The Effectiveness of Head-Mounted Displays and Anaglyphic Glasses in Engineering Graphics Education

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ABSTRACT- *This study compared the impacts of Head Mounted Displays (HMD) and anaglyphic glasses on students' learning and their understanding of 3D designs in engineering graphics classes. The two stereo display devices were used in an introductory design and engineering graphics class. Data concerning students' perceptions of the two systems was collected and analyzed. Results from the study reveal that HMDs are perceived to be more effective than anaglyphic glasses for enhancing students' learning and their understanding of 3D designs.*

I. INTRODUCTION

Virtual reality (VR) is a highly interactive, computer-generated environment for immersing a user in a "real world" scene. Previous studies have show that VR has the potential to change educational methods and improve upon the traditional ways that students are taught, in many fields.

Pantelidis (1997) presented several reasons for using VR in engineering education: VR provides motivation; VR can more accurately illustrate object features than other means; VR can provide extreme close-up examination of an object; and VR gives the opportunity for insights based on new perspectives. Pantelidis proposed many possible applications of VR in teaching, including: a virtual physics lab, a virtual engineering lab, and a virtual science lab. However, Pantelidis did not implement a real example, in which he applied and evaluated the effectiveness of VR in engineering education.

Crumpton and Harden (1997) conducted a study to explore the possibility of using VR in ergonomics courses in an industrial engineering curriculum. In their study, they used a survey to collect data concerning students' perceptions of conducting an ergonomic analysis in a virtual environment. Their results revealed that students' perceptions supported their belief that computer-generated virtual environments can be used in ergonomics classes.

Mills and de Araujo (1999) used a desktop VR system for teaching higher-education students basic concepts related to apportioning resources subject to constraints. When compared to students taught in a traditional way, Mills and de Araujo found that students taught using VR systems did not do significantly better. However, the authors found that students enjoyed learning more when they used VR environments than when they used traditional learning techniques. The authors identified a difference between learning gains and learning enjoyment, when using VR systems. The authors also stressed that, in future studies, students' learning preferences need to be analyzed more closely. They also identified the need for an instrument which

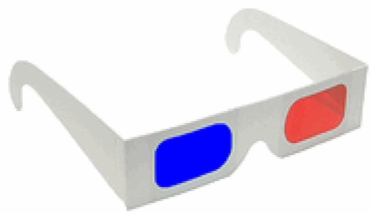

Figure 1. Anaglyphic glasses.

Figure 2. I-glasses HMD.

could be used to evaluate the VR system usability, based on students' learning preferences.

Additional studies have been conducted, which explored educational applications of VR technology in different fields. Kerridge, Kizil, and Howarth (2003) considered using VR technology in mining education to immerse students in 3D environments during mine design exercises. Chen (2000) explored impacts of VR on architectural education. Ota, Loftin, Saito, Lea, and Keller (1995) used VR, combined with fuzzy logic, for surgical education and training. Bell and Fogler (2004) applied VR in chemical engineering education. Barraclough and Guymer (1998) explored applications and benefits of using VR techniques in education related to environmental issues.

Although previous studies have considered using VR for science and engineering education, in several different areas, the authors' current study intends to explore applications and benefits of using VR technology in design and technical graphics education. The study intends to show that VR, as an immersive graphics-based technology, can have a significant impact on students' learning in technical graphics education.

II. RESEARCH PROBLEM

VR technology can provide a stereo image of an object in a virtual environment by creating depth (Z-axis) cues of the space to which the object belongs. With VR technology, depth information for a 3D design model can be conveyed by the stereo image of the model, which can help users better understand the design. Using VR stereo display technology, users can perceive geometric and design features more clearly, more realistically, and more accurately than when using conventional 2D display technologies.

Since there are differences in cost and quality between the different VR stereo display methods, the authors are interested in determining differences in effectiveness, between low-cost and high-cost stereo display methods, when used in technical graphics education. In this study, anaglyphic stereo, a low-cost VR stereo method, was compared to frame flipping, a high-cost VR stereo method.

Anaglyphic stereo generates two images of a single displayed object, a right-eye image and a left-eye image. Each image is colored with a complementary color (red/blue or red/green). With normal human vision naked eyes, a user sees two slightly offset images of the same object on the computer screen. However, when wearing anaglyphic glasses, which have two differently colored lenses, the user's right eye can see only the right-eye image and the user's left eye can see only the left-eye image. Thus, the user perceives a stereo image of the displayed object.

Frame flipping stereo generates two perspective views of a displayed object. Both views render the image using true object colors. Right-eye and left-eye images of the object are presented alternatively at a frequency of 120Hz. A user views the images through liquid crystal shutter glasses or a head mounted display. The shutter glasses or head mounted display are synchronized with the display projector and alternately block or unblock the image presented to each eye. As a result, each eye only sees one image of the displayed object, at a frequency of 60Hz. The result is a stereo view of the displayed object. In this study red/blue anaglyphic glasses (as shown in Figure 1) and an I-glasses HMD (as shown in Figure 2) were used to create stereo images of 3D design models.

In related work, Volbracht, Shahrbabaki, Domik, and Fels (1996) assessed the strengths and weakness of three display methods: perspective viewing (not stereo), anaglyphic stereo, and shutter glasses stereo. Volbracht et al. compared the effectiveness of different display methods by measuring accuracy and task time for students assigned to complete questions related to stereo displays. Totally, 81 students participated in the study, and the 81 students were divided into three groups. Each group contained 27 subjects, and each group completed the same set of tasks using one of the three display methods. Each subject was asked the same set of six questions. For each question, the number of errors made and the time taken to complete the question were recorded. Group means for number of errors and time to complete each question were then compared. Volbracht et al. found that using either anaglyphic or shutter display methods is more accurate and faster than using perspective display methods. They also found that there was no significant difference between anaglyphic and shutter display methods.

Volbracht et al.'s study only measured differences in students' objective performance when using different display methods. However, students' subjective perceptions also need to be considered as an important factor when comparing the effectiveness of technologies used in education. Therefore, the current study aims to determine if there is significant difference in students' perceptions related to the effectiveness of using HMD and anaglyphic glasses in design and technical graphics courses.

III. RESEARCH QUESTIONS, VARIABLES, AND HYPOTHESES

In this study, the effectiveness of using HMD and anaglyphic glasses in design and engineering graphics courses was evaluated with respect to seven dependent variables (as shown in Table 1). Students' perceptions of the value for each dependent variable were measured. For each dependent variable, a research question was formulated and a hypothesis was given, as shown in Table 1.

IV. POPULATION AND SAMPLE

The population used in the study was a group of undergraduate students in mechanical engineering, industrial engineering, and industrial technology, who were taking an entry level design and engineering graphics course. A total of 63 students were in the class, 60 of the students were male.

V. RESEARCH DESIGN

In this study, two different sets of VR systems (Head Mounted Display & Anaglyphic Glasses) were used. When wearing either an HMD (Figure 3) or Anaglyphic glasses (Figure 4), students could see stereo views of 3D design models which were rendered by a desktop computer. Both display methods allowed students to manipulate the displayed stereo 3D objects, so students could clearly see any desired orientation of the displayed objects. The purpose of the study was to compare the

Table 1. Research questions, variables, and hypotheses.

Research Questions	Variables		Hypothesis
Which system do the students perceive to be better for helping visualize 3D designs?	Independent	Types of VR systems	HMD is better than Anaglyphic glasses.
	Dependent	Helps to visualize 3D designs	
Which system do the students perceive to be better for helping understand 3D designs?	Independent	Types of VR systems	HMD is better than Anaglyphic glasses.
	Dependent	Helps to understand 3D designs	
Which system do the students think is more physically comfortable?	Independent	Types of VR systems	HMD is more comfortable than Anaglyphic glasses.
	Dependent	Physical comfort	
Which system do students perceive to be more user-friendly?	Independent	Types of VR systems	Anaglyphic glasses are more user-friendly than HMD.
	Dependent	User-friendly	
Which system do students think gives a greater sense of immersion in the 3D environment?	Independent	Types of VR systems	HMD gives greater sense of immersion than Anaglyphic glasses.
	Dependent	Sense of immersion	
Which system do students prefer for use in future design and engineering graphics curricula?	Independent	Types of VR systems	HMD is preferred more than Anaglyphic glasses for future use.
	Dependent	Preference for future use	
Which system do students think stimulates more interest in learning?	Independent	Types of VR systems	HMD stimulates more interest than Anaglyphic glasses
	Dependent	Amount of interest in learning.	

Figure 3. A user with HMD.

Figure 4. A user with Anaglyphic glasses.

effectiveness of the two systems for enhancing students' learning and their understanding of 3D designs.

Students' perceptions about the two systems' effectiveness were measured. As a result, each student was exposed to both of the systems. Each of the 63 subjects used each system twice. Totally, each subject used the stereo display systems four times in a random order. After a subject finished all of four times, he/she was asked to complete a survey. After the survey was returned, the data was analyzed and comparisons between the two systems were made.

VI. INSTRUMENTATION

The survey used in the study contained 21 questions. The first 5 questions were designed to collect demographic information. The last question was an open ended question for collecting information related to possible reasons for students' preferences toward the two stereo systems. The 15 remaining questions were designed to answer the research questions. The correspondence between research questions and survey questions is shown in Table 2. Survey questions, Q6, Q7, Q8, Q9, Q10, Q11, Q12, and Q13 were four-point rating scale questions (1 = strongly agree, 2 = agree, 3 = disagree, 4 = strongly disagree). Students were asked to rate the extent to which they agreed or disagreed with what was described for HMDs or anaglyphic glasses.

VII. ANALYSIS OF COLLECTED DATA

Survey questions Q14, Q15, Q16, Q17, Q18, Q19, and Q20 asked students to indicate one answer (either HMD or anaglyphic glasses) which satisfied the description provided by the question, based on their perceptions.

During the study, 63 surveys were sent out, and 50 surveys were returned (a 79% return rate). 96% of the respondents were males, 34% were freshman, 38% were sophomores, 22% were juniors, and 6% were seniors. 2% of the students were majoring in mechanical engineering, 8% were majoring in industrial engineering, 78% were majoring in industrial technology, and 12% were majoring in other programs. 68% of the students had not taken any related graphics courses before. 70% of the students had not experienced any VR systems before they used HMDs and anaglyphic glasses in the study class. The demographic information of the respondents indicates that the sample can be used to represent a similar general population.

For survey items which used a four-point rating scale (continuous variables), paired sample *t*-tests were used to test for significant differences between mean responses to the survey items. For survey items which were nominal (categorical) variables, frequency statistics were utilized.

Table2. Research questions and survey questions.

Research questions	Survey questions
Question 1	Q6, Q7, Q10, Q11, Q14
Question 2	Q8, Q9, Q18
Question 3	Q12, Q13, Q15
Question 4	Q17
Question 5	Q16
Question 6	Q19
Question 7	Q20

VIII. RESULTS

Frequency statistics for examined categorical variables show that 90% of respondents perceived that HMDs were better than anaglyphic glasses for helping to enhance 3D visualization skills, 88% of respondents perceived that HMDs were better than anaglyphic glasses for helping to understand projection views of 3D models, 96% of respondents perceived that HMDs provided a greater sense of immersion in a 3D environment. When asked which system was more physically comfortable, 66% of respondents chose the HMD. When asked which system was more user-friendly, 52% of respondents chose the HMD. When asked which system they would prefer for use in future 3D design learning classes, 84% of respondents preferred the HMD. The frequency statistics also show that 86% of respondents think HMDs stimulate more interest in learning 3D designs.

For the paired sample *t*-test results, 1 = strongly agree and 4 = strongly disagree. Therefore, lower mean values indicate a more favorable subject response (better perceived system performance). The paired sample *t*-test results are shown in Table 3. Table 3 shows that, based upon student perceptions, the HMD was significantly better than anaglyphic glasses for helping to enhance 3D visualization skills. Table 3 also shows that the HMD was significantly better than anaglyphic glasses for improving students' ability to identify

Table 3. Paired sample *t*-test results.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	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

projection views of 3D designs. The survey item related to enhancing 3D visualization skills and the survey item related to improving ability to identify projection views were combined to measure the degree to which a given system helped students to visualizing 3D designs. The combined measure shows that the HMD was significantly better than anaglyphic glasses for helping students to visualize 3D designs. In addition, 90% of respondents perceived that the HMD was better than anaglyphic glasses for helping to enhance 3D visualization skills, and 88% of respondents perceived that the HMD was better than anaglyphic glasses for helping to understand projection views of 3D models. Therefore, the study results confirmed the first research question.

The paired sample *t*-test results, in Table 3, show that the HMD was significantly better than anaglyphic glasses for improving students' ability to understand 3D designs. Therefore, study results also confirmed the second research question.

For the survey item related to eye discomfort, Table 3 shows that the mean response for HMD was significantly greater than the mean response for anaglyphic glasses. Since a greater mean value indicates that students strongly disagreed with the survey item statement, the survey results indicate that the HMD system was significantly more comfortable to use, for their eyes, than the anaglyphic glasses. In addition, 66% of respondents thought the HMD was more physically comfortable to wear than the anaglyphic glasses. Thus, the survey results confirmed the hypothesis for the third research question.

Frequency statistics for Research Question 4 show that 52% of respondents perceived that the HMD was more user-friendly that the anaglyphic glasses. Therefore, the hypothesis for Research Question 4 was rejected. However, frequency statistics for Research Questions 5, 6, and 7 were all consistent with the research hypotheses. Therefore, the hypotheses for Research Questions 5, 6, and 7 were all accepted.

IX. DISCUSSION

The sample used in this study was a convenience sample, rather than a random sample. The sampling method used could allow extraneous variables to have an impact on explaining the results. For example, gender of students could have been a confounding factor in the interpretation of the results. Since the HMD could display colorful stereo images, while the anaglyphic glasses could only provide white and gray stereo images. In this study, 96% of respondents were males. If the gender of users impacts sensitivity to the color of images, gender could also be a confounding factor in interpreting the results. This confounding factor may have effect on testing hypotheses for Research Questions 1, 2, and 5.

Hypothesis 4 was rejected, which indicates that the HMD was perceived to be more user-friendly. All of the remaining research hypotheses were confirmed, which indicates that the HMD was perceived to be more effective for design and engineering graphics education than the anaglyphic glasses.

To generalize the findings of this study, further study using a random sample of students would be better. In future studies, to eliminate the possible confounding factor of gender, the sample should be even or near even in the gender.

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