Using Virtual Reality Tools in Design and Technical Graphics Curricula: An Experience in Learning

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Abstract

This paper presents findings from a project for introducing virtual reality (VR) technology into design and technical graphics curricula. In particular, findings are presented that show how the implementation of VR technology affected and changed pedagogical practices between instructors and students in classrooms at three educational institutions. Classroom observations were obtained from a team of curriculum and instruction professors and graduate students, who provided feedback concerning use of VR technology in the classrooms. Student surveys, both before and after using VR tools, and focus group interviews, were also conducted. Quantitative and qualitative evaluation data was analyzed and used to plan for future use of VR technology. Implementation findings provide insights into how to use VR technology in design and technical graphics education, which can help instructors to effectively introduce the new VR tools in their classrooms.

Introduction

Three-dimensional visualization ability, to a great extent, determines students' performance in design and technical graphics courses. Prior research shows that 3-D visualization ability greatly influences students' future career success in science, engineering, and technology (McKim, 1980; Norman, 1994; Pleck et al., 1990). Prior research also shows that visualization is a skill that can be learned, developed, and improved with proper instruction and methods (Bishop, 1973; Gagon, 1985; McKim, 1980). Thus, educators need effective methods for delivering graphics concepts and for enhancing student 3-D spatial visualization skills.

One way to enhance students' ability to visualize 3-D objects is to make their experience of the objects as realistic as possible while learning. Recently, virtual reality has brought learners closer to natural learning environments. VR immerses viewers in computer-generated stereoscopic environments. Using special equipment such as data gloves and joysticks, users can interact directly, and more realistically, with virtual models in virtual environments.

In industry, VR has proven to be an effective tool for worker training and for helping designers evaluate product designs. For example, GE Corporation used VR to determine part removal paths for machine maintenance (Abshire & Barron, 1998). Motorola developed a VR system for training workers to run a pager assembly line. They discovered that participants trained in VR environments perform better on the job than those trained for the same time in real environments (Wittenberg, 1995).

In academia, the potential of VR has especially drawn the interest of mathematics and science educators. Several prior experiments have shown that VR can help students understand abstract spatial data and scenes that cannot be physically realized (Bell & Fogler, 1997; Haufmann et al., 2000; Winn & Bricken, 1992). In contrast to reading textbooks and listening to lectures, VR allows students to see images and move around in virtual environments. Using new technology in education can both improve learning and make learning more enjoyable. At the same time, new technologies demand critical evaluation to determine their proper and vital role in transforming educational styles. For example, due to advances in information technology, multimedia now provides greater flexibility in teaching and learning.

Although prior short-term experimental programs conclude strongly that VR can enhance learning, educators still must overcome several technological and educational challenges to bring VR into regular classroom use:

- When, where, and how should we introduce VR into existing curricula to improve learning and visualization skills?
- How can VR be used to communicate graphics concepts?
- How should we teach students to use VR tools?

Introducing new technology into classrooms also brings in the requirement for course reformation. This paper describes a teaching and learning experience in which VR tools were introduced into design and technical graphics courses at three educational institutions. In particular, findings are presented that show how the implementation of VR technology affected and changed pedagogical practices between instructors and students in classrooms at the three educational institutions. After introducing VR tools into courses, gains in student visualization skills were also measured. Implementation findings provide insights into how to use VR technology in design and technical graphics education, which can help instructors effectively introduce and use the new VR tools to engage students, communicate graphics concepts, and strengthen students' visualization skills.

Figure 1a (above) & 1b (below) First class test

Implementation

The project was a collaborative effort, which involved two community colleges and one four-year university. A VR software tool, VRCADViewer, was developed using open source software from OpenSceneGraph (www.opensourcegraph.org). VRCADViewer can create and separate left-eye and right-eye images of a CAD model, so that the model can be viewed stereoscopically. Each of the participating instructors developed instructional VR models for topics they planned to cover in their classes. For this project Autodesk Inventor was used for CAD model creation. However, since Autodesk Inventor does not have VR display capability, Inventor CAD models were converted to file formats that VRCADViewer could recognize, for example, .3ds, .osg, .wrl, and .iv.

Participating instructors were invited to attend each other's classes to provide peer-observations. Several curriculum and instruction professors and graduate students were also invited to each class to provide feedback concerning instructional delivery and pedagogical practices.

In the first test class, which was held at the four-year university, basic information concerning 3D engineering graphics was introduced. Example 3D models, corresponding to printed images from the course textbook, were used to present the concepts. Rather than using traditional CAD model viewing methods, the new VR tool was used to help students visualize 3D models from different views (Figure 1). After the students acquired 3-D spatial concepts, they were asked to sketch pictorial views and projection multiviews of the models. The purpose of this exercise was to let students become familiar with the relationships between pictorial views and their associated multiviews.

Immediately following the test class, the curriculum and instruction professors and graduate students held a meeting to discuss their experiences and to develop recommendations for improving instructional delivery and pedagogical practices. The team of experts recommended using virtual models of real-world mechanical parts for instruction, rather than less-meaningful models from the textbook. They also recommended allowing students to create and manipulate models. Both recommendations were followed in a second test class.

Figure 2 Second class test

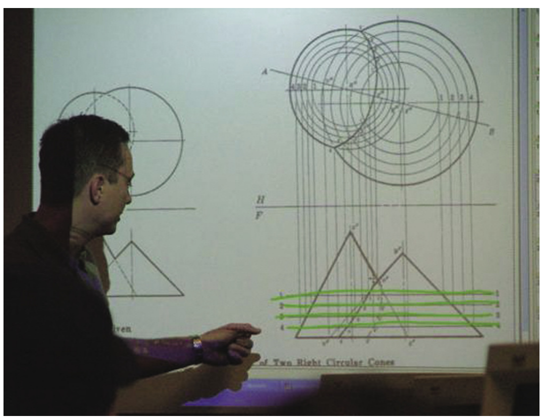
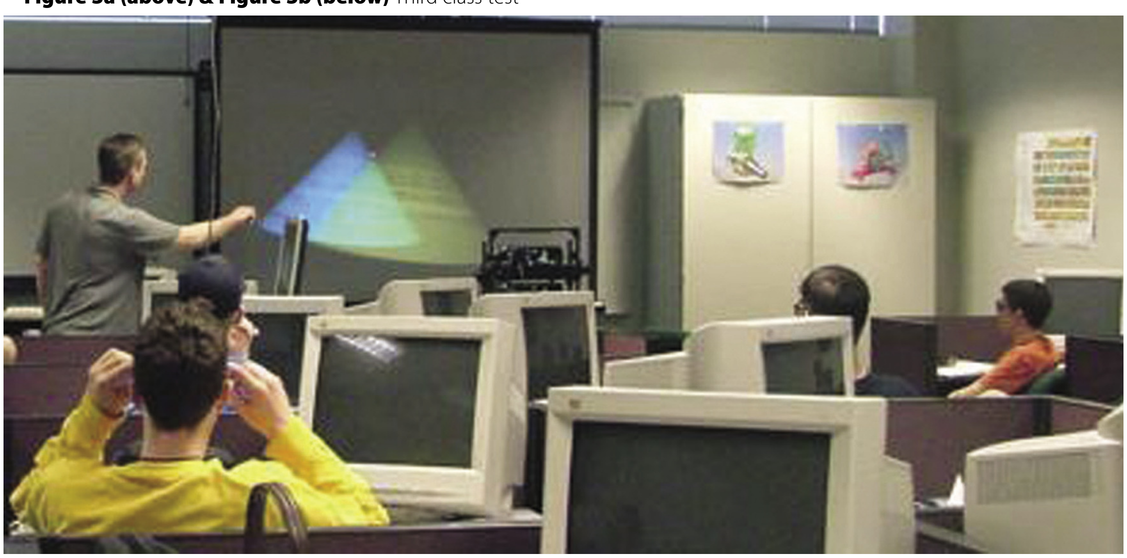


Figure 3a (above) & Figure 3b (below) Third class test



In the second test class, held at the four-year university, the concept of pictorial views was covered. Students were allowed to personally manipulate models and to explore the models from different views (Figure 2). Real-world mechanical parts, with more complex geometries and moving parts, were used. Students involved in the test classes made positive comments about using the VR equipment during lectures.

In the third test class, held at one of the community colleges, descriptive geometry was covered. The instructor explained how to find and draw a surface line that represents the intersection of two cones. The instructor first used a SMARTBoard™ to explain the concept using 2D sketches (Figure 3a). He then used the VR tool to show the 3D relationship between the two cones (Figure 3b). Using conventional 2D viewing methods, most students struggle to grasp the true shape of the surface line. The VR tool gave a better spatial realization of the objects and what the surface line actually looked like in 3D space.

In the fourth test class, held at the second community college, the instructor covered using

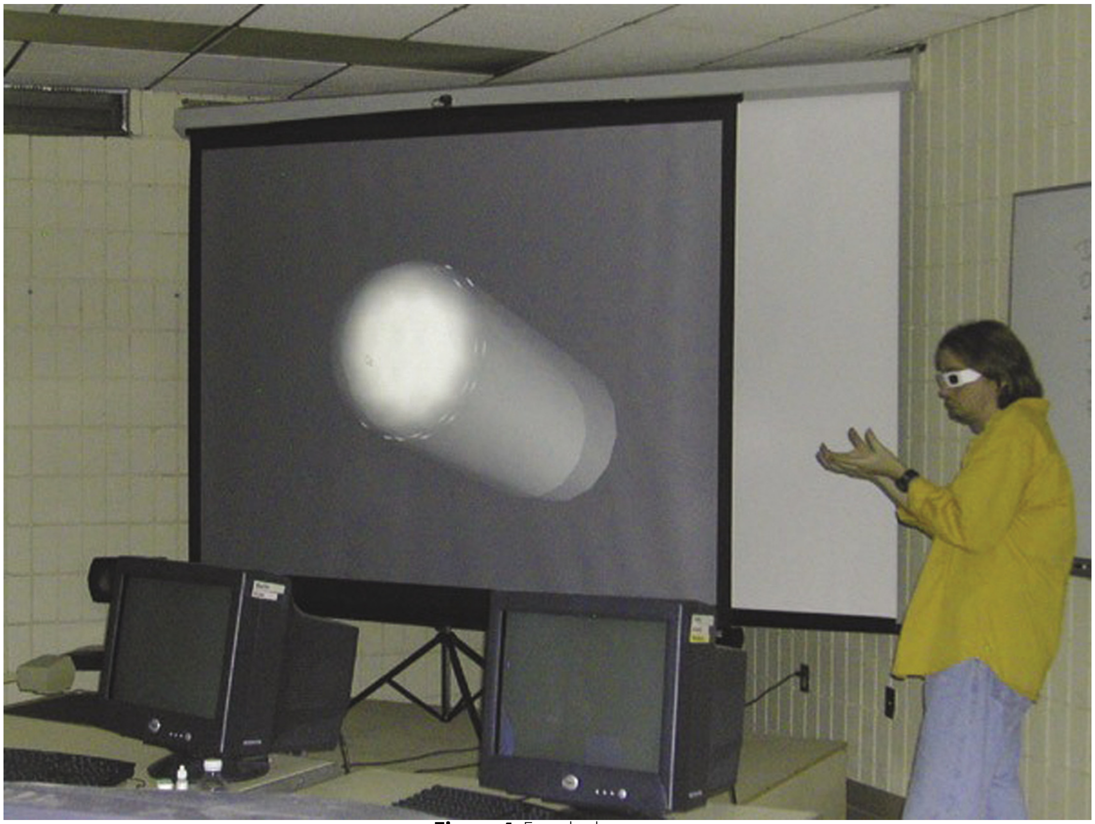


Figure 4 Fourth class test

Visual Basic programs to drive a CAD software tool for creating generic geometric forms representing mechanical parts. First, students were asked to develop a program that would produce a cylinder and a sphere with specific dimensions. They were then asked to verify their results against a VR model. Next, they were asked to modify their programs to make the center of the sphere coincident with the center of the cylinder. Again, students used a VR model to verify that the output met their expectations. Finally, students were asked to visualize shortening the cylinder by a specific amount and to produce the change by editing their programs. After their programs produced the change, they were again asked to examine a virtual model and to compare their results with their expectations (Figure 4).

The purpose of the learning exercise in the fourth test class had three goals: (1) to enhance logical thinking and design processes through programming, (2) to use a 3D virtual model to verify and illustrate the results of logical thinking and design processes, and (3) to begin to develop a visual and conceptual 'sense' for the effects of change in both the local and global state of a component's form. All three goals rested upon the precept that students, when offered a model with which to compare their own concepts, would develop a sense of how change creates impact on a design. After the first change exercise, students were led through a full series of model changes and given an opportunity to compare their 'mental' expectations against a virtual model illustrating the change impact.

Classroom Impacts and Pedagogical Change

The most obvious impact that using VR technology had in the test classes was *increased student motivation*. Students appeared to be excited about using a new technology, which previously was not available in the classrooms. Within the first few minutes of using the VR tool, students often made comments that they were either surprised about or felt affirmed in their expectations by what they were seeing. A handful of students made casual comments comparing what they were seeing to video games they used at home. The correlation was interesting, because it indicated that students were attempting to adapt to a new instructional technique by relating their classroom experience to a familiar personal experience. They were attempting to create a zone of comfort by comparing what they saw to a similar technology that they had already used.

From the instructors' observations, students' engagement with their instructors and other students increased, due to several factors. The first factor was a significantly shorter mental feedback cycle. Students could produce a model and see the result using the VR tool. As a result, they had a realistic virtual 3-D product that was similar to a real object that they could hold in their hands.

A second factor which had an impact on classroom interaction was that students appeared to accept the technology as an *instructional tool* rather than as a tool for critiquing their work. Students who were normally reticent about sharing their CAD drawings with other students seemed more willing to share their models and images. On the surface, it seemed that one reason for the change in classroom behavior was that, since the technology was new to the classroom, most students felt they were on equal footing; they were all embarking on a journey together. As a side point, students may also have felt more comfortable sharing virtual models because they generally require less explanation than 2-D drawings.

Virtual models also created a stronger connection between instructors and students, since they were able to explore 'what-if' scenarios together. The instructors and students, for the first time, were able to share a common 'mindspace' together as they proposed changes and saw the immediate impact of the changes. Receiving immediate virtual results allowed instructors to use even faulty expectations as teachable moments.

Evaluation Instruments

To assess students' VR experiences and learning gains, several evaluation instruments, such as a student survey, focus group interviews, a VR literacy test, and a mental rotation test were developed and conducted.

Student survey

A survey was used to examine students' perceptions of the effectiveness of using VR in the course curricula, as well as to investigate issues related to physical comfort associated with VR. The survey items were developed based upon prior published research findings. For example, the following survey items:

(a) I considered dropping out of the program;

(b) My instructor encouraged me not to major in CAD;

were based on prior research by McKim (1980), Norman (1994), and Pleck et al. (1990), which demonstrates that student 3-D visualization ability greatly influences students' future career success in science, engineering, and technology.

Research by Bishop (1973), Gagnon (1985), and McKim (1980) found that visualization is a skill that can be learned, developed, and improved with instruction. The survey items based on their findings included:

(a) The class improved the way that I learn;

(b) The course improved my graphics communication skills.

Osberg (1997) found that a 3-D class culminating in a virtual experience can enhance spatial processing skills, and Winn and Bricken (1992) found that VR has the potential for making a significant improvement in the way students learn [mathematics]. The survey items based on their findings include:

(a) I gained confidence in my 3-D visualization skills in this course;

(b) My 3-D spatial visualization skills improved as a result of this course.

Haufmann, Schmalsteig, and Wagner (2000) found that VR is a very good playground for experiments. In their study, all participants wanted to experience VR again, and students thought it was easier to view a 3-D world in VR than on a flat screen. The survey items based on their findings included:

(a) VR is a good playground for experiments;

(b) I want to experience VR again;

(c) It is easier to view a 3-D world in VR than on a flat computer screen.

Sulbaran and Baker (2000) found that learners thought learning with VR was more engaging than learning from reading books and listening to lectures using overheads containing graphics or pictures and that, in a follow-up survey, learners strongly agreed or agreed that their learning experiences benefit from the use of VR. The survey items based on their findings include:

(a) Learning with VR is more engaging than learning from reading books and listening to lectures using overheads containing graphics or pictures;

(b) VR helped me better remember how to do something again the next time I used it.

Survey items were also worded in the opposite vernacular to determine the consistency of responses, for example, (a) The VR program was dull and uninteresting and (b) The VR was not easy to understand.

Focus groups

Focus groups were conducted to probe for a deeper understanding about students' experiences with the VR technology in the classroom. Focus groups were conducted with the participating classes from the university and two community colleges after students completed the post-mental rotation test (MRT) and the survey. Focus group protocol was implemented and topics were explored in more depth through a variety of questions such as:

(a) How was your experience in this class different, using the VR tool, than in classes that did not use it?

(b) What do you believe the strengths are of using the VR tool?

Focus group responses from each class were recorded and then analyzed based upon the questions posed during the focus group. The responses were then analyzed and compared to determine thematic relationships, if any.

VR literacy tests and mental rotation tests

In order to examine students' knowledge growth about VR, pre- and post- VR literacy tests were developed. A mental rotation test was used to assess students' growth in spatial visualization over the course of the semester. The mental rotation test was drawn from Vandenberg and Kuse (1978).

Evaluation Results

Student survey

Demographics A total of 8 females and 30 males from the three institutions participated in the student survey. Students ranged in age from 18-57. Nineteen students were freshman, 11 students were sophomores, 5 students were juniors, 1 student was a senior, and 2 students identified themselves as other.

Students' graphics experience: Students' years of graphics experience ranged from 0 to 8 years.

Open-ended questions: Students were asked to respond to 3 open-ended questions. Overall, responses to the questions were positive. The questions, with a summary statement, follow.

Q: Describe the ways in which you found the VR models effective for your learning and provide examples.

Students' responses described their learning experience with the VR models as fun, more realistic, engaging them in their learning, and providing them with visualization enhancements.

Q: Describe two major strengths and two major weaknesses of the VR models and give examples for each.

Students' described the strengths of the VR models as realistic, good for visualization, easy to understand, retained attention, made learning fun, gave ability to rotate objects and parts, improved depth perception, created better understanding, and was exciting. Weaknesses reported by students included expense, size of equipment, needed better resolution, difficult to work with, lag time and inconsistency of the program, more time consuming, some people not being able to see the stereoscopic view, location not mobile, dizziness and sickness as a result of viewing the VR models.

Q: Please describe your previous experience using VR and provide detailed examples.

Previous experiences using VR cited by students included Disneyland, university virtual reality CAVE, and one student who was epileptic and could not wear the 3D eyewear or participate in the VR experience because of the physical condition. Eight students had never used VR before and it was their first experience with the technology.

Student survey results and existing research findings: Survey results from the three institutions support existing research findings. A Likert scale was used for the survey, with 1 = strongly agree, 2 = agree, 3 = undecided, 4 = disagree, and 5 = strongly disagree. Table 1 details the aggregate means for survey items.

The results of the survey show that students

Aggregate means for common survey items. Survey Items	Aggregate Mean (n=38)
The course improved my ability to design products.	1.83
The course improved my problem-solving ability.	2.03
The course improved my presentation skills.	2.47
The course improved my graphics communication skills.	1.90
I considered dropping out of the program.	4.50
My instructor encouraged me not to major in CAD.	4.43
I gained confidence in my 3-D visualization skills in this course.	2.00
I enjoyed the 3-D instruction in this course.	1.73
I was fully engaged in the instruction in this course.	2.03
This method of delivering graphics concepts is the most effective.	2.23
My experiencing of the 3-D objects was realistic.	1.93
The class stimulated my interest in leading-edge technology.	2.00
The class improved the way that I learn.	2.33
VR is a good playground for experiments.	1.73
I want to experience VR again.	1.67
It is easier to view a 3-D world in VR than on a flat computer screen.	2.13
Learning with VR is more engaging than learning from reading books and listening to lectures using overheads containing graphics or pictures.	1.83
VR helped me better remember how to do something again the next time I used it.	2.50
VR technology is a useful tool for design and technical graphics education.	1.90
I can now use VR technology in product design.	2.77
My 3-D spatial visualization skills improved as a result of this course.	2.20
The instructional materials for this course were clear.	2.17
The instructional materials for this course contributed to my learning.	2.10
The VR is easy to use.	2.33
The VR program is user-friendly.	2.53
I believe that I could learn more in other subjects if VR programs like this one were available.	2.20
The VR program was dull and uninteresting.	4.03
The VR was not easy to understand	3.77
I could not clearly understand the material presented in VR.	3.77
I prefer to learn multi-view projections using 2-D pictures rather than VR 3-D simulation.	3.53
Viewing the VR model makes me feel dizzy.	3.77
I cannot see the stereoscopic view of the VR model.	3.93
I feel physically uncomfortable when using VR.	4.03
Using VR makes my eyes hurt.	4.00

Scale: 1=strongly agree, 2=agree, 3=-undecided, 4=disagree, 5=strongly disagree agreed or strongly agreed that the course improved their graphics communication skills; students agreed that they gained confidence in their 3-D visualization skills in the courses; students agreed or strongly agreed that VR is a good playground for experiments and that they wanted to experience VR again; students agreed or strongly agreed that learning with VR is more engaging than learning from reading books and listening to lectures using overheads containing graphics or pictures. Further, students from the three institutions disagreed with the item, "The VR program was dull and uninteresting," (mean=4.03).

Focus Groups

Focus groups were conducted to probe for a deeper understanding about students' experiences with the VR technology in the classroom. A total of five focus groups were conducted, which involved students enrolled in classes at the three institutions. Consistent focus group protocol was used for each focus group at the participating sites. The questions posed to students during the focus group follow with a summary statement for each question.

Q: How was your experience in this class different, using the VR tool, than in classes that did not use it?

All students stated that the use of the VR tool in their classes was a positive experience. All students reported that the use of VR in their classrooms was primarily in the form of a visual aid by the instructor, but unfortunately, they did not have access to the technology or equipment on their desktop computers for their own use. Several students mentioned that the use of the VR equipment by their instructors enhanced their ability to visualize models and that it made the experience more realistic.

Q: Are you now able to use VR tools in product design?

Because the students did not have the VR capability on their laboratory desktop computers, they did not have access to VR for product design assignments or projects. Some students speculated on the usefulness of VR for product design and others interchanged the idea of VR with 3D modeling software.

Q: Do you feel that you are now a better candidate to join the workforce because of your experiences using VR technology?

Limited experience with and exposure to VR was again the prominent factor in students' responses. Students' frames of references were primarily to the different software programs they learned during the semester, however, some students saw the value of VR use to their future in the workforce.

Q: What do you believe the strengths are of using the VR equipment/technology?

Students identified visualization, the ability to manipulate and rotate objects, the depth and perspective created through the use of VR, and advantages for product design as strengths of the VR equipment/technology. Students cited infrequency of use, no hands-on experience, and lack of exposure to VR as obstacles to providing a completely informed response.

Results for pre- and post-VR literacy tests

To examine students' knowledge growth about VR, pre- and post-VR literacy tests were developed. The test used includes 50 items, weighted at 2 points each, for a total of 100 points.

Twenty-five students took the pre-VR literacy test. Students' scores ranged from a low of 18 out of 100 to a high of 66 out of 100, with a mean score of 39.00. Post-test scores ranged from a low of 28 out of 100 to a high of 70 out of 100, with a mean score of 52.96. The mean increase for the students was 14.23%.

Results for pre- and post-mental rotation tests

A mental rotation test was used to assess students' growth in spatial visualization over the course of the semester. Twenty-nine students took the pre- and post-MRT tests. Pre-MRT test scores ranged from a low of 2 to a high of 34. Post-test MRT scores ranged from a low of 6 to a high of 39. The mean for the pre-MRT test was 17.69, and the mean for the post-MRT test was 24.17.

Discussion

All instructors and students were enthusiastic about using the VR tool in their classrooms. The use of VR models was integrated into the overall curricula taught in the classes. Thus, the use of VR models seemed to have a purpose, and was not just an add-on to the lessons. Students seemed more engaged in collaborative groups formed to solve problems during the lessons.

Primary suggestions made by the curriculum and instruction professors and graduate students included providing opportunities for students to have more hands-on experiences with the VR tools, increasing student group activity, increasing opportunities for students to manipulate the VR models, and increasing student engagement during class sessions. Evaluation results confirmed the suggestions. To provide more hands-on opportunities, the instructors suggested developing an independent lab, separate from the instructors' computers and their classroom facilities, where students could work with their design models and then bring them into a VR environment. To connect use of the VR tool with authentic meaningful activities for students, it is important to invite representatives from industry, who are currently using VR for product testing and development, to speak with the students and to demonstrate possibilities for use of similar VR tools in the business world.

Future Directions

For the given study, students were usually in a passive role, however, they expressed interest in more hands-on opportunities for working with the software. The instructors need to redesign their existing lectures and labs to provide more hands-on interactive opportunities for students, opportunities that will give them more control over their own learning and that will create a cognitively active learning environment. Course curricula need to include more problem-based learning lessons using VR. Integrating VR in the classroom, beyond using VR as a visual aid during lectures, needs to be studied. Applying VR in other courses needs to be explored.

To shift students from a passive role to a more active role, students need to explore current uses of VR in their particular areas of interest. Students also need to learn how to use VR to evaluate other students' designs. Finally, further research is needed to determine how the VR tool affects students' engagement in the subject matter and changes that can be made in both software design and in pedagogical methods to make the tool more useful and available to students, at a level comparable to other multimedia tools now used in education.

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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.

Bell, J. T. & Fogler, H. S. (1997). Ten steps to developing virtual reality applications for engineering education, *Proceedings of the 1997 ASEE Annual Conference*, Retrieved February 15, 2002, from http://www.vrupl.evl.uic.edu/vrichel/.

Bishop, A. J. (1973). The use of structural apparatus and spatial ability – A possible relationship, *Research in Education*, *9*, 4-49.

Gagnon, D. (1985). Videogames and spatial skills: An exploratory study, *Educational Communications and Technology Journal*, *33*(4), 263-275.

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.

McKim, R. H. (1980). *Experiences in visual thinking*. Boston, MA:PWS Publishers.

Norman, K. L. (1994). Spatial visualization – A gateway to computer-based technology, *Journal of Special Educational Technology, XII* (3), 195-206.

Osberg, K. M. (1997). Spatial Cognition in the Virtual Environment. *Human Interface Technology Laboratory, University of Washington*, Retrieved June 10, 2002, from http://www.hitl.washington.edu/publications/r-97-18/

Pleck, M. H., Mcgrath, M. B., Bertoline, G. R., Browers, D. H. & Sadowski, M. A. (1990). Factors affecting the engineering design graphics curriculum: Past, present, future. *Proceedings of the NSF Symposium on Modernization of the Engineering Design Graphics Curriculum*, Austin, Texas, 43-52.

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.

Vandenberg, S. G. & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization, *Perceptual and Motor Skills, 47*, 599-604.

Winn, W. & Bricken, W. (1992). 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.