Int. J. Engng Ed. Vol. 23, No. 6, pp. 1192–1198, 2007
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Experiences in Using Virtual Reality in Design and Graphics Classrooms*

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This paper discusses how the use of virtual reality technology impacts student learning and faculty teaching methods, both individually and collectively. Experiences concerning implementation and interactions between instructors and students are presented. Surveys were conducted to collect students' responses concerning the use of VR in design and graphics classrooms. Students noted that the use of VR offers advantages over other learning methods. Students' spatial skills were significantly improved after a semester of virtual reality-based instruction. Some challenges in implementing virtual reality in classrooms are also discussed.

Keywords: virtual reality; visualization; design and graphics

INTRODUCTION

THREE-DIMENSIONAL VISUALIZATION ABILITY impacts, to a great extent, students' performance in design and technical graphics courses. In addition, prior research shows that a student's 3D visualization ability greatly influences their future career success in science, engineering, and technology [1–2].

One way to enhance students' abilities to visualize 3D objects is to make their experience of the objects, while learning, as realistic as possible. In fact, in general, it can be very difficult to clearly describe to students a 3D object and the spatial relationships between object components, without using a physical mockup. However, physical mockups take a lot of time to construct, especially for more-complex objects.

As a result, graphics educators have started to use 3D CAD tools to help students understand spatial relationships between objects and to bridge the gaps in design and manufacturing education [3–4]. However, traditional CAD tools only allow students to examine 3D models from outside flat computer monitors. In other words, the models and the viewers are in different realms. Using CAD tools, students cannot view models with natural stereoscopic vision.

Now, however, low-cost virtual reality (VR) tools are becoming available that can be used to improve visualization capabilities in classrooms [3–7]. In fact, with advances in hardware and software, most PC computers now have the capability to create VR images. It is also clear that there is a growing use of VR in industry as well. In 2004, the National Institute of Standards and Technology (NIST) website listed more than 60 projects for which it provided industry grants to develop and apply VR technology.

VR is a way of simulating or replicating an environment to give the user a sense of being in, taking control of, and physically interacting with the environment [8]. VR technology creates a

* Accepted 13 August 2007.

simulated 3D environment by using computer technology to create and alternately display separate right-eye and left-eye images of the same 3D objects. The viewer's brain integrates the information from the two perspectives to create the perception of 3D space. As a result, VR technology can break down barriers between humans and computers by immersing viewers in a computer-generated stereoscopic environment.

Prior research supports the use of VR as a useful tool for encouraging interaction [9], engaging and motivating learners [10], and increasing knowledge retention [11]. However, there is little guidance from prior studies regarding instructional design and classroom use of VR technologies. As a result, the study project had two primary aims: first, to design and implement VR-based instruction for design and technical graphics classes and, second, to examine how VR use influences student/faculty interaction.

This paper presents the results of a three-year study that introduced VR tools into design and graphics classrooms at three higher education institutions, including two two-year colleges and one four-year college. The paper considers how the use of VR technology in design and graphics classrooms impacts both learners (students) and learning facilitators (faculty). First, the impact of technology change on each of the individual components is examined. Next, challenges that using VR technology creates for interactions between students and faculty are discussed. Finally, possible ways that VR technology could be used to enhance design and graphics education are discussed.

FACULTY

Changing roles

It is important to recognize the resulting shifts in faculty roles that accompany efforts to develop new learning environments. There is a need to see the role of teachers as designers and managers of the learning environments (including the design and development of electronic materials), not merely as presenters of information or facilitators for achieving traditional learning outcomes [12].

It is difficult for faculty to revise, restructure, and reinvent courses in an effort to incorporate new technologies. One significant challenge is the need to devote time and energy into new efforts with uncertain benefits. Second, faculty often struggle with ways to use technology-enhanced pedagogies. This struggle is often caused by a combination of little exposure to research about the process of teaching and learning and a lack of attention to these processes in higher education environments.

During the project, the new challenges faculty faced when developing the new learning environments entailed not only creating virtual models that were relevant to various course content, but also finding ways to incorporate the virtual models into effective learning activities. To overcome the challenges, based upon recommendations by Bass [12], the participating faculty members, to different degrees, took a research-based approach to developing both relevant models and learning exercises. In particular, faculty members reviewed prior use of VR visualization tools in classrooms, visualization skills development methods, and available low-cost VR tools. The research-intensive approach led to successful implementation and study results.

Certainly, the use of new technology creates new challenges for faculty members that require new learning, in the research domain. In other words, use of technology re-shapes faculty roles during the learning process. It is also important to acknowledge that the shifts in faculty roles occur over time and continue throughout the implementation and use of the new technology.

Use of VR

As an example of how VR tools were used in study classrooms, two faculty members independently considered how to effectively use the new VR tools to develop students' spatial visualization skills. In most cases, to develop students' 3D spatial skills, graphics curricula begin with multi-view sketching (an abstract concept) and then move to pictorial sketching (a semi-concrete concept). As a result, in one course at a community college, students were given sets of multi-view sketches and were asked to develop 3D CAD models that matched the sketches. Students then converted the 3D CAD models into VR models, some of the VR models were projected onto a display screen at the front of the class, and the class, as a group, viewed and discussed the resulting models.

However, at the four-year college, the participating faculty member discovered, from prior research related to spatial skills development, that the traditional topic sequence is opposite to the way that many educational psychologists believe students learn. As a result, in a similar course at the four-year college, students were asked to view VR models, to gain an understanding of the models' appearance and the 3D spatial relationships between parts of the models, as shown in Fig. 1. They were then asked to create multi-view projections for the 3D virtual objects. A remote control was also developed, so students could manipulate the models into different views.

This example illustrates how different faculty members, who participated in the study, considered not only how to physically generate VR models that were relevant to course content, but also how to effectively incorporate the models into structured learning activities designed to achieve course objectives.

Challenges of integrating technology

It is important to consider the challenges associated with integrating VR technology into design

Fig. 1. Students observed VR models using 3D glasses.

and graphics curricula. For example, Olkun [13] indicated that timing and content are two crucial elements when designing instructional tasks to improve spatial abilities.

One of the faculty members who participated in the study commented that VR seems to open new vistas, but that it can be difficult to find the best ways to implement VR in the classroom, "There is so much power, and I think that I am only using half of the power . . .There are not a lot of books about how to teach using VR." All of the faculty members felt that their teaching methods changed and developed while using the technology. Study results verify conclusions drawn by Bass [12] that integration of a new technology requires a revised view of teachers' roles as designers and managers of their learning environments.

A specific challenge associated with using VR in this study was to find ways to integrate the use of the technology into the existing curricula and learning experiences. Faculty members had to find and develop ways to use the new VR technology that supported, rather than interfered, with student learning. For example, early in the study, instructors found that delays for converting 3D models into VR format, and then displaying the VR models, could disrupt the educational flow. As a result, several improvements were made during the course of the project to enhance the incorporation of VR models in the classrooms.

One improvement that was made was the development and acquisition of various software applications to facilitate converting CAD models into VR models. A second improvement that was made was the integration of VR hardware into the regular classroom setup. At one site, prior to the change, the faculty member used one computer to present most course information and a second computer to present VR models. The set up required using a video switch to change projectors and the video settings required for VR projections, which did not allow simultaneous use of multiple technologies (e.g., use of a Smart Board and a VR model), required additional set-up time, and caused interruptions during classroom lessons. To resolve the problem, all of the course content, including VR models and VR software were incorporated onto a single computer with a single projection system. In addition, to reduce the time required to calibrate the projection systems used for displaying VR images, the VR projectors at all three sites were permanently mounted on the ceilings of all of the study classrooms. The changes helped promote attention to intended course content, rather than the VR software and hardware associated with the challenges.

Faculty members also faced a challenge concerning how much time was appropriate for using the new VR technology in their classrooms. While all participating faculty members agreed that the VR technology provided students with another way to think about design and provided a new technology to help students find solutions to design problems, they also recognized that VR represents one among several tools. Specifically, participating faculty members commented that, although students need to learn how to use the new tools and technology, they also need to maintain their ability to use and integrate various technology tools. Faculty members also felt that students need to develop design skills without relying on any single technology tool for assistance.

STUDENTS

The use of VR may be particularly effective for students in design or engineering drawing classes, because interactive VR environments capitalize on visual learning styles and allow visual interaction and experimentation with complex information, which can enhance understanding of engineering principles [11]. The project faculty members were interested in determining both student perceptions of VR effectiveness and the impact of VR use on students' visualization skills. Each of the areas is discussed below.

Student perceptions of VR effectiveness

A survey was administered at the end of the semester to examine students' perceptions of the effectiveness of integrating VR into the course curricula and to investigate issues of physical discomfort associated with VR.

Demographics

A total of 27 students completed the survey, including 2 females and 25 males. Students ranged in age from 18 to 36. Seven students were freshman, nine were sophomores, eight were juniors, and three were seniors.

Student survey

Survey results provided information regarding students' perceptions of the course: how the course influenced their abilities, how the experience contributed to course objectives, and how experiencing VR affected them physically. A Likert scale was used for the survey, where 1 = disagree strongly, 2 = disagree, 3 = undecided, 4 = agree, and 5 = agree strongly.

Ability

Table 1 provides the means and standard deviations for students on survey items related to ability. Students agreed that the course improved their abilities in several areas, including their ability to design products (mean = 4.56) and their ability to communicate using graphics (mean = 4.30). Students also indicated that they gained confidence in 3D visualization skills (mean = 3.96).

Students indicated they did not find the course frustrating and were planning on staying in the program. Students provided relatively high rankings for course enjoyment, noting that they were fully engaged in the instruction (mean = 4.00) and that they enjoyed the 3D VR instruction delivered in the course (mean = 4.37). Additionally, students agreed that the class improved the way that they learned (mean = 3.81).

Perception

Table 2 provides the means and standard deviations for students on survey items related to perception of VR use. Students were asked several questions related to their perceptions of VR and the instructional materials for the course. Responses indicated that students agreed with all items associated with a positive perception of VR and the instructional materials for the course. Students also indicated that the VR program was interesting, easy to understand, provided clear understanding of presented material, and represented a preferred learning method.

Students noted that the use of VR offers advantages over other learning methods. Students agreed that it is easier to view a 3D world in VR than on a flat computer screen (mean = 3.96), that learning with VR is more engaging than learning from books or lectures (mean = 4.19), and that they could learn more in other subjects if VR programs were available (mean = 3.78). Similarly, students disagreed (mean = 2.37) that they preferred to learn multi-view projections using 2D pictures rather than VR 3D simulation.

Table 1 Means, standard deviation, and composite means for ability survey items ($n = 27$)[1]

Ability	Mean	SD
The course improved my ability to design products	4.56	0.51
The course improved my problem-solving ability	3.78	0.75
The course improved my presentation skills	3.52	0.64
The course improved my graphics communication skills	4.30	0.54
The course and 3D components were frustrating for me	1.89	0.89
I considered dropping out of the program	1.60	0.87
My instructor encouraged me not to major in CAD	1.96	0.90
I gained confidence in my 3D visualization skills in this course	3.96	0.76
I enjoyed the 3D instruction in this course	4.37	0.49
I was fully engaged in the instruction in this course	4.00	0.63
The class improved the way that I learn	3.81	0.79
VR helped me better remember how to do something again the next time I used it	3.63	0.63
I can now use VR technology in product design	3.65	0.69
My 3D spatial visualization skills improved as a result of this course	3.85	0.82

[1] Scale: 1 = disagree strongly, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree.

Table 2. Means, standard deviation, and composite means for perception survey items ($n = 27$)[1]

Perception	Mean	SD
This method of delivering graphics concepts is the most effective	3.96	0.59
My experiencing of the 3D objects was realistic	4.27	0.45
The class stimulated my interest in leading-edge technology	4.00	0.62
VR is a good playground for experiments	4.11	0.42
I want to experience VR again	4.26	0.45
It is easier to view a 3D world in VR than on a flat computer screen	3.96	0.85
Learning with VR is more engaging than learning from reading books and listening to lectures using overheads containing graphics or pictures	4.19	0.94
VR technology is a useful tool for design and technical graphics education	4.15	0.66
The instructional materials for this course were clear	4.07	0.47
The instructional materials for this course contributed to my learning	3.96	0.45
The VR is easy to use	3.70	0.72
The VR program is user-friendly	3.65	0.63
I believe that I could learn more in other subjects if VR programs like this one were available	3.78	0.70
The VR program was dull and uninteresting	2.30	0.82
The VR was not easy to understand	2.37	0.88
I could not clearly understand the material presented in VR	2.07	0.73
I prefer to learn multi-view projections using 2D pictures rather than VR 3D simulation	2.37	0.88

[1] Scale: 1 = disagree strongly, 2 = disagree, 3 = undecided, 4 = agree, 5 = strongly agree

Pre- and post-mental rotation tests (MRT)

To assess students' growth in spatial visualization skills, a mental rotation test (MRT) was administered at the beginning and end of the semester, at all three participating institutions.

Combined results

A total of 56 students completed both the pre- and post-MRT. For the overall group of 56 students, the mean post-MRT score (25.29) was statistically significantly higher than the mean pre-MRT score (21.70), $t\ (55) = 4.84$, $p < 0.001$. When comparing the change in scores from pre- to post-test, ten students had a lower post-test score, four students had the same score, and 42 students had a higher post-test score. The two sets of data show a statistically significant difference; the mean post-MRT score was higher than the mean pre-MRT.

STUDENT/FACULTY INTERACTION

Information from various project activities (e.g., faculty project reports and student focus groups) indicated that VR technology use in classrooms may enhance interaction between students and faculty in significant ways. One common theme expressed by students who participated in focus groups, at all three study institutions, was that each faculty member used coaching strategies and group activities to encourage self-directed problem solving. The common learning strategy appears to be a response to industry recommendations, from interviews, concerning ways to enhance skill development.

One way the new VR technology further enhances the likelihood of coaching and group activities is that the technology promotes spending more time with students to explore questions or learning topics through example models in 3D VR format. Without VR technology, faculty members are often limited in what they can consider with students, since developing physical models or attempting to help students visualize specific components of an object simply takes too much time. With the new VR technology, instructors can maintain focus on learning objectives and, at the same time, coach students to help them achieve learning goals.

The participating faculty also found that the use of VR may assist students and faculty members create opportunities to discuss ideas and to visualize objects. Rather than students engaging in a solitary process, which may be misguided, the use of VR may allow opportunities to make the process more collaborative. An additional benefit may be the ability to quickly detect any mistakes in the visualization or ideation aspects of the design process, which gives student more time to focus on learning content, rather than duplicating efforts to correct initial mistakes.

In short, study findings show that VR tools can help faculty and students to focus on improving comprehension of complex systems through discourse and processing, rather than to focus on transmission of concepts or terms. An additional benefit of VR is that the creation of visible and accessible records of learning (i.e., models) makes it possible to engage students in metacognitive activities in which developing critical perspectives on their own learning or peer's learning becomes an integral part of the experience [12]. For example, when students use VR to present models that they have created to meet specific criteria, it makes learning visible and engages students and faculty in learning discussions.

CHALLENGES IN VR RESEARCH

Several researchers have highlighted problems that limit current efforts to pursue VR research. Some of the challenges include lack of necessary computing equipment for testing VR applications [14], lack of standardization for VR systems [14], difficulty in establishing equivalent control groups [15], and lack of solid theoretical frameworks for both design and evaluation of VR [9]. Such challenges make it difficult to develop research based on experimental comparisons between VR-based and traditional instruction techniques, carefully controlled trials and comparisons of specific applications of VR, and longitudinal analysis of VR use in classrooms [8]. For example, Jonassen [16] pointed out that there is no empirical research that examines the effects of using system-modeling cognitive tools for representing problems on problem-solving performance.

CONCLUSIONS

As Ausburn and Ausburn [8] indicate, there is a significant opportunity to expand and explore the use of VR in classrooms. VR represents a high-interest technology that offers great potential for education and for workforce preparation. VR technology is now readily available, both technically and financially, for classroom use. The study survey results show that VR has a positive impact on student design, graphics communication, and spatial abilities. Student perceptions about using VR in classrooms are also positive.

It is clear from the given research study that the use of VR may assist students and faculty members in creating opportunities to discuss ideas and to visualize objects. It is also clear that, to make use of VR technology properly in classrooms, it is not sufficient simply to insert the new technology into classrooms. Significant efforts are needed to incorporate the technology properly into meaningful learning experiences. Although much was accomplished in the given study, many challenges still remain. How can VR technology be seamlessly integrated into existing curricula and learning experiences, so that using VR technology supports, rather than interferes with student learning?

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