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Abstract
Virtual reality (VR) applications have been used in several learning processes that involve visualization and simulation. However, uses for and the effectiveness of VR in design and graphics education have not been extensively explored. Two kinds of VR tools were tested in this pilot study to examine the use of VR technologies for enhancing students' learning and the applications and potential of VR in design and graphics courses. Students in an introductory design and graphics course were given opportunities to experience VR during in-class lectures. A survey was developed to both quantitatively and qualitatively measure student perceptions, related to their VR experiences. The study survey shows that the effectiveness of integrating VR models in design courses is strongly affected by VR model image quality, which is determined by the VR tools used. Further study is needed for isolating factors (e.g., exposure time) that might influence learning design and graphics materials in VR environments.

Introduction
Recently, virtual reality (VR) has introduced an unprecedented communication method for product design. VR refers to an immersive, interactive, multi-sensory, viewer-centered, 3D computer-generated environment and the combination of technologies required to build such an environment (Aukstakalnis & Blatner, 1992; Cruz-Niera, 1993). By immersing viewers in a computer-generated stereoscopic environment, VR technology breaks down barriers between humans and computers.

VR technology simulates natural stereoscopic viewing processes by using computer technology to create right-eye and left-eye images of a given 3D object or scene. The viewer's brain integrates the information from these two perspectives to create the perception of 3D space. Thus, VR technology creates the illusion that on-screen objects have depth and presence beyond the flat image projected onto the screen. With VR technology, viewers can perceive distance and spatial relationships between different object components more realistically and accurately than with conventional visualization tools (such as traditional CAD tools).

VR in Industry
In industry, VR has proven to be an effective tool for helping workers evaluate product designs. In 1999, BMW explored the capability of virtual reality for verifying product designs (Gomes de Sa & Zachmann, 1999). They concluded that VR has the potential to reduce the number of physical mockups needed, to improve overall product quality, and to obtain quick answers in an intuitive way during the concept phase of a product. In addition, Motorola developed a VR system for training workers to run a pager assembly line (Wittenberg, 1995). They found that VR can be used to successfully train manufacturing personnel, and that participants trained in VR environments perform better on the job than those trained for the same time in real environments. In 1998, GE Corporate Research developed two VR software applications, Product Vision and Galileo, which allowed engineers to interactively fly through a virtual jet

engine (Abshire & Barron, 1998). They reported that the two applications were used successfully to enhance design communication and to solve maintenance problems early, with minimal cost, delays, and effort. They also reported that using the VR applications helped make maintenance an integral part of their product design process.

The success stories from industry show that VR-technology-literate professionals are a present and future industry need. However, most students currently do not have an opportunity to experience VR technologies while they are in school. Therefore, introducing VR into design and graphics curricula is imperative, to keep pace with the changing needs of industry.

VR in education

Mathematics and science teachers have used VR for explaining abstract spatial data. Winn and Bricken (1992) used VR to help students learn elementary algebra. They used three-dimensional space to express algebraic concepts and to interact with spatial representations in a virtual environment. They concluded that VR has the potential for making a significant improvement in the way students learn mathematics. Haufmann, Schmalstieg, and Wagner (2000) used VR in mathematics and geometry education, especially in vector analysis and descriptive geometry. Their survey showed that all participants (10 students) rated VR as a very good playground for experiments, and all participants wanted to experience VR again. Students also thought it was easier to view a 3D world in VR rather than on a flat screen. Bell and Fogler used VR to demonstrate molecular mechanisms in their chemical engineering courses (Bell, 1996; Bell & Fogler, 1998). They reported some evidence of enhanced learning in some cases, but they did not provide any statistical analyses.

Sulbaran and Baker (2000) created an online learning system to study the effectiveness of VR in engineering education. They used VR to train participants in how to operate a lock and to identify construction machines. They found that 82% of learners thought learning with VR was more engaging than learning from reading books and listening to lectures using overheads containing graphics or pictures. They also found, in their first survey, that 69% of the students thought they had learned how a lock operates, and 57% thought they had learned how to identify construction machines. Seven to 21 days later, 92% of the students were still able to operate a lock and identify construction machines. Finally, in their second survey, 91% of the learners strongly agreed or agreed that the learning experience benefits from the use of VR.

Although VR has been successfully used in many disciplines, design and graphics education has not introduced or considered using VR technology in classrooms. The investigators find the lack of VR use in design and graphics education surprising, because design and graphics are both visualization-intensive subjects.

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 a result, in this pilot study, the investigators used PC-based VR in their classroom.

To enhance students' academic performance and interest in design and graphics courses, and to keep abreast of the latest graphics and visualization technologies, integrating VR into design and graphics curricula now is essential. Using the innovative tools in teaching will also provide competitive advantages in recruiting and retaining students interested in design and graphics.

Low-Cost VR technology

Low-cost VR, also called PC-based VR, uses inexpensive devices such as PC workstations and VR glasses, combined with VR-enabled software applications, to partially immerse viewers in a virtual scene. Currently, most PC workstations have stereoscopic graphic display capability built into their graphics card chip sets. Therefore, with plug-in software for separating right-eye and left-eye and images, PC applications can now display VR stereoscopic views.

PC-based VR systems typically use one of several types of special viewing glasses to selectively send right- and the left-eye images to the viewer's corresponding eyes. Depending upon the type of glasses used, stereo systems can be classified into active or passive stereo systems. "Active" systems use glasses with electronic components; "passive" systems use glasses without electronic components. In active stereo systems, stereo images are presented by rapidly alternating the display of right-eye and left-eye images, while alternately masking the viewers' right and left eyes using synchronous shutter eyewear, such as LCD (liquid crystal display) shutter glasses.

Passive stereo systems are the most common and basic type of stereo systems. They are popular because they are very inexpensive, and cost is often a critical factor in public environments. Passive anaglyphic systems create a different colored image for the users' right and left eyes. Users then view the images using anaglyphic paper glasses made from colored filters (e.g., blue for the right eye and red for the left eye). One advantage of the anaglyphic VR images is that they can be projected onto a big screen using regular LCD projectors. However, image quality in passive anaglyphic systems is relatively poor, and they can only display gray-colored images. The lack of colored viewing capability is one of the major drawbacks of anaglyphic passive stereo systems.

Another method for passive stereo viewing is based on the principle of light polarization. With oppositely polarized filters attached to two projectors and matching filters in a pair of glasses, right- and left-eye images can be separated, and multiple colors can be preserved. However, polarized VR systems are relatively expensive because they need special projectors for polarizing the left- and right-eye images. Polarized projectors usually cost US$20-30K.

Implementation

In this study, VR models were integrated into to an introductory design and graphics course to help students visualize 3D graphic models. Anaglyphic and polarized systems were used and compared in two different semesters. There were thirty-two students in the class in which the anaglyphic system was used, and there were thirty-eight students in the class in which the polarized system was used. The study provided students an opportunity to experience VR by combining VR model viewing during lectures with engineering graphics workbook lessons. The shaded blocks in the course map shown in Figure 1 describe how VR models were integrated into an existing course.

Example models from an engineering graphics workbook were created, before the pilot test lectures, using Autodesk Inventor. The models were related to workbook lessons that covered orthographic multi-view projections, pictorial views, auxiliary views, and section views. A VR system was used during lectures to display and manipulate the models to different orientations and, as a result, to help students understand 3D concepts and the relationships between different views.

It was anticipated that using the VR system would enhance students' 3D visualization and freehand sketching skills. It was also anticipated that strengthening students' visualization and sketching skills would also enhance students' 3D solid modeling and 2D engineering drawing skills. Other design concepts and standards, e.g., design for manufacturability, teamwork, ANSI standards, dimensioning, fasteners, and material selection, were also introduced during the lectures to help students achieve more realistic and useful designs.

In the first pilot test, a PC-based anaglyphic VR system was used. The right- and left-eye images of VR models were separated into red and blue images, respectively. Passive red-blue paper anaglyphic glasses were used for viewing the models. During lectures, the instructor first projected the VR models onto a big screen (Figure 2(a)). Students wore anaglyphic VR glasses for viewing the stereoscopic images (Figure 3(a)). After students acquired spatial knowledge of a 3D model, by viewing a VR representation of the model, they were asked to free-hand sketch projection views of the object.

In the second pilot test, a PC-based polarized VR system was used. The right- and left-eye images of VR models were separated by the principle of light polarization. Figure 1. Integrating VR into an entry-level design course One advantage of polarized VR systems is that model colors are preserved. During lectures, the instructor first projected the VR models onto a big screen (Figure 2(b)). Students wore polarized VR glasses for viewing the stereoscopic images (Figure 3(b)).

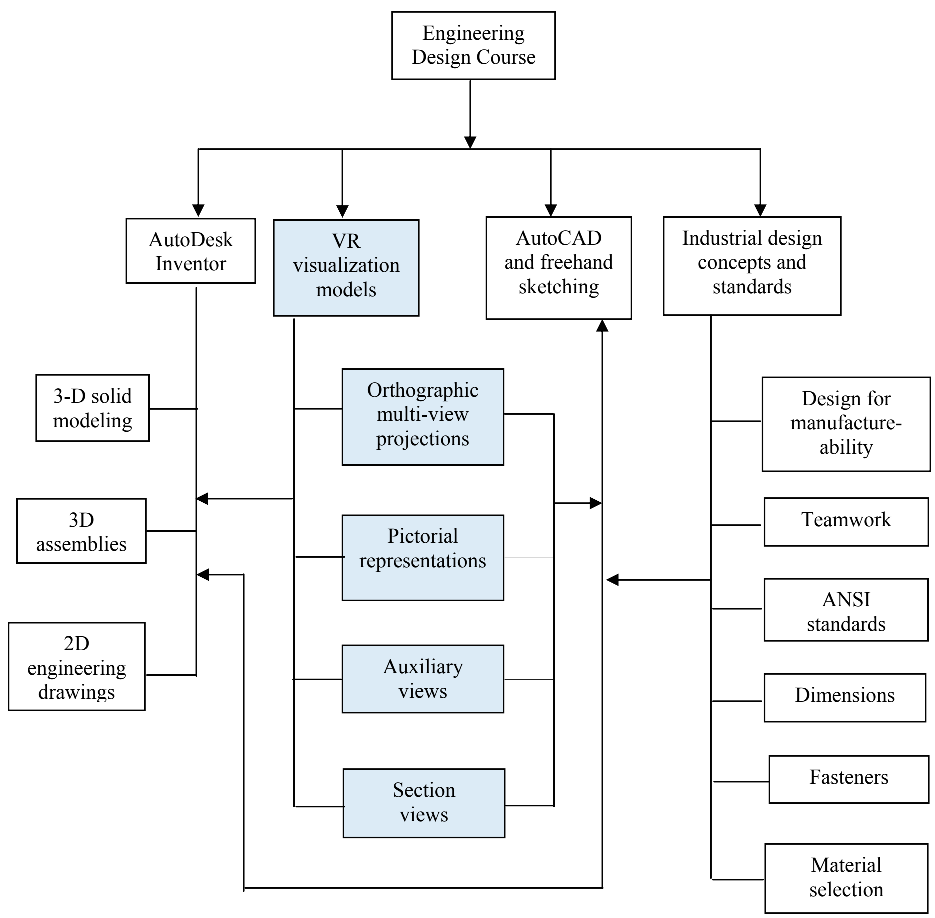
A questionnaire was administered, at the end of the two pilot-test semesters, to collect students' comments. The purpose of the questionnaire was to identify issues and concerns students had about viewing VR models that were used to help them visualize objects.

The study was conducted as the initial step in a comprehensive long-term study to determine the effectiveness and cost-effectiveness of using VR tools in design and graphics education. Specific objectives of the long-term study are to quantify the effects of using VR on student learning and visualization skills and to determine the most effective and cost-effective VR tools for classroom use.

Survey results

A survey was developed to measure student perceptions related to their VR experiences, with a series of statements

Figure 1. Integrating VR into an entry-level design course



using a five-point Likert scale. The scale used was:

1. Strongly Disagree
2. Disagree
3. Not sure
4. Agree
5. Strongly Agree

The results of the survey for the two semesters are presented in Table 1. Each student was asked to respond to 14-15 questions concerning the usefulness of and their satisfaction with using the VR models to enhance their learning. For the semester in which the polarized system was used, students were not asked Question 14, regarding opportunities to interact with virtual models.

For the semester in which the anaglyphic system was used, students' opinions tended to be neutral, but slightly positive. This can be seen from the result mean values, which were all very close to 3 (not sure). However, for the semester in which the polarized system was used, students' opinions tended to be clearly positive toward VR instruction.

Students were also asked about the "effectiveness", "strengths", and "weaknesses" of the VR models in an open-ended question format. Most of the students' comments, for both semesters, were positive. Positive comments for both VR tools included: "Helped view the object better", "We are actually able to see the model and understand the 3D perspective", "It gave a better view of 3D models than the 2D book", "It was interesting, fun, and I could see the 3D forms better", "They helped visualize the object", "Fun, Motivate", "Not as boring", and "good for visualization". The positive comments about the strength of the VR models indicate that VR models not only provide a better and more informative 3D view, but also motivate students' learning. Students were more engaged and involved when the VR models were presented. Classes were more fun and interesting when the new technology was used.

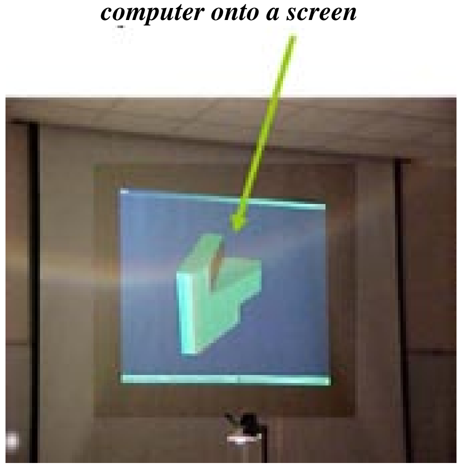
Weaknesses reported by students, for both VR tools, included "not being able to see the stereoscopic view", "location in that it is not mobile", "dizziness", and "sickness" as a result of viewing the VR. Some students had very strong 3D visualization skills, and they thought the VR tool did not help much. The stereoscopic effect was also affected by the distance between the students and the projection screen. Thus, due to available seating, some students had access to better images than others did. The results were also affected by certain physical conditions. Some students could not visualize stereoscopic views at all.

Some responses were related to specific aspects of the technology. For example, weaknesses reported for only the anaglyphic system include "Sometimes hard to see", "Contrast was not clear enough on surfaces", and "Doesn't always work well". The image quality of the anaglyphic VR models was not very good, and the system could only provide gray-colored images. As a result, some students complained about the contrast and quality of the images for the semester in which the anaglyphic system was used.

Discussion

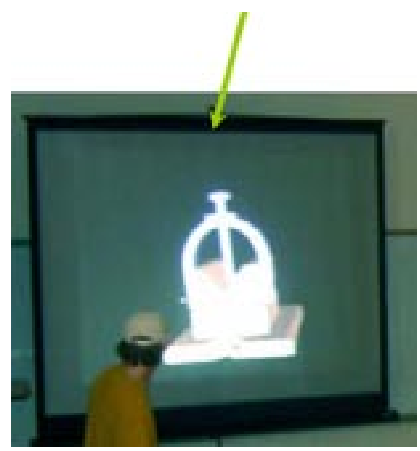
The survey results show that most students enjoyed learning design and graphics instructional materials with the aid of VR models, and that VR models helped most students to visualize 3D objects better. The effectiveness of VR models was affected by the technology used and each individual's physical reactions. Some students felt that using VR models was not necessary because they could visualize 3D models quite well using 2D graphics.

A VR model projected from a computer onto a screen



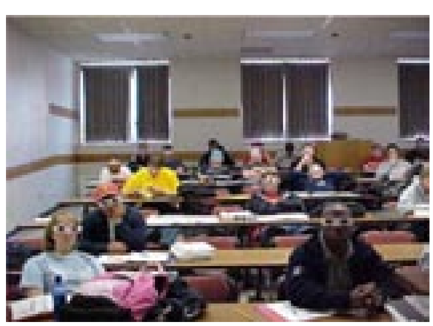
(a) An anaglyphic VR model

A 150" diagonal projection screen



(b) A polarized VR model

Figure 2. VR models projected on a big screen at the front of the classroom



(a) Anaglyphic system

(b) Polarized sytem

Figure 3. Students experiencing VR instruction

Some students could not visualize stereoscopic 3D images, or they felt uncomfortable and dizzy using VR glasses. However, most of the study survey comments from students were positive. In particular, most students felt the VR models were interesting and fun, and that the VR models made class less mundane. Overall, findings and comments were certainly positive enough to continue to explore possibilities for further implementation.

Some students felt that the inexpensive anaglyphic VR system used did not always work well. Since the anaglyphic VR system used inexpensive red-blue paper glasses, the system could only display gray-colored models. As a result, the contrast was not clear on model surfaces. As a result, some students' eyes hurt, they became dizzy, or sometimes it was hard for them to see the 3D effect. However, since polarized VR systems can provide better image quality and preserve model colors, for the semester in which the polarized system was used, students did not make negative comments about image quality. Quantitative survey results were also more positive for the semester in which the polarized VR system was used than for the semester in which the anaglyphic VR system was used.

In surveys (anaglyphic system) and in open-ended questions about strong and weak points of VR system use (both semesters), students stated that they would like to have opportunities to actively interact with the VR models, rather than being just passive viewers in the classroom. Providing students more opportunities to experience the new technology through direct interaction may further improve effectiveness. Providing Web-based VR models would allow students to access the models for working at their own pace outside the classroom.

Questions	Students Mean (Anaglyphic systems)	Students Mean (Polarized systems)
	Scale: 1 = strongly disagree 5 = strongly agree	
1. I found the VR models motivated me to learn.	3.00	3.97
2. The VR models used in class were boring and uninteresting.	2.91	1.97
3. The VR models were enjoyable and educational.	3.25	4.27
4. The VR models were not easy to understand.	2.66	2.23
5. I could learn faster using VR models than using the engineering graphics workbook.	3.34	4.17
6. I cannot see the stereoscopic view of the VR models.	2.94	2.07
7. I could not clearly understand the material presented in the VR models.	2.81	2.23
8. I believe that the VR models would be an excellent educational tool.	3.16	4.1
9. The three-dimensional models helped me to learn.	3.56	3.9
10. I believe that I could learn more in an introductory graphics course if VR models such as these were available.	3.06	3.8
11. The simulated graphics of the VR models enhanced educational value.	3.25	3.9
12. Viewing a VR model makes me feel dizzy.	2.84	2.23
13. The VR models were not an effective way to learn about engineering drawing.	2.78	2.47
14. I would appreciate interaction with the VR models.	3.25	N/A
15. The VR models did not help me learn engineering graphics.	2.81	2.47

Conclusions

This study provides a foundation for further implementing and refining VR use in design and graphics education. The results of the pilot test show that VR is a useful and promising learning and educational tool for design and graphics courses. However, the results of the pilot test also indicate that the effectiveness and quality of VR models are both greatly affected by the VR systems used and individual physical reactions. Future research for determining how to best use VR tools to promote learning, and for isolating factors (e.g., exposure time) that might influence learning design and graphics materials in VR environments also needs to be conducted.

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References

Abshire, K. J. & Barron, M. K. (1998). Virtual maintenance; Real-world applications within virtual environments, *IEEE Proceedings Annual Reliability and Maintainability Symposium*, 132-137.

Aukstakalnis, S. & Blatner, D. (1992). *Silicon Mirage*: *The Art and Science of Virtual Reality*, Peachpit Press, Berkley.

Bell, J. T. (1996). Introducing Virtual Reality into the Engineering Curriculum, Proceedings of University Programs in Computer Aided Engineering and Design Manufacturing, Charlottesville, VA. Retrieved from http://www.vrupl.evl.uic.edu/vrichel/.

Bell, J. T. and Fogler, H. S. (1998). Virtual Reality in the Chemical Engineering Classroom, *Proceedings of American Society for Engineering Education Annual Conference*, Seattle, WA, American Society for Engineering Education.

Cruz-Niera, C. (1993, Aug.). Virtual Reality Overview. *ACM SISGRAPH'93 Notes: Applied Virtual Reality* ACM SISGRAPH '93 Conference, Anaheim, California.

Gomes de Sa, A. & Zachmann, G. (1999). Virtual reality as a tool for verification of assembly and maintenance processes, *Computers and Graphics*, 23, 389-403.

Haufmann, H., Schmalstieg, D. & Wagner M. (2000). Construct3D: A Virtual Reality Application for Mathematics and Geometry Education, *Education and Information Technologies, 5* (4), 263-276.

Sulbaran, T. & Baker, N. C. (2000). Enhancing Engineering Education Through Distributed Virtual Reality, *30th ASEE/IEEE frontiers in Education Conference*, October 18-21, Kansas City, MO, S1D-13 – S1D-18.

Winn, W. & Bricken, W. (1992, December). Designing Virtual Worlds for Use in Mathematics Education: The Example of Experiential Algebra, *Educational Technology*, *32* (12), 12-19.

Wittenberg, G. (1995). Training with virtual reality, *Assembly Automation*, *15* (3), 12-14.