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Integrating Low-Cost Virtual Reality into Engineering Design Curricula

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1. Introduction

One way to enhance students' ability to visualize 3-D objects is to make their experience of the objects, while learning, as realistic as possible. However, in general, it is very difficult to clearly describe to students a 3-D object and the spatial relationship between the object components, without using a physical mockup. Physical mockups take a lot of time to construct, especially for more complex objects. As a result, graphics educators have started to use 3-D computer-aided design (CAD) tools to help students understand the spatial relationships between objects. However, CAD tools only allow students to examine 3-D models from outside flat computer monitors. In other words, the models and the viewers are in different realms. Using traditional CAD tools, students cannot view models with natural stereoscopic vision.

Virtual reality (VR) is a computer technology of simulating or replicating a physical environment to give users a sense of being there, taking control, and physically interacting with the environment (Ausburn & Ausburn, 2004). VR technology breaks down barriers between humans and computers by immersing viewers in a computer-generated stereoscopic environment. With advances in hardware and software, most PC computers now have the capability to support VR use. Thus, VR has now become an affordable visualization tool that can be used in classrooms.

As Ausburn and Ausburn (2004) indicated, there is a significant opportunity to expand and explore the use of VR in classrooms. Research suggests that VR is an effective tool that enhances learning in areas such as engineering (Sulbaran & Baker, 2000). In addition, VR engages the intellectual, social, and emotional processes of learners. The impact of VR is due to its ability to encourage interaction and ability to motivate learners (Winn et al., 1997). Salzman (1999) found that VR applications in education depends on VR features, class contents, students' characteristics, and students' prior experiences.

The emphasis of engineering graphics education has been placed on design, problem-solving, presentation, and communication skills. Three dimensional spatial visualization ability is the core requirement for successfully developing those skills. The use of VR may also represent an effective strategy that supports the development of spatial skills. It is important to combine exposure to VR models with activities such as sketching or drawing as a means for developing a capacity for visual imagery and creativity (Deno, 1995; Devon et al., 1994; Sorby, 1999). Sorby (1999) explained that in most cases, graphics curricula begin with multi-view sketching/drawing and then move to pictorial sketching. However, this

sequence of topics is opposite of how most educational psychologists say that students learn.

Although there are many advantages in VR applications, it is important to consider challenges in integrating VR into classrooms. There is little guidance regarding the instructional design and classroom facilitation of VR technologies (Ausburn & Ausburn, 2004). These challenges include lack of necessary computing equipment for testing VR applications (Riva, 2003), lack of standardization of VR systems (Riva, 2003), and difficulty in establishing equivalent control groups (Crosier et al., 2000).

This paper examines the use of VR at three higher education institutions, including one four-year university and two two-year community colleges. This paper considers how the use of new technology in the classrooms affects faculty and students. Experiences and survey results are presented for interested practitioners to follow.

2. Project activities

A VR software tool, VRCADViewer, and instructional materials necessary for class use such as a variety of VR models were developed. The university developed a VR software tool (VRCADViewer) which utilized an open source from Open SceneGraph (www.openscenegraph.org). VRCADViewer can separate left-eye images and right-eye images of a model, so that the model can be viewed stereoscopically. Polarized VR projectors, Da-Lite silver matte tripod polarized screens, polarized 3-D glasses from 3-D ImageTek Corp, and Dell computers equipped with dual graphics output were purchased each of the participating institution.

2.1 Class activities

During the project years, this tool was used for engineering design courses for both first and second year students. Figure 1 shows a VR model projected on a screen in one of the design classes.



Fig. 1. A VR model was projected on a screen

Students were taught about orthographic projection as a part of their drafting studies. Traditionally, this unit of instruction requires the students to identify surfaces and classify them (normal, inclined, and oblique). They were also asked to examine a drawing of an object with a set of orthographic views and to identify and classify surfaces according to information from the drawing. With the advent of computer technology, VR becomes another avenue by which the instructors can attempt to reach these students.

During the classes, VR models were projected onto the Da-Lite screen. Students wore polarized 3-D glasses to view the models stereoscopically. Once students had shown an understanding of the differences between the surfaces, and their roles within the orthographic representational system, more complex models were presented for the students to practice. Through these exercises, students were allowed to develop an understanding of the process of relating surfaces and edges to their representation in orthographic views.

2.2 Summer camp

Ninety-five high school students and 8 teachers were invited to attend a 3-day VR4U! summer camp. During the summer camp, hands-on CAD courses, VR presentations, team work projects, design competitions, industry tours, and career talks were provided. Figure 2 shows high school students presented their VR models at the end of the summer camp. During the final presentation, parents were invited.



Fig. 2. High school students presented their VR models

After attending the summer camp, most participants demonstrated increased interest in pursuing careers in science and technology. Approximately 74% of the participants in the VR4U! summer camp indicated that availability of VR would be a factor in their college choice. More male students than female students indicated that the availability of VR would be a more important factor in their college choice. Most high school students also expressed that learning with VR is more engaging than by traditional teaching methods.

Before students attended the VR4U! summer camp, there was also a significant difference between male and female students in their responses concerning their interest in pursuing a career in science and technology. However, the differences in male and female students' attitudes faded away after they were exposed to VR in the summer camps. After they attended the summer camp, there was no statistically significant difference in their attitudes concerning STEM careers. In fact, the number of female students who indicated that they were interested in a science and technology career doubled after they were exposed to VR.

3. Evaluation

In this project, various tests and surveys were administrated to examine students' conceptual growth and changes in their spatial abilities and class engagement.

Reports from the focus groups conducted in the project years, and comments from the open-end questions from the student survey supported the quantitative evaluation activities. The results from the evaluation provided clear evidence on how the use of VR influenced students' understanding of spatial concepts and course contents.

3.1 Influences on spatial ability

Spatial ability has been shown to be positively correlated with retention and achievement in engineering disciplines (His et al., 1997). Spatial ability has identified several different spatial domains, including spatial visualization and spatial orientation. Spatial visualization refers to the ability to image the movements of objects and spatial forms, and involves tests of mental rotation. Spatial orientation refers to the ability to imagine the appearance of objects from different orientations of the observers. The improvements of students' spatial abilities were measured with specific measures, such as the Mental Rotation Test (MRT) and the Picture Test (PT) developed by Hegarty and Waller (2004).

Survey results showed that VR was an efficient instructional method to develop the spatial ability of students who performed poorly by the traditional instructional method. Students who performed poorly in the pre-PT were more likely to improve their posttest scores than those who did better in the pretest. In surveys, students also noted that, with the new VR tools and learning methods, they were able to better see and understand examples that related to course content. Students further explained that they were able to see inside models and to visualize objects. Other survey results concerning students' spatial ability are as follows.

- After exposure to VR, students' spatial visualization abilities were statistically significantly improved.
- After exposure to VR, students' spatial orientation abilities were improved, but the differences between the pre- and post-tests were not statistically significant.

- About 80% of the poor performers in the pre-MRT reported their posttest scores increased by 10% or more.
- More than 68% of the students reached the project's goal, improving their spatial visualization abilities and test scores by 10% or above in the post-MRT.
- About one-half (53%) of the students increased their scores in the post-PT.

3.2 Efficiency of VR

Efficiency in the evaluation is about efficiency in learning and teaching, including students' perceptions or experiences with VR as an easy, fun, and motivational instruction method as well as instructors' experiences with VR as an interactive and time-efficient tool for teaching.

VR was fun, non-threatening, and interesting

Survey results concerning VR was fun, non-threatening, and interesting are as follows.

- About 92% of the high school students said that VR was fun.
- Students agreed that VR was easy to use and very user-friendly.
- More than 90% of the college students said that VR was not frustrating and they did not consider dropping out of the program.
- More than 90% of the students responded that the VR courses were not frustrating.

VR was efficient for students' acquisition of advanced concepts or skills in graphic design

Survey results showed that VR was an efficient instructional method to increase knowledge bases of graphic design among those students who performed poorly by the traditional instructional method. Due to fun, non-threatening, and the interesting nature of VR, students reported high achievements in mastering the advanced or difficult concepts or skills in graphic design. Other survey results are as follows.

- About 87% of the students indicated that the VR courses improved their abilities in engineering design, graphics communication, confidence in 3-D visualization, and so on.
- More than 90% of the students reported attainment of the advanced course objectives, such as 3-D solid modeling.
- About 83% of the students perceived VR and the instructional materials positively.
- Over 96% of the student did not perceive VR and the materials negatively.

Students' comments from focus groups also supported the results stated above.

- It was hard to draw and visualize from the textbook. When you see a bunch of lines and hidden lines, it is hard to understand what it is. It is easier when it is actually shown as an object. You can spin it and see what it is.
- It helps students recognize the views (front, top, right) of objects.

VR was efficient for both male and female students

Female students were more likely to report a lower mean than male students in the pretest; and were more likely to belong to the poor performer group in the pretest than male students. However, after female students were exposed to VR in their courses, they were more likely to have higher mean scores than male students on the posttest. Female students

also responded to VR learning methods more positively and less negatively than male students.

- Both male and female students improved in their posttest of MRT and PT.
- Female students or students who performed poorly with the traditional instructional method showed greater improvement after they were exposed to VR.

Time efficiency and increasing interactions in the class

VR was a time-efficient instructional tool for students and instructors. Instead of spending time trying to understand how parts of a mechanism interact during normal operation, the presentation of a VR model allows them to move their attention to later phases of the problem-solving process. Students commented:

- Each faculty member used coaching strategies and group activities to encourage self-directed problem solving.
- VR was useful to explain complex concepts to students.
- VR allowed students to go inside, zoom in, or go through the part.

Also, it was time efficient for instructors. VR enhances the likelihood of interactions between teacher-students and among students because the instructors were able to quickly provide example models through VR. Thus, additional time was available. Rather than focusing on either the development of physical models or attempting to help students visualize specific components of an object, instructors are able to concentrate on the learning objective and to coach students in achieving this goal.

4. Discussions

Survey results showed that students were more confident when sketching projection views after visualizing VR models. Students gave VR instruction high ratings for stimulating their interest in learning. Project results also showed that VR instruction stimulates better interaction between instructors and students because students often have higher engagement and are more interested in discussing, with their instructors, what they see or discover during VR instruction.

In one class, students were asked to locate surfaces on objects, identify the type of surface (e.g., inclined, oblique, or normal), and to identify how edges were formed at the intersection of surfaces. This exercise requires students to visualize an object in order to successfully locate and identify characteristics. By using the VR technology, students were able to concentrate on basic concepts before focusing on the development of their visualization skills.

In addition, it was discovered that during the summer camp, one of the students was epileptic. This was unanticipated and was a valuable lesson learned. This realization informed future participating classes, summer camps, and project activities about VR regarding precautions needed and potential risk. From this experience, the physical comfort measures were developed and incorporated into the VR student survey. About 91% of the students expressed physical comfort in using VR; whereas, 8.6% did not. Female students were more sensitive and expressed less physical comfort in VR than male students, although the difference was not statistically significant. These results will provide valuable information for future VR-related projects.

5. Conclusions

VR is an emerging visualization tool in STEM education which can help viewers acquire better knowledge about data or images. Many major companies or research institutions now use VR to enhance their visualization activities. It is important to use VR in classrooms, not only for enhancing visualization, but also for helping students to become familiar with the important emerging technology before they enter into the workforce.

As demonstrated by this project, VR technology is now readily available, both technically and financially, for classroom use. This paper describes our experiences in integrating low-cost VR into design and technical graphics curricula. The project was a collaborative effort between a four-year university and two community colleges. A low-cost VR tool, consisting of hardware and software was developed to enhance instructional delivery and students' 3-D visualization skills. Using the innovative tools in teaching will also provide competitive advantages in recruiting and retaining students interested in design and graphics, and will promote student engagement in lifelong learning, by stimulating interest in leading-edge technology.

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Technological advancement in graphics and other human motion tracking hardware has promoted pushing "virtual reality" closer to "reality" and thus usage of virtual reality has been extended to various fields. The most typical fields for the application of virtual reality are medicine and engineering. The reviews in this book describe the latest virtual reality-related knowledge in these two fields such as: advanced human-computer interaction and virtual reality technologies, evaluation tools for cognition and behavior, medical and surgical treatment, neuroscience and neuro-rehabilitation, assistant tools for overcoming mental illnesses, educational and industrial uses. In addition, the considerations for virtual worlds in human society are discussed. This book will serve as a state-of-the-art resource for researchers who are interested in developing a beneficial technology for human society.

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