Enhancing Spatial Visualization through Virtual Reality on the Web: Software Design and Impact Analysis

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Abstract: Rapid advances in the global information infrastructure herald a new era of computer-assisted instruction based on multimedia capabilities and online access. One of the most promising developments lies in virtual reality (VR), which allows for an immersed learning experience in simulated environments spanning 3 dimensions. VR can be used to merge images, video, animation, and text to provide a rich sensory environment. This capability can be deployed to support instruction in spatial visualization and geometric reasoning. The multimedia presentation in concert with the active involvement of the user can make the learning experience more comprehensible, enjoyable, and memorable. This paper explores some background issues relating to the use of VR on the Internet, and demonstrates the promise of the novel technology in the context of spatial visualization.

Introduction

In recent years, the rapid development of the Internet and multimedia capabilities has led to rapid innovations in the fields of science, education, business, and other domains. One of the most promising applications of the infobahn lies in education. A widely recognized strength of the Internet lies in its vast arsenal of data and documents (Pea and Gomez, 1992).

The potential of computer networks to revolutionize education has been widely acclaimed. Unfortunately, much like the earlier technologies of television and film, the envisioned promise of computer networks has remained largely unfulfilled (Solis, 1997).

Since the mid-1990s, a promising new technology has appeared in the form of virtual reality (VR) on the Internet. The technology allows for the simulation of 3-dimensional worlds on a 2-dimensional computer screen. Through a simulated control panel known as a dashboard, the user can explore the virtual environment in any direction: moving forward, backward, up, down, and sideways or spinning on the spot. Moreover, the interaction occurs in real time.

In the literature, several studies have reported on training materials to enhance spatial visualization abilities in general and spatial visualization in particular. To date, most of the programs have focused on the manipulation of physical objects. However, the use of tangible objects is subject to drawbacks such as procurement cost, storage space, restricted access, and mechanical failure. These limitations underscore the need for materials which transcend the constraints of temporal access and physical space. To this end, VR on the Internet represents a promising vehicle to enhance the learning environment.

The next section presents the background behind spatial visualization as well as VR on the Web. The material is followed by a case study in the form of an educational program to enhance spatial visualization. The concluding section presents some final remarks and directions for the future.

Theoretical Background

Spatial visualization represents a subset of spatial skills. The former has been described by McGee (1979) as “the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object.” (McGee, 1979, p. 893). According to one school of thought, mental manipulation is the primary task in spatial visualization (Ben-Chaim et al., 1988).

The importance of spatial visualization springs its relationship to most technical and artistic occupations including mathematics, science, art, and engineering. However, spatial visualization is not one of the standard components of the school curriculum. Rather, spatial reasoning is acquired informally through informal channels.

Even so, several studies of training programs to improve spatial visualization have been reported in the literature, in concert with various theoretical analyses and hypotheses regarding spatial visualization ability (Ben-Chaim et al., 1988; Battista, 1990; Battista & Clements, 1996; Lean & Clements, 1981).

Virtual reality on the Internet is a technology which allows for the fusion of multimedia files ranging from text to video. In addition, the technology offers a novel capability through its ability to present simulated 3-dimensional worlds.

VR on the Internet has been implemented through various formats. Perhaps the most versatile among these standards lies in the Virtual Reality Modeling Language (VRML). The language provides a relatively compact description of 3-D worlds which can be rendered or depicted using appropriate software.

VRML is a complement to the HyperText Markup Language (HTML), which specifies how information should be presented in a 2-D format on a computer screen. The complementary nature of HTML and VRML is illustrated by a program in which HTML is used to specify a window on a computer monitor. For this application, HTML could be used to partition the window into several frames, one of which might present a 3-D world specified through VRML; another frame might provide explanatory material for the VRML world through text and 2-D images specified in

HTML.

A third complementary standard lies in the Java programming language. Java is a general-purpose language which can be used to depict objects in HTML or control a VRML world. For instance, an applet is a small program written in Java which may be used for, say, providing an animation of a dog running across a 2-D scene whose overall structure is specified in HTML. In an analogous way, Java can be used to process information or specify complex relationships among objects in a 3-D world whose overall organization is specified in VRML.

The technologies of HTML, VRML, and Java provide a versatile vehicle for presenting information to students in multiple media formats. HTML can be used to lay out the 2-D presentation on the screen, while VRML provides a 3-D multisensory experience, and Java is used to control behaviors within and between the following interfaces: the 2-D screen, the 3-D world, and complex interactions with the user.

The present study involves the creation of software using VR to enhance spatial visualization skills, followed by an analysis of its efficacy. Differences in the performance among the students on a spatial visualization test were investigated, both before and after instruction using the software. More specifically, the study was designed to address the following questions:

- Does Web-based instruction in spatial visualization affect the attendant capabilities among students?
- Do the effects differ for spatial visualization instruction through virtual reality in comparison to simple text and graphics?
- Which sub-factors of spatial visualization are affected the most by the use of virtual reality on the Web?

Methodology

The study was conducted in fall 1999 at two girls' high schools in neighboring districts in southern Korea. The schools were the most prestigious in their respective districts, and were of equal caliber as measured by scores on a nation-wide entrance exam. Each of the two schools featured about 50 PC's in its computer laboratory, all of them with full Internet connectivity.

All students in the sample were members of tenth-grade computer classes taught by mathematics teachers. The two teachers, both male, had recently become digital enthusiasts and wished to introduce their students to the potential of the Internet.

Before embarking on the instruction, all the students were administered the MGMP Spatial Visualization Test to obtain a baseline and background information on their skills. The Test was developed by the Middle Grade Mathematics Project (MGMP) funded by the National Science Foundation (Ben-Chaim et al., 1988). Thirty-two multiple-choice items, each with five options, comprise the test. The test is an untimed test with 10 different types of items. The types of representations used are as follows: two-dimensional flat views, three-dimensional corner views, and a "map plan," which depicts the base of a building using numbers within squares to indicate the number of cubes to be placed on each spot. The test includes tasks such as finding either flat or corner views of "buildings," adding and removing cubes, combining two solids, or applying the notion of a "map plan".

After the pretest was given, all the students studied the software on the Web. The material required an average of about 2 hours of study, spaced over a period of approximately 2 weeks in December 1999. Then the posttest was administered immediately after the end of this period.

Case Study

A vital aspect of effective learning is the engagement of the student as an active participant. The use of virtual reality as a vehicle for education offers the following advantages.

- *Student interest.* VR offers a lively medium with a richer sensory texture than 2-D platforms such as books or television. The medium naturally attracts the student's attention. A motivated student is more likely to absorb and retain the material presented. In addition to the inherent attractiveness of VR, our case study elicits interest by presenting the target material in the form of a game.
- *Multiple media.* An amalgam of visual media helps to capture the student's attention and to develop a mental model of the material at hand. The technology of VR offers multiple visual formats such as imagery, animation, and video. Moreover, VR provides an integrated platform for sound and text as well as visual modes. These sensory models can be combined in synergistic fashion to convey concepts in a compelling way.
- *Learning by doing.* Many courses in the curriculum involve laboratory exercises in order to provide an immersive experience for the student. However, experimental facilities can be expensive to maintain, cumbersome to handle, time-consuming to run, and sometimes hazardous for the users. All these limitations can be reduced or even eliminated through computer simulations, while at the same time providing a realistic experience. These same factors have been prompting organizations around the world to rely on computer simulations to an increasing extent, ranging from business games to military training.

Our case study involved the development of an educational software to enhance spatial visualization ability. The software itself was implemented in VRML code. A snapshot of the primary module in VRML is shown in the left pane of the screenshot in Figure 1. By using the mouse, a student could rotate the virtual building along any axis, or “move around” to see any side of the building at will.

As shown in the figure, the VRML module was displayed in one of two key frames in the window. The overall format of the window was specified through HTML.

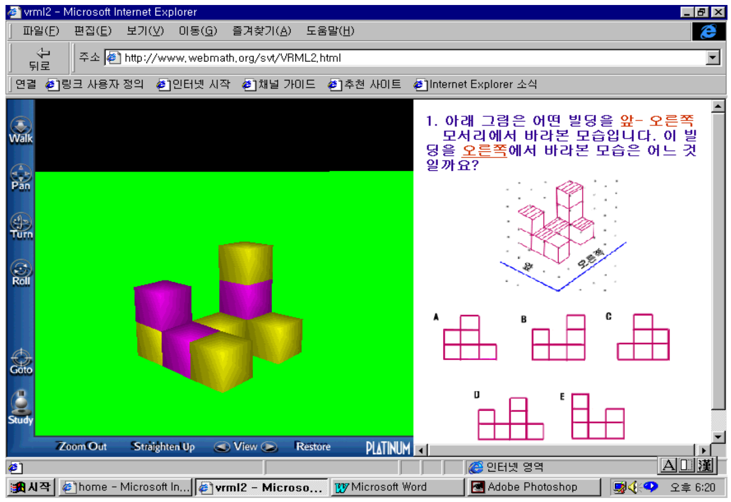

Figure 1. Spatial visualization software using virtual reality.

Data Analysis and Results

An analysis of the pretest data was first conducted in order to determine whether the group difference in spatial visualization was statistically significant. A summary of the analysis of variance on the pretest scores for the treatment and control groups is reported in Table 1. As anticipated, the intergroup difference was not statistically significant at the .05 level. The result indicated that the two groups were relatively homogeneous in their spatial visualization skills prior to instruction.

Table 1. Comparison of the pretest scores between the treatment and control groups.

	N	Mean	Standard Deviation	t	p
Treatment Group	36	25.55	4.39	1.163	.250
Control Croup	31	24.09	5.66		

An analysis of variance for the gain scores (posttest minus pretest) for the treatment and control groups separately is reported in Table 2. For each group, there was a significant overall gain on the MGMP Spatial Test. According to the t-test for two dependent samples, the t-value was -6.69 with $p< .000$ for the treatment group; and -3.36 with $p< .002$ for control group. Therefore, for each of the two groups, the difference between the pretest and posttest was statistically significant. One interesting outcome was that the standard deviation for the treatment group declined dramatically after the experiment. The result of this investigation showed that spatial visualization ability for each group improved significantly after the Web-based instruction.

Table 2. Comparison of the gain scores for the two groups.

	Treatment Group (N=36)		Control Group (N=31)	
	Pretest	Posttest	Pretest	Posttest
Mean	25.55	29.66	24.09	27.00
Standard Deviation	4.39	1.62	5.66	4.78
t	-6.69		-3.36	
p	.000**		.002*	

*p< .01

**p< .001

Table 3 presents an analysis the posttest results for the treatment and control groups. This comparison indicates the differential impact between software using virtual reality versus that without. The t-value using the t-test for two independent samples was 2.95 with p< .005. This result indicated that the instructional effect of the program using virtual reality was higher than that employing only text and images.

Table 3. Comparison of the posttest results for the treatment and control groups.

	N	Mean	Standard Deviation	t	p
Treatment Group	36	29.66	1.62	2.95	.005*
Control Group	31	27.00	4.78		

*p< .01

Table 4 presents the results of the pretest and posttest by item type for both the treatment and control groups. Item type 10 yielded a surprise: the difference between the treatment and control groups on the pretest was statistically significant at the .01 level. On the whole, however, spatial ability between the two groups did not differ significantly prior to the Web-based instruction intervention.

On the other hand, a significant difference in improvement due to the treatment was observed for item types 1, 2, 4, 8, and 10. There five item types dealt with the rotation factor, one of the sub-factors of spatial visualization. We may infer that the spatial visualization program using virtual reality was more effective than the one without. Moreover, VR software was most effective for enhancing the rotation factor in the spatial visualization task.

Table 4. The proportion of correct responses on the pretest and posttest by item type for each group.

Item Type	Pretest Treatment Group (N=36)	Pretest Control Group (N=31)	p	Posttest Treatment Group (N=36)	Posttest Control Group (N=31)	p
1	.89	.81	.117	.97	.86	.019*
2	.91	.79	.079	.93	.79	.032*
3	.92	.83	.489	.96	.95	.860
4	.98	.95	.330	1.00	.82	.003**
5	.70	.75	.441	.71	.66	.482
6	.87	.88	.866	.93	.93	.918
7	.83	.87	.274	.97	.95	.407
8	.63	.55	.277	.91	.79	.041*
9	.83	.69	.070	.94	.88	.212
10	.74	.55	.003**	.93	.84	.008**

*p < .05

**p < .01

Conclusion

The study investigated a number of issues relating to spatial visualization. The results were follows. First, Web-based instruction for spatial visualization was capable of improving the target skills. Second, the spatial visualization program using virtual reality was more effective than its counterpart composed solely of text and images. Finally, the Web-based program using virtual reality for spatial visualization was particularly effective for enhancing skills in three dimensional rotation.

The results indicate that certain materials which are difficult to teach in the mathematics curriculum can be taught effectively through suitable Web-based instruction. In particular, virtual reality is a versatile vehicle for enhancing spatial visualization, presumably due to its interactivity and dynamic display for the user.

The efficacy of Web-based instruction has been demonstrated through an educational program encoded in VRML. Virtual reality on the Internet provides an integrated environment for accessing the wealth of information being digitized all over the globe. Not only is access possible, but VR offers a multisensory vehicle for presenting information in a compelling way. The active role of the user in navigating a virtual 3-D space and the instant response of the system provide an immersive experience.

One promising direction for the future lies in autonomous learning capabilities. The maturation of machine learning techniques offers a means of developing intelligent tutoring systems which can tailor a presentation not only to the basic level of expertise for a particular student, but also to his or her changing level of knowledge. The learning capabilities may be implemented using techniques such as case based reasoning, neural networks, and induction.

Such intelligence may be implemented as a kernel of a smart system for multimedia presentations. A framework for such intelligent systems has already been developed (Bordegoni et al., 1997). The framework for intelligent presentations has been adapted to software agents and their embodiment as icons (Andre, 1997). The framework may also be tailored readily to the educational environment. We plan to investigate these and related topics in the years to come.

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