VIRTUAL ENGINEERING EDUCATION – THE NEXT STEP IN BRINGING TECHNOLOGY TO THE CLASSROOM

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0 ABSTRACT

Most of today's educators have been taught by the conventional two-dimensional technology known as the chalkboard. It has been the default teaching medium and is still used effectively by many in the engineering field as the preferred means of conveying information to students. However, one great inherent problem is its difficulty in conveying three-dimensional (3D) information. As virtual reality (VR) becomes more and more prevalent in the automobile industry, the power industry, and many others, it seems evident that the ability to display and interact with 3D information be brought to the classroom. This paper explores the possibilities of using VR as a teaching device in a variety of engineering courses as well as presents some anecdotal evidence of its popularity and its problems from students in a statics course in which VR was used to display 3D vectors. The cost of its use from an instructor's point of view will also be addressed.

1 INTRODUCTION

As technology explodes around us, one of the many constants in teaching has been the chalkboard. (For the sake of this paper we will include markerboards and any other two dimensional medium in which the instructor writes either directly or indirectly on a flat surface, i.e., blank overhead transparencies can also be included here. There are differences between these media but in regards to this discussion, they fall in the same category.) Despite its longevity, a major weakness of the blackboard is the difficulty in displaying 3D diagrams on a 2D surface. A possible solution to this problem is the introduction of 3D visualization into the classroom.

Virtual reality is a phrase that has been used so often to describe such a high number of different technologies that it is impossible to use the term without defining it. In this paper the term virtual reality will refer to any technology that combines 3D stereo displays with physical user interaction. It is preferable for the interaction to be intuitive to the user but this is not essential to the definition. A more detailed definition can be attributed to [Cruz-Neira, '93] – "… immersive, interactive, multi-sensory, viewer-centered, three-dimensional computer generated environments and the combination of technologies required to build these environments".

This paper will discuss the success of using VR in a statics course. We will pay particular attention to the affect on the attention of the students involved as well as the added cost to the educator of including this technology in a course. Finally, the future of VR in the

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classroom will be discussed including distinct areas of mechanical and civil engineering in which VR can be used for teaching.

2 BACKGROUND

Hardware for 3D visualization has been in existence for several decades, though only since 1993 has it seen significant use in education [Youngblut, '98]. Educational advances have increased since that time, albeit slowly. Important advances include Christopher Dede's application of visualization hardware to general scientific concepts [Dede, '96 a] and the teaching of electromagnetics in particular with the well-known MaxwellWorld [Dede, '96 b]. Other applications include education of elementary school students in basic zoological concepts at Georgia Tech [Bowman, '98; Bowman, '99], the NICE project for elementary education at the University of Illinois at Chicago [Roussos, '97; Roussos, '99, Johnson, '01], and engineering education research at East Carolina University [Pantelidis, '97].

The system used in this research is the Visbox X2 virtual reality system, manufactured by Visbox, Inc. (www.visbox.com). It consists of a 12' x 9' screen with dual projected images which are filtered so as to present a different image to each eye (Figure 1, left). In addition, the system includes a tracked user-interface device (a "wand") which allows the user to interact with the programs in six degrees-of-freedom. Finally, the user wears tracked glasses which allow the display to customize the image to their viewpoint.
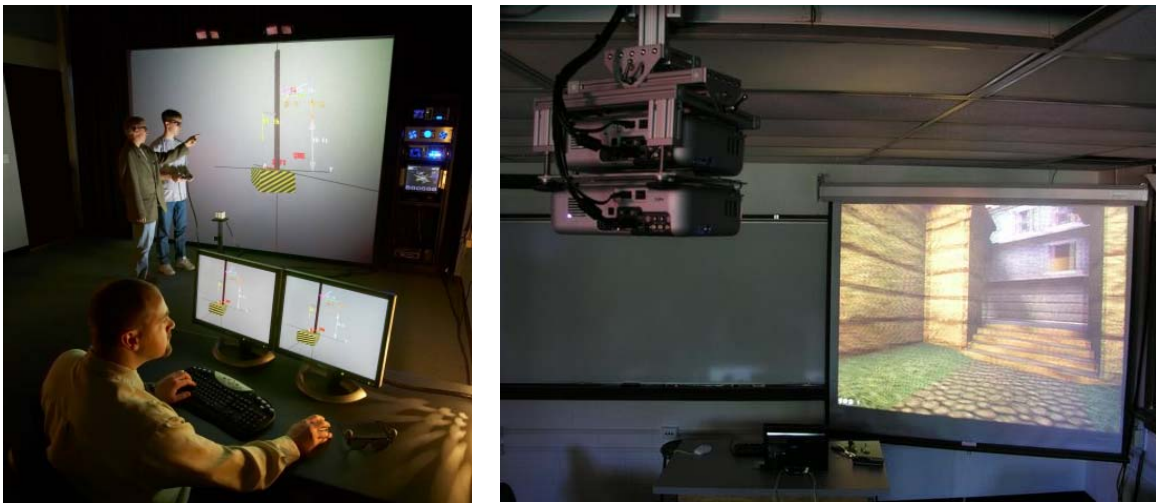

Figure 1. The Visbox X2 System and VisDuo Classroom Display

Our classroom VR system is called the "VisDuo" and is also a product of Visbox, Inc. It consists of a 6' x 4.5' front-projected screen (Figure 1, right). Students view this screen sitting in their seats in a classroom. As with the Visbox system, users wear polarized glasses to view the screen. However, in this system, the user's glasses are not tracked so their viewpoint is fixed. The instructor can manipulate the models and otherwise interact

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with the display application. This can be used to show a model in 3D in contrast to drawing it on the board or passing out a photocopy.

An important note is that there is an inherent difference between the 3D display in the Visbox system compared to the VisDuo system. In the Visbox environment, the user is able to move their head, which changes the perspective rendered in the image (as a person would experience in real life). Also, the user is controlling and interacting with the application in the case of the Visbox. The VisDuo is a passive medium, where a many-user display is controlled by the instructor and does not respond to an individual's movement of head or hands.

A significant note is the order of magnitude of cost of these systems. In one decade, the cost of a VR system has gone down roughly two orders of magnitude. Today's low-cost VR ranges from $10,000 - $100,000 for various systems. This is typically within the reach of the four-year university. Our research focused on the VisDuo, costing $12,000, and the Visbox X2 system costing $92,000. This is the high- and low-end range of typical low-cost VR systems. It should be noted that the standard Visbox system is $50,000, a pleasant middle of the range system.

3 STATIC-VU – AN APPLICATION FOR USING VR IN A STATICS COURSE
We have incorporated a VR application into our Mechanics-Statics course for three consecutive semesters (Fall 2004, Spring 2005, Fall 2005) and have found quantitative as well as qualitative results [Johnson, '05]. Although initially there were problems to overcome due to learning to use the hardware and the software, eventually the extra time added to class preparation was minimal. We would even go so far as to say that the preparation time necessary for creating a model is not dissimilar to the added cost of using Powerpoint in one's lecture plans. There may be a steeper learning curve, but it is not prohibitively more difficult to use than standard slide software to the technologically capable user.

The software we use is called StaticVU and it was created by Chris Graunke, an undergraduate student at Valparaiso University. Using the preliminary application, SVUBuilder, the user can create almost any 3D free body diagram (FBD) imaginable based on a set of 18 primitives. These primitives include vectors, hexahedrons, spheres, cylinders, pyramids, etc. or using more descriptive terminology, forces, beams, pipes, etc. The user defines the coordinates, size, and color of these primitives and they have the option to label the object as well to more clearly define the scene using dimensions, angles and planes. As with the drawing application in Powerpoint, the more familiar the user becomes with the primitive protocol, the greater ability one develops for creating almost any scene or FBD.

Just like a Powerpoint presentation, the FBD scene is created prior to class time. SVUBuilder creates a small text file that is loaded into StaticVU by the user when the presentation is to be given. For example, the text files for the FBDs shown in Figures 2 and 3 can be seen in Appendices A and B.

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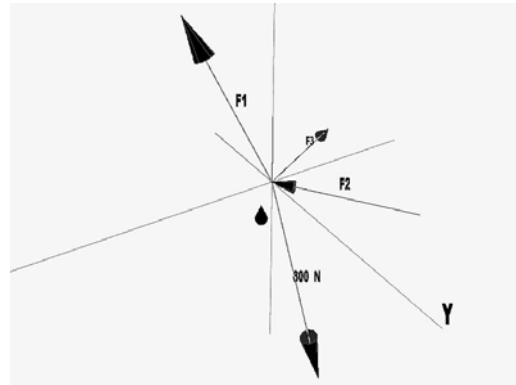*2006 Illinois-Indiana and North Central Joint Section Conference*

Figure 2. The 2D version of FBD #1 is shown on the left. The rendered version is shown on the right. The rendered version was displayed in stereo in a much larger format and in color. The text file used to generate the diagrams is shown in the text.

When used in a virtual environment, StaticVU allows the user to interact with the FBD just as if it were a small object in one's hand. The FBD can also be manipulated through the use of a joystick/controller in either the Visbox or the VisDuo (classroom) settings. The keyboard may also be used for interaction. For example, 'n' and 'm' will rotate the FBD around the z axis, 'u' and 'j' will move the model into and out of the screen.
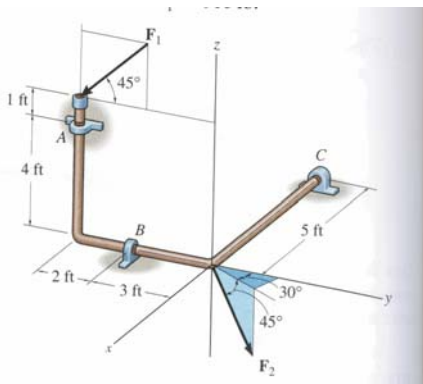

Figure 3. The 2D version of FBD #2 is shown on the left. The rendered version is shown on the right. The rendered version was displayed in stereo in a much larger format and in color. The text file used to generate the diagrams is shown in the text.

3.1 Results of Using StaticVU in the Classroom
During the three semesters of its use in the statics course, the software was used to determine whether VR would help students to see 3D objects more accurately (Johnson, '05). Many students of varying abilities struggle with visualizing a 3D scene mapped onto a 2D piece of paper (Figures 2 and 3). Even with the visual cues given in the textbook (shading, dotted lines showing the projection of a vector onto a plane, etc.),

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students often have difficulty understanding the problem. Without understanding the visualization it is virtually impossible for them to actually apply the principles taught in class. Some may say that part of engineering is learning to "see" the 3D object from a given 2D drawing but our argument is that somehow students must *learn* how to see this. Using new technology such as this will hopefully help. However, it is important to learn more about if and how this technology helps first.

During the first semester, both sections of the class were treated equally and given the same medium during the study [Johnson, '05]. The second and third semesters, one section of the class used VR and the other was treated as the control. For the control groups, only standard 2D representations were used to display 3D FBDs. An important result that was found in the first semester and supported in the following semester is that a significant number of students using the VR *thought* they did better even though the actual data was not as conclusive. This is a major point that should not be overlooked and deserves more study. We plan to learn more about the impact that student enthusiasm has on their ability to visualize as well as a variety of other factors that can be used to distinguish between different presentation media.

3.1 Added Instructor Time/Effort
From the instructor point of view, the added cost of creating the models became minimal (with practice, a textbook homework problem could be created in 10-15 minutes depending on the level of detail the instructor was willing to include). As with any course development, as time goes on, the library of models created increases. Currently, we have 12-15 models created that can be used at a given moment for an in-class demonstration, and are developing over 20 more that will all be available electronically.

Using the VisDuo was also not as time-consuming as many may think. The most time-consuming aspect of using the 3D display in class has been passing out and collecting the polarized glasses and surveys. As with any demonstration, the instructor can put as much or as little time as they are willing into the actual presentation. For example, during the Fall '05 semester, short surveys were given once a week for 12 weeks. These surveys were given at the start of class so class time was not interrupted. The total time was typically between 10-12 minutes of class time. This time included passing out and collecting the glasses and surveys, starting the computer and projectors, and interacting with the FBD. This was only slightly (1-2 min.) more than the time it took during the control section to display the 2D version of the FBD, passing out and collecting the surveys, and allowing the students to fill out the surveys. Since the courses were taught by the same instructor, it was easy to see that the time spent on each survey was approximately the same. The same course material was presented in each case and neither class was ahead or behind due to any differences in the amount of time spent in the survey process.

After learning to use the software, the increase in faculty time and effort is not considerable, and learning to use the software is only slightly more difficult than learning to use Powerpoint or any other application. To better understand the cost to the instructor

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from an external viewpoint, a new faculty member will be teaching the statics course this spring (2006). Although this instructor is a member of the faculty at the home institution of the authors, he has no previous experience with the software or hardware and has promised to give his unbiased opinion of the experience. Furthermore, a grant proposal to the NSF has been written in which we propose to distribute a variety of VR applications to be tested by faculty at other institutions. StaticVU will be one of those applications and we will survey those instructors as well as the students to learn more about the costs and benefits of using this application.

We believe that in some ways the step from the current state of educational technology to the incorporation of VR in the classroom is similar to the step from only chalkboards and whiteboards to Powerpoint presentations. With that in mind, it is important to note a drawback to the latter. That is, the overuse of Powerpoint in the classroom. Powerpoint makes it easy for an instructor to display images, diagrams that cannot be easily drawn, etc. However, if overused or used unwisely (i.e., not providing parts or all of the slides to students before class, etc.), the instructor can easily speed through slides leaving behind the students. Likewise, the technological advance of 3D visualization for classroom presentations can be overused. As mentioned earlier, an important part of engineering education is in learning how to understand 2D representations of 3D systems. If 3D visualization is the sole means of displaying 3D systems, this gap between 3D and 2D displays will continue to exist. As we learn more about which level of technology is best in terms of student comprehension, we must continue to keep the overall goal in mind – advancing students' ability to visualize 2D representations.

4 FUTURE IMPLEMENTATION OF THIS TECHNOLOGY
The current research effort has been in exploring the costs and benefits of using VR in a statics course. Other courses/areas in which our VR systems have been used include electromagnetics, computer architecture, linear optimization, calculus, materials science, VLSI, physical chemistry, computer-aided drafting, and transportation. The applications focus on supporting a particular topic within a course, as well as providing laboratory exercises for individual experiential learning. We see the future possibilities of these tools being applied to a variety of other engineering courses including the following which more directly relate to civil and mechanical engineering.

4.1 Future Civil Engineering Applications
In civil engineering, as in other areas of education, instructors are often limited by the capabilities of the method of presentation. For example, in courses such as structural mechanics, the instructor must rely on extensive explanations, 2D diagrams, and possibly artistic drawings on a 2D medium to convey the concept of the torsional response of a building subjected to wind loads. Because of this, it can be a very time consuming and inefficient method of conveying this information to students. Implementing 3D technology into a course in structural mechanics would greatly reduce the time and effort necessary for student understanding of these topics by giving the instructor the tool necessary for explaining the 3D aspects of the effects of these loads.

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Environmental and geotechnical topics could also benefit from 3D visualization. Variations in soil composition is limited to 2D theoretical examples that do not exist in the real world. Exploring the 3D characteristics of the soil would give students a more complete understanding of this area. Students would similarly benefit from witnessing the distribution of liquid environmental contaminants through a 3D plume in the soil or air pollution from a stack. By seeing things as they naturally occur, a stronger understanding of the material will be developed. Currently, we are using a commercially available program called Fledermaus for viewing terrain and proposed roadways. This software has the potential to be used in a transportation class to better visualize real terrains as opposed to 2D representations.

4.2 Future Mechanical Engineering Applications
Many areas exist in mechanical engineering courses in which 3D visualization would help students visualize and help instructors explain various concepts. For example, control volumes are often first introduced in introductory thermodynamics courses and expanded to 3D during fluid mechanics courses. The 3D aspect of this concept is not necessary for the understanding of thermodynamic principles but it is important in fluid mechanics. The flowfield variables (density; x-, y-, z-components of the velocity; etc.) may vary across the surfaces of the control volume and the integrals necessary to compute the conservation of mass flow, momentum, and energy can be explained more clearly if the students are able to witness these variations in the full three dimensions.

Although the 3D aspect of control volumes may not be necessary in introductory thermodynamics courses, 3D visualization could benefit student understanding of other principles in this course. Property diagrams for pressure, temperature, and volume are typically shown in 2D, displaying only combinations of two of these variables, i.e., pressure and temperature, pressure and volume, etc. Often a 2D representation of the combined 3D diagram of these variables is shown and perhaps discussed from a distance. However, using 3D visualization and/or VR techniques, instructors could dive more deeply into this topic, explaining how the three variables behave with respect to one another more easily. Interaction with this 3D model could also help to show how the 2D diagrams of T vs. P, P vs. V, etc. correspond to the full 3D diagram.

5 CONCLUSIONS
The introduction of 3D visualization into the classroom has great potential as an educational tool. Many have already been incorporated this technology into a variety of courses. However, it is important to learn more about its effectiveness as a means of conveying knowledge. Alternatively, it is just as important to learn more about the time and effort necessary for an instructor to learn to use this technology.

Without even realizing it, instructors are hamstringed into focusing on 2D models with the 3D aspect being ignored or only mentioned as if it is unimportant or an easy jump for any engineer. In fact, the step from 2D models to 3D is often more difficult than this. Using virtual reality and/or 3D visualization in the classroom offers an alternative technology to assist instructors in their coverage of this leap to 3D. As more is learned

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about whether and/or how much these technologies help students, instructors will be better able to assess whether or not they should include 3D visualization techniques into their courses.

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7 APPENDIX A

Sample primitive code for FBD #1 shown in Figure 2:

```
FORCE 0 0 0 3 0 6 1 YELLOW "F1"
FORCE -3 4 0 0 0 0 1 YELLOW "F2"
FORCE 0 0 0 -6 -3 0 1 YELLOW  "F3"
FORCE 0 0 0 0 3 -6 1 YELLOW  "F4"
PLANE4 0 0 0 0 4 0 -3 4 0 -3 0 0  BLUE
PLANE4 0 0 0 0 3 0 0 3 -6 0 0 -6 RED
PLANE4 0 0 0 3 0 0 3 0 6 0 0 6 GREEN
PLANE4 0 0 0 -6 0 0 -6 -3 0 0 -3 0 WHITE
```

8 APPENDIX B

Sample primitive code for FBD #2 shown in Figure 3.

```
PIPE -6 0 0 0 0 0 0.25 BrMETAL
PIPE 0 0 0 0 -5 0 0.25 BrMETAL
PIPE 0 -5 0 0 -5 5 0.25 BrMETAL
WIRE 0 0 0 2.5 4.33 0 0.5 WHITE
ANGLE 0 2 0 1 1.732 0 0 0 0 BLUE "30 degs"
FORCE 0 0 0 1.25 2.165 -2.5 0 RED "F2 = 500 lbs"
ANGLE 1 1.732 0 0.707 1.225 -1.414 0 0 0 BLUE "45 degs"
WIRE 0 -5 5 0 0 5 0.5 WHITE
FORCE 0 -2 8 0 -5 5 1 YELLOW "F1 = 600 lbs"
ANGLE 0 -3.586 6.414 0 -3 5 0 -5 5 GREEN "45 degs"
PIPE -5.1 0 0 -4.9 0 0 0.4 BMETAL
BEAM -5.1 0 -0.4 -4.9 0 -0.4 1.0 0.2 0 BMETAL
DIMENSION -5 1 0 1 0 1 0 1 0 TEAL "5 ft"
WIRE -5 0 0 -5 1.5 0 0.5 WHITE
TEXT -5 0 1 BMETAL "C - bearing"
PIPE 0 -2.9 0 0 -3.1 0 0.4 BMETAL
BEAM 0 -2.9 -0.4 0 -3.1 -0.4 0.2 1 0 BMETAL
WIRE 0 -3 0 1.5 -3 0 0.5 WHITE
DIMENSION 1 -3 0 1 1 0 0 1 0 TEAL "3 ft"
WIRE 0 -5 0 1.5 -5 0 0.5 WHITE
DIMENSION 1 -5 0 1 1 -3 0 1 0 TEAL "2 ft"
PIPE 0 -5 3.9 0 -5 4.1 0.4 BMETAL
BEAM -0.4 -5 3.9 -0.4 -5 4.1 1 0.2 0 BMETAL
TEXT 0 -3 1 BMETAL "B - bearing"
TEXT 0 -4 4 BMETAL "A - bearing"
WIRE 0 -5 4 0 -6.5 4 0.5 WHITE
DIMENSION 0 -6 0 1 0 -6 4 1 0 TEAL "4 ft"
DIMENSION 0 -6 4 1 0 -6 5 1 0 TEAL "1 ft"
WIRE 0 -5 5 0 -6.5 5 0.5 WHITE
```

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