2006-706: A STUDY OF 3D STEREO VISION SYSTEM FOR IMPROVING VISUALIZATION SKILLS

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A Study of 3D Stereo Vision System Effectiveness for Improving Visualization Skills

Abstract

This study compared the effectiveness of a Head Mounted Display (HMD) and anaglyphic glasses on students' learning of 3D designs. The two stereo display systems were used in an introductory design and graphics class. Data related to students' subjective perceptions and their objective performance were collected and analyzed. Results of the study reveal that, subjectively, students perceived the HMD to be more effective for learning of 3D designs. However, the study also found that, objectively, students' did not perform significantly better, when using the HMD.

Introduction

Virtual reality (VR) is a highly interactive, computer-generated environment for providing users with a sense of being immersed in a real-world scene. Previous studies have shown that VR has the potential to change and improve upon traditional ways that students are taught in many fields.

Pantelidis (1997) presented several reasons for using VR in engineering education, some of which include: VR provides motivation, VR can more accurately illustrate some features than other means, VR allows extreme close-up examination of an object, and VR gives the opportunity for insights based on new perspectives. Pantelidis also provided a review of many possible applications for VR in teaching: a virtual physics lab, a virtual engineering lab, a virtual science lab, and using VR in other technical courses. However, Pantelidis did not give a concrete example of applying VR in engineering education, he also did not evaluate the effectiveness of VR when used in engineering education.

Crumpton and Harden (1997) conducted a study in which they explored possibilities for using VR in ergonomics courses, within an industrial engineering curriculum. In their study, a survey was used to collect data on students' perceptions of doing ergonomic analyses in virtual environments. Their results revealed that students' perceptions supported the belief that computer-generated virtual work environments can enrich ergonomic classes.

Mills and deAraujo (1999) used a desktop VR system for teaching higher education students the basic concept of apportioning resources subject to constraints. Compared with students who were taught in traditional ways, Mills and deAraujo found that students who were taught using a VR system did not do significantly better. However, they pointed out that there might be other differences between learning with a VR system and with traditional methods. In particular, they indicated that there might be a difference between students' concepts concerning their level of learning enjoyment, when learning with the VR system, and what they actually learned. Mills and deAraujo pointed out that further work was required to investigate possible reasons for the indicated difference. They also emphasized that students' learning preferences needed to be analyzed more closely. Finally, Mills and deAraujo indicated that an instrument was needed that could be used to evaluate the usability of a VR system, with respect to students' learning preferences.

Several additional studies have been conducted that explored applications of VR technology in education, within different fields of study. Kerridge, Kizil, and Howarth (2003) explored the application of VR technology in mining education. Their study was designed to immerse students in virtual environments while studying 3D mine design methods. Chen (2000) explored the possible impacts of VR on architectural education. Ota, Loftin, Saito, Lea, and Keller (1995) used VR, combined with fuzzy logic, in surgical education and training. Bell and Fogler (2004) applied VR in chemical engineering education. Barraclough and Guymer (1998) studied applications and benefits of using VR techniques in environmental education.

Based upon a review of previous studies related to applying VR technology in education, within many other fields of study, we are particularly interested in applying VR technology in design and graphics education. We believe that VR technology might be particularly well-suited to design and graphics education, since VR can provide graphics-based immersive environments, while design and graphics education is an intensely visual field of study.

Research Problem

VR technology can produce a stereo image of an object within a virtual environment, by creating depth (Z-axis) cues for the space to which the object belongs. The depth information provided in stereo images can help users perceive geometric and design features more clearly, more realistically, and more accurately than traditional 2D projection views. Therefore, stereo VR display systems can help users more fully understand design objects, when compared with conventional 2D display systems.

Currently, there are several different methods for generating a stereo view of a 3D object. The most popular stereo display methods include: anaglyphic, polarized, line interlaced, frame flipping, and sync doubling. Each stereo display method characteristically has its own strengths and weaknesses.

Both anaglyphic and polarized stereo systems are low cost systems. However, anaglyphic stereo methods cannot provide colored displays of objects, while polarized stereo methods sometimes cannot completely filter out images between the user's two eyes, resulting in some "double vision" effects. Anaglyphic stereo systems tend to be less expensive than polarized stereo systems, since anaglyphic stereo systems typically only use common computer monitors, while polarized stereo systems need two projectors and a special projection screen designed for polarized image display (Seth & Smith, 2004).

Line interlaced, frame flipping, and sync doubling stereo are all high-cost stereo technologies. They can provide high quality stereo images, with high resolution and high fidelity. The three high-cost stereo methods commonly use LCD shutter glasses or head mounted displays.

Since there are differences in cost and stereo image display quality among the different stereo display methods, the authors are interested in studying differences in effectiveness for design and graphics education, between low cost and high cost stereo display methods. In this study, we chose to study differences in effectiveness between a low-cost anaglyphic stereo system (as shown in Figure1) and a high-cost frame-flipping stereo system (as shown in Figure2).

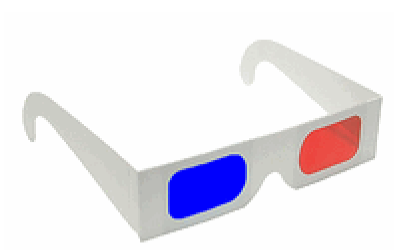


Figure1. Anaglyphic glasses

Figure2. I-glasses HMD

An anaglyphic stereo system generates two images of a single object, a right-eye image and a left-eye image. Each image is colored with a complementary color (red/blue or red/green). To the naked eye, users can see two images on the computer screen. However, with anaglyphic glasses, the right eye can only see the right-eye image and the left eye can only see the left-eye image. As a result, the two images appear, to the user, to be a single stereoscopic grayscale image of the object.

Frame flipping stereo generates two perspective views of a single object, in the same colors as the true object. The right-eye and left-eye images of the object are presented, alternatively, at a 120 Hz frame flipping frequency. Through LCD shutter glasses or a synchronized head mounted display, each of the user's eyes sees only one image, at a 60 Hz repetition rate. Thus, the user perceives a single stereo image of the object.

In a related prior study, Volbracht, Shahrbabaki, Domik, and Fels (1996) assessed the strengths and weakness of three display methods: perspective views (not stereo), anaglyphic stereo, and polarized stereo using shutter glasses. The effectiveness of different display methods were compared by measuring accuracy and time used during performance of tasks by their study subjects. Their subjects, 81 student participants, were divided into three groups. Each group had 27 subjects, and each group completed the assigned tasks using a single different display method. After completing the assigned tasks, each subject was asked the same set of 6 questions. For each question, the number of errors made and the time used by the subject were recorded. Average number of errors and the group mean time used for each question were then compared. From their data and analysis, Volbracht et al. found that students who used either anaglyphic stereo or polarized stereo with shutter glasses performed more accurately and faster than students who used the 2D perspective display method. They also found that there was no significant performance difference between students who used the anaglyphic stereo method and students who used the polarized stereo method.

Although Volbracht et al.'s study provided quantified effectiveness measures for different display methods, they only collected data related to their subjects' objective performance, when using the different display methods. However, Mills and deAraujo (1999) determined that students' subjective perceptions of technologies used in teaching should not be ignored when comparing the effectiveness of different technologies used in education.

The research problem of this study was to determine whether there is a significant difference in the effectiveness of anaglyphic and HMD-based stereo display methods in design and graphics education. Specifically, the study intended to measure the impact of the two stereo display methods on improving 3D visualization skills and understanding of 3D designs, in design and graphics courses, by measuring both students' objective performance and subjective perceptions.

Table 1. Research questions, variables, and hypotheses

Research Questions	Dependent Variables (Responses)	Hypotheses
Question1: Which system do students perceive to be better in helping to visualize 3D designs?	Helps to visualize 3D designs	HMD is better than anaglyphic glasses.
Question2: Which system do students perceive to be better for helping to understand 3D designs?	Helps to understand 3D designs	HMD is better than anaglyphic glasses.
Question3: Which system do students think is more physically comfortable?	Physical comfort	HMD is more comfortable than anaglyphic glasses.
Question4: Which system do students perceive to be more user-friendly?	User-friendly	HMD is more user-friendly than anaglyphic glasses.
Question5: Which system do students think provides a greater sense of immersion in the 3D environment?	Sense of immersion	HMD provides a greater sense of immersion than anaglyphic glasses.
Question6: Which system do students think stimulates more interest in learning?	Amount of interest in learning.	HMD stimulates more interest than anaglyphic glasses

Research Questions, Variables, and Hypotheses

In this study, the effectiveness of using anaglyphic and HMD stereo display methods in design and graphics courses was evaluated in two ways: subjective perceptions and objective performance.

In the subjective aspect, six dependent variables (response variables), as described in Table 1, were measured. Students' perceptions of the value of a given display method, with respect to each dependent variable, were used as measurements of effectiveness. As a result, for each dependent variable, a research question was also formulated and a hypothesis was given, as shown in Table 1. In this study, for all research questions, the independent variable was the type of stereo system used.

In the objective aspect, an independent research question was formulated: which stereo display system is better at helping to visualize 3D design models and identify 2D projection views? The dependent variable (response variable) for the given research question was: helps to visualize 3D designs and to identify 2D projection views. The independent variable for the given research question was: stereo display method. The corresponding hypothesis for the given research question was: HMD is better than anaglyphic glasses at helping to visualize 3D design models and identify 2D projection views. A set of visualization tests was used to assess students' objective performance when using the two VR systems.

Population and Sample

The population for the study was a group of undergraduate students in mechanical engineering, industrial engineering, and industrial technology majors, who were taking an entry-level design and graphics course. All 30 students in the class participated in the study; 28 of the students were male and two were female.

Research Design

In this study, two different types of stereo display systems (HMD & anaglyphic glasses) were used. When a student wore either an HMD or anaglyphic glasses, he or she could see a stereo view of a 3D design model, which was generated by a desktop computer. Both systems allowed the study subjects to manipulate the stereo 3D objects, so they could see the displayed object clearly from different perspectives. The purpose of the study was to compare the effectiveness of the two stereo display systems for enhancing students' learning of 3D designs.

In the study, the effectiveness of the stereo display systems was evaluated based on both objective and subjective data. The objective data were derived from a designed experiment using a set of four tests. The subjective data were derived from students' perceptions about the two systems' effectiveness.

In the designed experiment, a blocked design was used, with each student defined to be a block. Each student was asked to use each system twice, in a randomly assigned order. For each use, the given subject was randomly assigned one of four tests to complete. Thus, the design included replication for each treatment within each block. As a result, the experiment was designed to be able to detect significant differences between systems, even if there was interaction between blocks (students) and treatments (systems).

For the given blocked design, the number of blocks (students) was 30, and the number of treatments (display systems) was 2. The number of replications for each treatment within each block was 2. Thus, sample size for each treatment was 60. With an experiment-wise α error rate of 5% and experiment-wise β error rate of 10%, the difference size to be detected (Δ/σ) was less than 0.6, according to Nelson (1985). As a result, the given designed experiment could detect small difference between treatments.

In this study, since the difficulty of the four tests was equivalent, effects for tests were not considered. The effect to be studied was the effect of different display systems. For each replication, a student used a randomly assigned display system to finish a randomly assigned test.

For each replication, the subject's score on the given test was recorded. As a result, for each student, two HMD system scores and two anaglyphic system scores were recorded.

During objective testing, the time students used to complete a test could have acted as a confounding factor. Thus, to eliminate the potential confounding factor, every subject was given 15 seconds to complete each assigned test.

After subjects completed the objective tests, the subjective data were collected. A survey was given to each subject and each subject was given one week to complete the survey. After all the surveys were returned, the subjective data, for the two display systems, was analyzed and compared.

Objective Tests

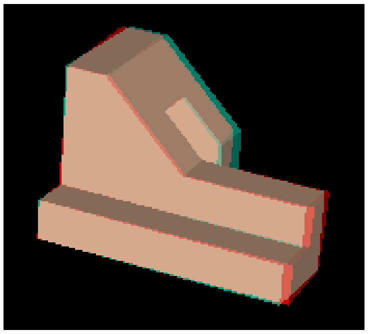
Students' objective performance, when using the two VR systems, was measured by their ability to visualize 3D models and identify their corresponding 2D projection views. The measurement instrument used was a set of quantitative tests. Each student took four equivalent tests, with respect to difficulty or skill level required (two for each VR system). Each test was composed of two problems. Full score, for any of the tests, was 20 points, 10 for each problem. In each test, the student was asked to view and manipulate two 3D stereo models on a computer screen (as shown in Figure 3) or on the display screen of the HMD (as shown in Figure 4).

Analysis of Objective Data

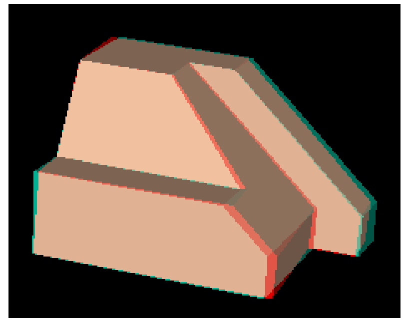
In an initial analysis, all known effects, including student, system, and the interaction between student and system, were considered. Analysis results for the effects of each factor are shown in Figure 6.

Figure 3. Anaglyphic glasses in use

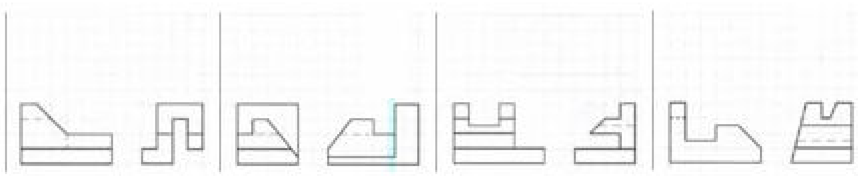
Figure 4. HMD in use



(a). Problem 1

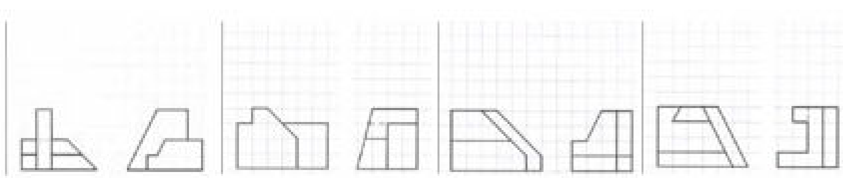


(b). Problem 2



(1) (2) (3) (4)

(c). The multiple choice question for Problem 1



(1) (2) (3) (4)

(d). The multiple choice question for Problem 2

Figure 5. The two problems in Test 1

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Student	29	29	804.16667	0.8116	0.7268
System	1	1	40.83333	1.1951	0.2787
Student*System	29	29	384.16667	0.3877	0.9967

Figure 6. Effect test for each known factor

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Student	29	29	804.16667	1.0139	0.4614
System	1	1	40.83333	1.4930	0.2250

Figure 7. Effect test for each known factor in the refined analysis

Level		Least Sq Mean
Anaglyphic	A	17.666667
HMD	A	16.500000

Levels not connected by same letter are significantly different

Figure 8. LSMeans Difference Student's t

The student was then asked to select the correct projection view for the displayed 3D models. Figure 5 shows the 3D models and the sets of associated projection views from Test 1. For the four tests, the level of difficulty associated with identifying the correct projection views for the displayed 3D models was equivalent.

The initial effect test results indicated that the effect of display systems on students' test scores was not statistically significant. At the same time, the results indicated that the interaction between student and system did not have a significant effect on test scores. Thus, the analysis was refined, by removing the interaction item. Results for the refined analysis are shown in Figure 7.

At a 95% significance level, the effect tests for each factor in the refined analysis also revealed that there was no statistically significant difference in student's objective performance (mean test scores), when using the two stereo display systems, since the *p*-value for system was much greater than 0.05.

The investigators found that the mean performance score when using anaglyphic glasses (17.67) was a little higher than the mean score when using a HMD (16.50). However, using LSMeans Difference Student's t to compare mean scores for the two display systems also showed that the difference in mean scores when using anaglyphic glasses and a HMD was not statistically significant, as shown in Figure 8.

Analysis of the objective test data indicated that there was no significant difference in students' objective performance when using either of the two stereo display systems. Therefore, the investigators rejected the hypothesis for the objective research question that the HMD would help students visualize 3D models and identify 2D projection views better than the anaglyphic system.

Survey Instrument

The survey instrument used in the study included 21 questions. The first 5 questions were designed to collect demographic information of the sample. The next 15 questions were related to the research questions. The last question was an open-ended question used to collect subjective information concerning possible reasons for students' preferences for either of the two stereo systems. A four-point Likert scale was used to rate the extent to which the subjects agreed or disagreed with descriptions of using a HMD or anaglyphic glasses.

Analysis of Subjective Data

To complete the study, 30 surveys were sent out; 27 of them were returned (90% return rate). Among all respondents, 92.6% were male and 7.4% were female. 29.6% of respondents were freshman, 33.3% were sophomores, 25.9% were juniors, and 11.1% were seniors. 7.4% students were majoring in industrial engineering, 74.1% in industrial technology, and 18.5% in other majors. 70.4% of respondents had not taken any technical graphics courses, before they took the Introduction to Design course in which the study was conducted, and 74.1% had no previous experience with any VR systems, before they used the HMD and anaglyphic glasses in the class. Demographic information collected for the respondents indicated that the sample could be used to represent the population considered in the study.

For the four-point Likert scale (continuous) variables, paired samples *t*-tests (as shown in Figure 9) were used to determine if there were significant differences between the response means, for the stereo display systems. For nominal (categorical) variables, frequency statistics (as shown in Figure 10) were utilized.

For the paired samples *t*-tests, since 1 = strongly agree and 4 = strongly disagree, lower mean values indicated better perceptions concerning the given system. The paired samples *t*-test results showed that students perceived that the HMD was significantly better for enhancing 3D visualization skills; the mean value for the HMD was significantly less than the mean value for the anaglyphic glasses, and the associated *p*-value was less than 0.05. The paired samples *t*-test results also showed that students perceived that the HMD was significantly better than anaglyphic glasses for improving students' ability to identify projection views of 3D designs; the mean value for the HMD was significantly less than the mean value for the anaglyphic glasses, and the associated *p*-value was less than 0.05. Both survey items, "helps to enhance 3D visualization skills" and "helps improve ability to identify projection views", were used to measure survey item "helps to visualize 3D designs". Therefore, students perceived that the HMD was significantly better than anaglyphic glasses for helping to visualize 3D designs. Therefore, the hypothesis for the first subjective research question was confirmed.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper			
Pair 1	HMD helped enhance my 3D visualization skills - Anaglyphic glasses helped enhance my 3D visualization skills	-.148	.362	.070	-.291	-.005	-2.126	26	.043
Pair 2	HMD improved my ability to understand 3D designs - Anaglyphic glasses improved my ability to understand 3D designs	-.269	.452	.089	-.452	-.087	-3.035	25	.006
Pair 3	HMD improved my ability to identify projection views for 3D designs - Anaglyphic glasses improved my ability to identify projection views for 3D designs	-.259	.447	.086	-.436	-.083	-3.017	26	.006
Pair 4	HMD makes my eyes uncomfortable - Anaglyphic glasses makes my eyes uncomfortable	.407	.888	.171	.056	.759	2.383	26	.025

Figure 9. Paired samples *t*-tests for continuous variables

Paired samples *t*-test results indicated that the HMD was significantly better than the anaglyphic glasses for improving students' ability to understand 3D designs. Frequency statistics also showed that 85.2% of the respondents perceived that the HMD was better for helping to understand projection views of 3D models. As a result, the hypothesis for the second subjective research question was confirmed.

Paired samples *t*-test results indicated that the HMD was significantly more comfortable for users' eyes than anaglyphic glasses. In addition, frequency statistics showed that 70.4% of respondents thought that the HMD was more physically comfortable than the anaglyphic glasses. Therefore, the hypothesis for the third subjective research question was also confirmed. Hypotheses for the remaining subjective research questions were all accepted, based upon the corresponding frequency statistics results.

Discussion

Since hypotheses for all of the subjective research questions were confirmed, the research study results indicate that students perceived that the HMD was more effective for design and graphics education than anaglyphic glasses. Since the research hypothesis for the objective research question was rejected, the research study results indicate that there was actually no statistically significant difference in students' objective performance when using the two stereo

Which system is better in enhancing your 3D visualization skills?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HMD	24	88.9	88.9	88.9
	Anaglyphic	3	11.1	11.1	100.0
	Total	27	100.0	100.0	

Which system is better in helping you understand projection views of 3D models?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HMD	23	85.2	92.0	92.0
	Anaglyphic	2	7.4	8.0	100.0
	Total	25	92.6	100.0	
Missing	System	2	7.4		
Total		27	100.0		

With which system do you feel more physically comfortable?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HMD	19	70.4	70.4	70.4
	Anaglyphic	8	29.6	29.6	100.0
	Total	27	100.0	100.0	

Which system is more user-friendly to you?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HMD	16	59.3	61.5	61.5
	Anaglyphic	10	37.0	38.5	100.0
	Total	26	96.3	100.0	
Missing	System	1	3.7		
Total		27	100.0		

Which system gives you a greater sense of immersion in 3D environment?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HMD	26	96.3	96.3	96.3
	Anaglyphic	1	3.7	3.7	100.0
	Total	27	100.0	100.0	

Which system do you prefer in future 3D designs learning?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HMD	23	85.2	85.2	85.2
	Anaglyphic	4	14.8	14.8	100.0
	Total	27	100.0	100.0	

Which system stimulates more of your interest in learning 3D designs?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	HMD	24	88.9	88.9	88.9
	Anaglyphic	3	11.1	11.1	100.0
	Total	27	100.0	100.0	

Figure 10. Frequency statistics for nominal variables

display systems. In other words, with respect to impact on objective performance, the results indicate that there is no difference between the two stereo display systems for use in the design and graphics courses.

The inconsistency between objective test results and subjective survey results indicates that there is a gap between students' subjective preference and their actual objective learning ability, when using the two systems. Since there was a significant difference in students' subjective preference between the two stereo display systems, further study is needed to investigate whether students' preference for a particular educational technology might affect their actual long-term learning gains. If students' preference for a particular educational technology does have an effect on their actual long-term learning gains, then the HMD would be a better choice, based upon study findings. If students' preference for a particular educational technology does not have an effect on their actual long-term learning gains, then, when cost is more important than student satisfaction, educators could use the lower-cost anaglyphic system to reduce cost without sacrificing objective learning gains.

The sample used in this study was a convenience sample, rather than a random sample. The sample or sampling method could have affected the results; plausible extraneous variables might include, for example, gender of the respondents. Among the respondents, 92.6% were male and 7.4% were female. The HMD could display colorful stereo images, while the anaglyphic glasses could only provide grayscale stereo images. If gender of the users had an impact on sensitivity to color of the displayed images, gender may have been a confounding factor in interpreting the results.

The population of this study was undergraduate students in mechanical engineering, industrial engineering, and industrial technology majors. In the convenience sample, the percentages of students in mechanical engineering and in industrial engineering majors were much lower than the percentage of students in the industrial technology major. Thus, in future studies, the percentages of students from each of the three majors should be equivalent or nearly equivalent.

References

Barraclough, A. & Guymer, I. (1998). Virtual reality - a role in environmental engineering education? *Water Science and Technology, 38*(11), 303-310.

Bell, J. & Fogler, S. (2004). The Application of Virtual Reality to (Chemical Engineering) Education. *IEEE Virtual Reality 2004*, 217-218.

Chen, X. (2000). Impact of virtual reality to architectural education. *Xinjianzhu/New Architecture, 70*, 67-68.

Crumpton, L. & Harden, E. (1997). Using virtual reality as a tool to enhance classroom instruction. *Computers & Industrial Engineering*, *33*(1-2), 217-220.

Mills, S. & deAraujo, M. (1999). Learning through virtual reality: a preliminary investigation. *Interacting with Computers*, *11*(4), 453-462.

Nelson, L. S. (1985). Sample size tables for analysis of variance. *Journal of Quality Technology, 17*(3), 167-169.

Pantelidis, V. (1997). Virtual reality and engineering education. *Computer Applications in Engineering Education*, *5*(1), 3-12.

Seth, A., & Smith, S. S-F. (Fall 2004). PC-based virtual reality for CAD model viewing. *The Journal of Technology Studies*, *30*(4), 32-37.

Volbracht, S., Shahrbabaki, K., Domik, G., & Fels, G. (1996). Perspective viewing, anaglyphic stereo or shutter glass stereo? *IEEE Symposium on Visual Languages, Proceedings,* 192-193.

Kerridge, A., Kizil, M. & Howarth, D. (2003). Use of virtual reality in mining education.*Australasian Institute of Mining and Metallurgy Publication Series*, n 2, 15.

Ota, D., Loftin, B., Saito, T., Lea, R., & Keller, J. (1995). Virtual reality in surgical education**.** *Computers in Biology and Medicine, 25*(2), 127-137.