Virtual Reality for 3D Visualization in a Statics Course

Peter E. Johnson[1], Jeffrey D. Will[2], and Christopher R. Graunke[2]
[1]Department of Mechanical Engineering, Valparaiso University
[2]Department of Electrical and Computer Engineering, Valparaiso University

Introduction

Learning subjects in the sciences or engineering require the ability of students to think in three dimensions. However, this is one of the greatest challenges to students [1]. Even in the best students, these skills are typically underdeveloped [2]. There is a great need for students to be taught how to understand and visualize spatial relationships [3], yet research is sparse in this area.

One particular area of science and engineering that heavily relies on students' abilities in visualizing objects and their relationships in 3D is statics. Often taken early in the student's study, most students come into the subject having little 3D visualization ability, which is a great challenge for them. Thus, statics courses are typically "training grounds" for students to develop visualization acuity as well as learn to solve for forces and masses in diagrams.

Hardware to display 3D models and interact with them has been in existence for several decades, though only since 1993 has it seen applications in education [4]. Educational advances have increased since that time, albeit slowly. Important advances include Christopher Dede's application of visualization hardware to general scientific concepts [5] and the teaching of electromagnetics in particular with the well-known MaxwellWorld [6]. Other applications include education of elementary school students in basic zoological concepts at Georgia Tech [7, 8], the NICE project for elementary education at the University of Illinois at Chicago [9]-[11], and engineering education research at East Carolina University [12].

This paper describes work done to study subjects in a statics class taught at Valparaiso University as to the development of their ability to visualize in 3D. Four different media were explored, from paper-and-pencil to a fully immersive virtual reality experience. Wide-ranging data in this course was collected, and its analysis is here presented. A framework for analyzing virtual reality media for applications in education is included. Special effort is directed towards practicality in the field of engineering education, i.e., analyzing the cost to benefit ratio of using different teaching technologies. Lessons learned from this experiment are included.

A key factor in the utility of this work is that only recently have virtual reality hardware systems become financially available to primarily undergraduate institutions. A new kind of stripped-down virtual reality display has emerged that makes the technology affordable to most. Thus, bringing virtual reality into the classroom and assessing the cost benefit ratio from a student cognition standpoint is of special interest at the present time.

Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition

Virtual Reality System

In the past decade, visualization systems have cost from $300,000 to several million dollars. On the low end, companies such as FakeSpace (www.fakespace.com) have made available such devices as a one-user ImmersaDesk, offering a display of roughly three by four feet. High-end systems such as the 6-walled CAVE at the University of Illinois at Urbana Champaign utilize 10'x10' walls on all sides of the user to create a truly immersive effect. Such systems can cost on the order of $10M.

Due to the high cost of such systems, most work done in visualization has not focused on education. The investment required to purchase visualization systems has been out of the reach of most teaching-oriented schools and has not allowed them to be prevalent in classrooms. However, within the past few years, low-cost devices offering much of the functionality of classic systems for one or two orders of magnitude less in cost have become available. These devices are based on commercially available commodity computer hardware, only recently powerful enough to drive graphics-intensive applications. Such systems are typically PC-based and utilize high-end graphics cards and LCD projectors. These devices project a three-dimensional image onto a large screen, giving the user a sense of immersion and allowing a person to see depth through binocular disparity. An overview of current hardware is given in [13].

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 (Fig. 1). 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.

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 (Fig. 1). Students view this screen sitting in their seats in a classroom. Users wear polarized glasses to view the screen. The instructor can manipulate the models and otherwise interact with the display application. This can be used to show a model in three dimensions in contrast to drawing it on the board or passing out a photocopy. These are the media that were studied in this research.

An important note is that there is an inherent difference between the three dimensional 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.

For this research, it was necessary to have a VR application which could not only display and manipulate free body diagrams on a three-dimensional display, but a way to rapidly and efficiently develop and prepare these models. To that end, our work involved the development of the software StaticVU. This application uses a custom-developed model description based on primitives used often in statics. The description language is easy to use, and an instructor can be trained in using it in about 10 minutes. It takes 5-10 minutes to prepare a typical free body diagram, depending on complexity.

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.

Thus, this research addresses the issue of performance of these systems in the classroom, specifically the area of teaching statics students to be able to visualize in 3D. The issue of *Is the high-end model worth the price* is quantitatively analyzed here.

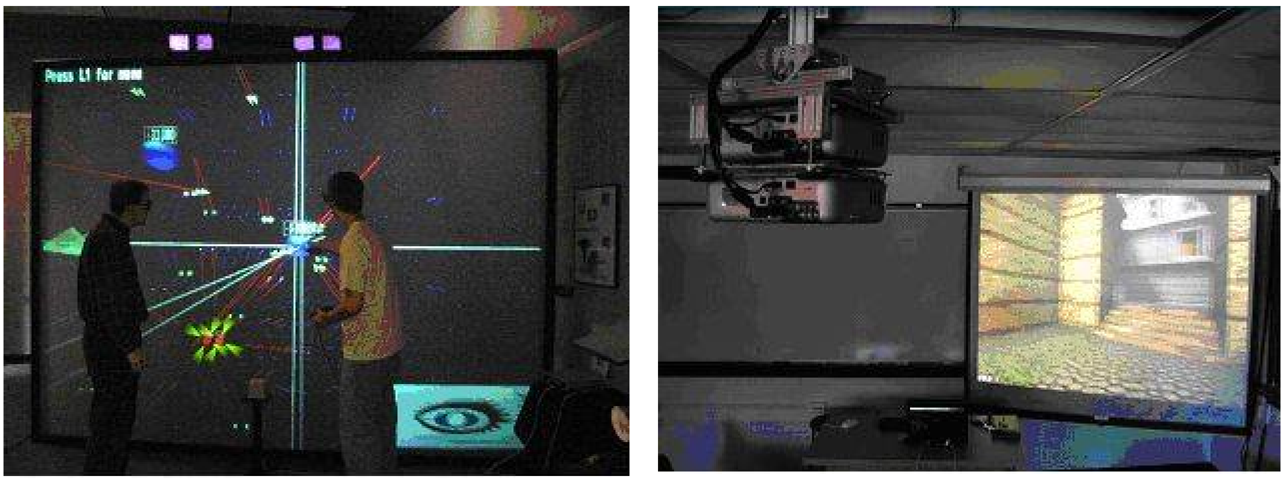

Figure 1. The Visbox X2 System and VisDuo Classroom Display

A Framework for Evaluating Teaching Systems

As low-cost virtual reality systems become more and more prevalent, it is necessary to have a comprehensive framework to classify and evaluate different media. The taxonomy here provided is based upon our experience in working with several different modes of 3D information communication. It is in this framework that our data is evaluated.

Our framework consists of the description of the system on nine factors. These descriptions thus form a nine-dimensional space in which the medium is precisely defined. The dimensions include: Tracking, Interaction, Dimensions, Model Movement, Duration, Collaboration, Cost, Resources, and Novelty. These are defined below and shown in Table 1.

Tracking: The level of system tracking, including head and/or wand tracking, and the subsequent response of the application to this information.

Interactive: The ability of the subject to change the orientation/placement of the object themselves. This does not include if the viewpoint changes, only if the subject themselves have control of the rotations and translations.

Dimensions: If the display medium is in 2D or 3D

Model Movement: No model movement is described as a static view of the model, where one face only is presented to the user. This is contrasted to the moving model, where either multiple views are shown, or the object can fully be rotated and translated

Duration: The amount of time that the subject can spend to interpret and interact with the medium. The duration can be limited or unlimited

Collaboration: Collaboration involves whether the subject is alone in their interpretation, or if communication is allowed between two or more subjects.

Cost: The investment cost of the physical medium to display the object.

Resources: The time invested to prepare and display the object by the administrators of the medium.

Novelty: The perceived interest generated in the user by the medium. The level of excitement/enthusiasm of the subject to use the medium is proposed to influence the effectiveness of the medium.

Table 1. Summary of Nine-dimensional Framework

Dimension	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Value	**Tracking**	**Interaction**	**Dimensions**	**Model Movement**	**Duration**	**Collaboration**	**Cost**	**Resources**	**Novelty**
Overhead	No	Passive	2D	Static	Limited	No	$0	Low	0
VisDuo – Static	No	Passive	3D	Static	Limited	No	$12K	Low	5
VisDuo – Moving	No	Active	3D	Motion	Limited	Some	$12K	Low-med	7
Visbox	No	Active	3D	Motion	Unlimited	Possible	$87K	High	10

Experimental Procedure

The basic issue studied was the students' ability to visualize and interpret three-dimensional representations presented through various media. The media studied in this experiment were:

1.) The standard method, a two-dimensional diagram from a textbook displayed using an overhead projector;
2.) A three-dimensional, stationary (i.e., no interaction) model using the VisDuo;
3.) A three-dimensional, semi-interactive (instructor controlled) model using the VisDuo; and
4.) A three-dimensional, fully interactive model using the Visbox.

Data was gathered from two sections of the Mechanics-Statics course at Valparaiso University. The sections consisted of 25 and 18 students. Results from all students are combined for analysis in this presentation. Students were primarily sophomore mechanical (32 students) and civil (7 students) engineering majors. One freshman mechanical engineering major was also involved in the experiment as well as one senior electrical engineering major, one junior biology major, and one freshman non-engineering major.

Two different experiments were conducted. In the first, students were shown a particle with three or four (depending on the problem) 3D forces acting on it (Fig. 2). Students were then asked to complete a short multiple-choice quiz to obtain a quantitative measure of their ability to interpret 3D information from the various media. The following question was asked for each dimension of each force vector:

For the force, is the *s*-component of the force
- a. Positive
- b. Negative
- c. Zero

where *s* is either x, y, or z.

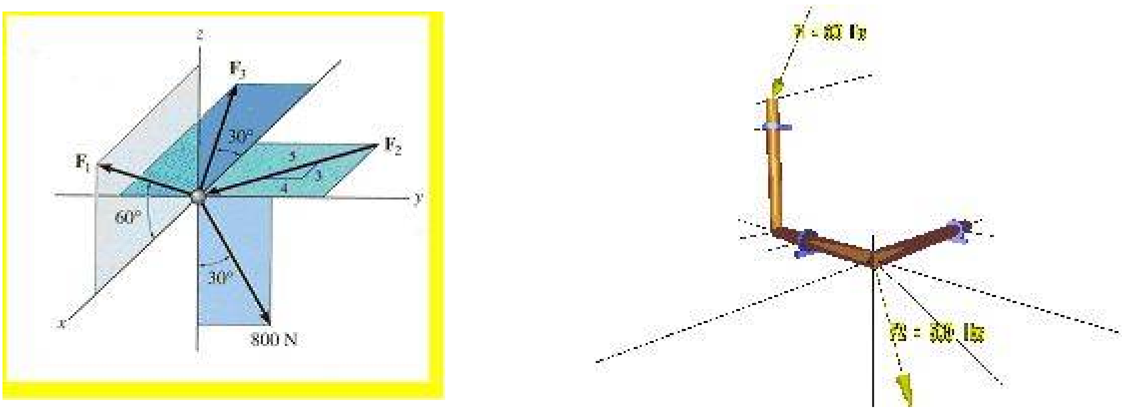

Figure 2. The 2D version of Question 1 is shown on the left. The rendered version is shown on the right. The rendered version was displayed in stereo in a much larger format and in color.

In the second experiment, a 3D rigid body was shown with two forces acting on it (Fig. 3). Again a multiple-choice quiz was given. For both forces acting on the rigid body the following questions were asked:

For the force, is the *s*-component of the force
- a. Positive
- b. Negative
- c. Zero

For the point on which this force acts, is the *s*-location of the point
- a. Positive
- b. Negative
- c. Zero

again *s* is either x, y, or z.

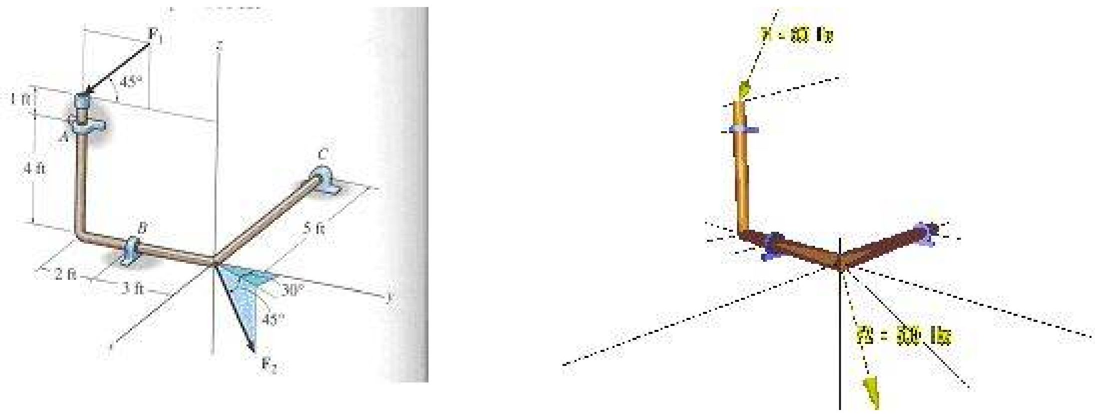

Figure 3. The 2D version of Question 2 is shown on the left. The rendered version is shown on the right. The rendered version was displayed in stereo in a much larger format and in color.

Qualitative questions were also asked throughout the study. For example, after using the stationary VisDuo, students were asked if this method was better than/worse than/same as using the overhead. Similar questions were asked comparing the interactive VisDuo to the stationary VisDuo and to the overhead, as well as comparing the Visbox to each of the first three media. A survey was given after the first experiment in which the students were asked to rank each of the display methods studied on a scale of one to five (one being "difficult to visualize" and five being "easy to visualize") as well as which method they preferred to use for 3D problems.

Results and Discussion

The results of the two studies are shown in Table 2. There are three key methods for analyzing this data. The first is to simply look at the average score of the students. The first two columns show this information. A second method of analysis was used in which the number of students who scored perfect on the quiz was counted. The next three columns relate to this information. Qualitative information should not be undervalued and therefore, data from the survey has also been included in this analysis and is presented in the final column.

Table 2. Summary of the results of the two studies.

	Average Score	Error	Number of Students Sampled	Number of Perfect Scores	Percent of Perfect Scores	Average Student Rating (1-5)
Overhead #1	**83.9%**	**5.8%**	**43**	**18**	**41.9%**	**3.0**
VisDuo-static	**78.2%**	**4.5%**	**42**	**8**	**19.0%**	**2.9**
VisDuo-motion	**88.6%**	**4.0%**	**43**	**19**	**44.2%**	**3.8**
Visbox #1	**98.3%**	**1.7%**	**39**	**35**	**89.7%**	**4.6**
Overhead #2	**91.7%**	**4.1%**	**39**	**25**	**64.1%**	
Visbox #2	**96.8%**	**2.8%**	**34**	**38**	**82.4%**	

Figure 4 illustrates the disparity between the various media when analyzing the average scores. From this information it can be seen that students performed best while using the Visbox, as expected. The static form of the VisDuo contributed the least to student performance. The two passive media with static models (overhead and the static VisDuo) were less helpful than the two interactive media with moving models (the VisDuo in motion and the Visbox). One point that may be argued is that placing students in an active role or having a moving model may lead to better 3D visualization. These two characteristics were not analyzed separately so no conclusions can be drawn about which parameter is more influential in understanding 3D representations. In future studies the distinction between the effectiveness of user interaction and moving models will be made.

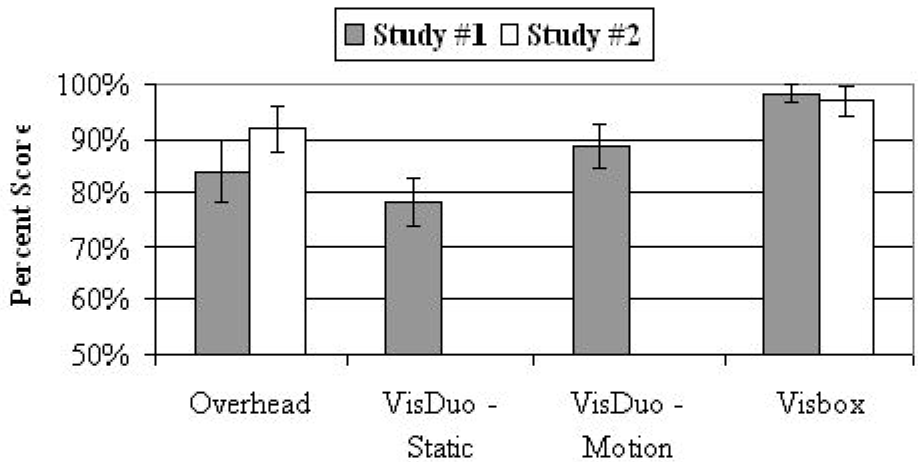

Figure 4. Analysis of the average score on the two different studies.

Figure 5 illustrates the percentage of perfect scores that were obtained in the two studies. Although this analysis shows a greater disparity between the fully interactive Visbox and both the overhead and the VisDuo in motion, it hides the difference between these last two media. It also illustrates that the static VisDuo is the least helpful of the four media studied in this experiment. This was surprising since the VisDuo displays in three dimensions. One conclusion based on this data is that the visual cue of shading the vectors' planes better represents 3D systems than using only binocular disparity.

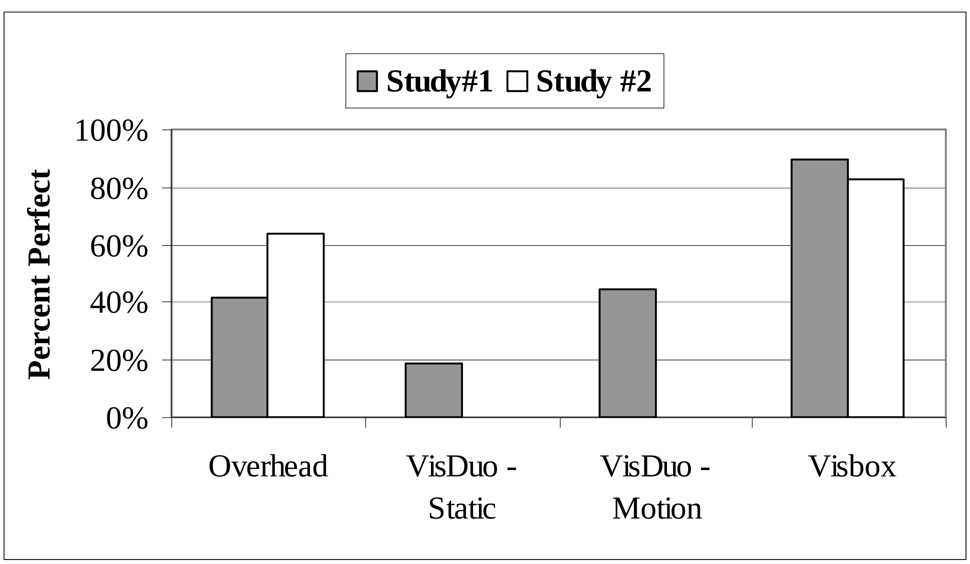

Figure 5. Analysis of the percentage of perfect quizzes on the two different studies.

According to our 9D framework, an important characteristic of an information communication medium is the students' perception, or the novelty, of the device. To measure this, qualitative information was obtained through a survey. In the survey, 85.4% of the students felt that the Visbox was the easiest method to view 3D representations. Students also rated each of the four media, and these average ratings are illustrated graphically in Fig. 6. This graph points out that even though the overhead and the VisDuo in motion are similar in their effectiveness in interpreting 3D representations according to the percentage of perfect quizzes, the VisDuo in motion is perceived by the students as being a considerably more useful tool. 68.4% of the students felt it was easier to see the vectors using the VisDuo in motion than using the overhead while only 9.3% felt the overhead made it easier and 23.3% felt the two media were equivalent (two of the 43 students failed to respond). Obtaining clearer separation between these two media will be studied further in future courses.

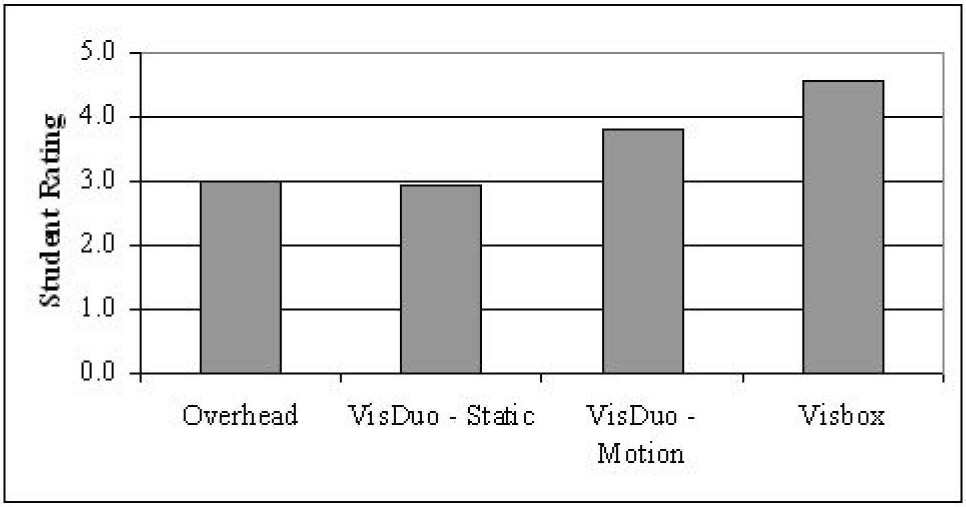

Figure 6. Average student rankings of the four media used in the studies.

Another important characteristic that should also be considered is the overall aspect of the ability of the students to recreate the 3D object in their minds. This is difficult to quantify but the instructor can make an overall assessment of the students' progress. The instructor noticed a considerable reduction in the amount of questions asked throughout the semester on 2D diagrams of 3D systems when compared to the previous year in which the media being studied were not involved. It is not clear whether the study itself improved student's ability to pick up the visual cues better or if one of the individual media was the driving force behind this. The anecdotal evidence presented here should not be overemphasized, however it should also not be neglected.

Contributions and Future Work

Virtual Reality media can do a better job of imparting three-dimensional information to students and has promise in the area of education. It has been shown that using a fully interactive virtual device (the Visbox system) is the most useful for students in interpreting 3D representations. This was illustrated quantitatively by both methods of analysis. The average score method resulted in the Visbox being 14.6% more effective than the overhead, 20.5% more effective than the static VisDuo, and 9.9% more effective than the VisDuo in motion. The percent of perfect quizzes showed an even more significant disparity between the Visbox and the other three methods – 53.4%, 78.8%, and 50.8% for the overhead, static VisDuo, and VisDuo in motion, respectively. This conclusion was also supported qualitatively through the survey questions asked. 85.4% of the students felt it was the best method for interpreting 3D vectors and it received a significantly higher rating than the other three methods.

Contrarily, the worst media was the static VisDuo. The binocular disparity of the VisDuo is not enough to give students the proper perspective necessary to visualize and regenerate the 3D system in their minds. Even the shading and visual cues of the 2D overhead was more useful in aiding students in their understanding of the 3D representations.

Although the overhead and the VisDuo in motion appeared to be less successful than the Visbox for interpreting 3D representations, there was a noticeable difference between the two. The VisDuo in motion was slightly more effective considering the percent of perfect quizzes and even more discernibly useful in terms of the average score of the students. More importantly, the students' perceptions were that the VisDuo in motion was more effective at helping students understand 3D representations. 62.8% felt the moving VisDuo was better than the overhead, and the average rating of the VisDuo in motion was significantly higher than the overhead which was rated only slightly above the static VisDuo.

A final conclusion may be the most important of all. This refers to the practicality of the VisDuo as a teaching tool. Although the students performed best when using the Visbox, not every university can afford to spend the resources and money on such a device. It has been shown that the VisDuo is an effective method, it did not require significantly more resources than more common media, and is not as costly as the Visbox. From this we conclude that the lowest cost-to-benefit ratio of the hardware we studied is the VisDuo system and that it shows a great deal of promise for education. Furthermore, teaching with virtual reality is accessible to most university educators and is encouraged by our experiences in teaching with this hardware.

There is still much to learn about the effectiveness of these various media as well as other types of visualization and virtual reality devices. Future studies include the effectiveness of a static stereo display versus non-stereo interaction, i.e., a static 3D model versus an interactive 2D model. Similarly, more research will be performed in the contrasting the VisDuo and the overhead to better clarify the disparity between these two media.

References

[1] P. C. Wankat, F. S. Oreovicz, *Teaching Engineering*. New York: McGraw Hill, 1993.

[2] C. Dede, M. Salzman, B. Loftin, and K. Ash, "Using virtual reality technology to convey abstract scientific concepts," in *Learning the Sciences of the 21st Century: Research, Design, and Implementing Advanced Technology Learning Environments*, Jacobson, M. J., Kozma, R. B., Ed. Mahwah, NJ: Lawrence Erlbaum Associates, 1997.

[3] B. G. Baartmans, S. A. Sorby, *Introduction to 3-D Spatial Visualization.* Englewood Cliffs, NJ: Prentice Hall, 1996.

[4] C. Youngblut, "Educational uses of virtual reality technology", Institute for Defense Analyses, Alexandria, VA, January 1998.

[5] C. Dede, M. Salzman, and B. Loftin, "ScienceSpace: virtual realities for learning complex and abstract scientific concepts," in *Proc. of VRAIS '96*, San Jose, CA, pp. 246-252.

[6] C. D., M. Salzman, B. Loftin, "MaxwellWorld: learning complex scientific concepts via immersion in virtual reality." In *Proc. 2nd International Conference on Learning Sciences*, Charlottesville, VA, 1996, pp. 22-29.

[7] D. A. Bowman, J. Wineman, L. F. Hodges, and D. Allison, "Designing animal habitats within an immersive VE," *IEEE Computer Graphics & Applications*, vol. 18, no. 5, pp. 9-13, September/October 1998.

[8] D. A. Bowman, J. Wineman, L. F. Hodges, and D. Allison, "The educational value of an information-rich virtual environment," *Presence: Teleoperators and Virtual Environments*, vol. 8, no. 3, June 1999, pp. 317-331.

[9] A. E. Johnson, T. G. Moher, S. Ohlsson, J. Leigh, "Exploring multiple representations in elementary school science education" in *Proc. of IEEE VR 2001*, Yokahama, Japan, 2001, pp. 201-208.

[10] M. Roussos, A. E. Johnson, J. Leigh, C. A.Vasilakis, C. R. Barnes, and T. G. Moher, "NICE: combining constructionism, narrative, and collaboration in a virtual learning environment," in *Computer Graphics* vol. 31 no. 3, August 1997, pp. 62-63.

[11] M. Roussos, A. E. Johnson, T. G. Moher, J. Leigh, C. Vasilakis and C. Barnes "Learning and building together in an immersive virtual world" *Presence: Teleoperators and Virtual Environments*, vol. 8, no. 3, June 1999, pp. 247-263.

[12] V. S. Pantelidis "Virtual reality in the engineering classroom." *Computer Applications in Engineering Education*, vol. 5, no. 1, 1997, pp. 3-12.

[13] D. Tougaw and J. Will "Visualizing the Future of Virtual Reality" *Computing in Science and Engineering*, vol. 5, no. 4, July/August 2003, pp. 8-11.

Biographies

Peter E. Johnson is an assistant professor in the mechanical engineering department at Valparaiso University. His research interests include engineering education, complex adaptive systems, virtual engineering, and thermal systems.

Jeffrey Will is an assistant professor in the electrical and computer engineering department at Valparaiso University. He is director of the Scientific Visualization Laboratory, dedicated to promoting applications in scientific visualization for undergraduate education.

Christopher Graunke graduated from Valparaiso University with a B.S.E.E., where he performed substantial undergraduate research in both virtual reality and in quantum computing. He is the author of StaticVU, as well as several other virtual reality applications. He is presently in graduate study in electrical engineering.