presence as fully immersive VR. It seems that the desktop VR environment implements VR environment with only software authoring tool without using hardware equipment like HMD (Head Mounted Display), haptic devices, etc.

CONCLUSIONS

This paper presented the educational possibilities of Web-based science education using a desktop VR system. It is feasible to use a virtual reality simulation program doing laboratory activities on the Web. Even if the VRSP does not support full enjoyment of the VR experience, it is useful for realistic hands-on experimentation and replacement of dangerous and high-cost laboratories. Also, it enhances the learner's understanding with interactive learning environments.

We developed virtual reality simulation programs to teach science concepts such as radiation balance, earthquake waves, the earth's crust balance, the movement of the ocean, and the solar system at the level of middle school.

We can support that the VRSP on the Web for scientific education can be more effectively used as a virtual class when we consider the rapid development of VR technology and lowering of cost in the future.

ACKNOWLEDGMENT

This work was supported by Korean Research Foundation Grant (KRF-99-005-D00076).

REFERENCES


BIOGRAPHY

Young-Suk Shin is a Funded Processor at the Chonbuk National University of Electronics and Information Engineering in Jeonju. She has a master’s degree in computer education and a PhD in cognitive science from the Yonsei University, Korea. Her research interests include virtual reality, cognitive modeling, computer vision, and pattern recognition. She has been teaching computer vision and pattern recognition and has studied pedagogical models for education project using the virtual reality and emotion recognition based on facial expression.