Integrating Computer-generated Stereoscopic Models Into An Introductory Design Course

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Abstract

Stereoscopic technology has been successfully used in several learning and education environments. However, uses for and the effectiveness of computer-generated stereo models in design and graphics education still have not been extensively explored, especially in a large classroom setting. This pilot study examines the applications and potential of computer-generated stereo models in design and graphics courses in a large classroom setting. Computer-generated stereo models were displayed and manipulated in the classroom to help students acquire 3-D concepts. A survey was developed to both quantitatively and qualitatively measure student perceptions with and without using the stereoscopic systems. The study survey shows that the effectiveness of integrating computer-generated stereo models in design courses is not only affected by model image quality, but also by physical reactions to stereoscopy (e.g., some students felt dizzy or could not visualize stereoscopic views). Since model image quality is greatly influenced by the stereoscopic system used, further study is needed for determining the most cost-effective stereoscopic system for general design and graphics classroom use. In addition, pedagogical factors for best use the models to promote learning also need to be investigated.

Introduction

With the advance of computer technology, graphics technology has progressed from manual drafting to computer-aided design. The objectives of graphics education have also changed accordingly. Increased emphasis has been placed on design, problem-solving, presentation, and communication skills. However, three-dimensional (3-D) spatial visualization ability is the core requirement for successfully developing those skills.

Three-dimensional visualization ability, to a great extent, determines students' performance in design and technical graphics courses. Prior research has shown that student 3-D visualization ability greatly influences students' future career success in science, engineering, and technology (McKim, 1980; Norman, 1994; Pleck, McGrath, Bertoline, Bowers & Sadowski, 1990). Students without sufficient 3-D perception ability may become frustrated and drop out of CAD programs, or they may be encouraged to not major in CAD programs. If students can improve and gain confidence in their 3-D visualization skills, they will enjoy CAD instruction more and become more engaged.

Prior research shows that visualization is a skill that can be learned, developed, and improved with proper instruction and methods (Gagon, 1985; McKim, 1980). Thus, in order to help students remain in and succeed in CAD programs and to succeed in their future careers, it is essential to find the most effective method to deliver graphics concepts and to enhance student 3-D spatial visualization skills.

One way to enhance students' ability to visualize 3-D objects is to make their experience of the objects, while learning, as realistic as possible. However, in general, it is very difficult to clearly describe to students a 3-D object and the spatial relationships between object components, without using a physical mockup. Physical mockups take a significant amount of time to construct, especially for more-complex objects. As a result, graphics educators have been using 3-D CAD tools to help students understand spatial relationships between objects. However, CAD tools only allow students to examine 3-D models from outside flat computer monitors. In other words, the models and the viewers are in different realms. Using traditional CAD tools, students cannot view models with natural stereoscopic vision.

Stereoscopic technology simulates the natural vision process by using computer technology to create right-eye and left-eye images of a given 3-D object or scene. The brain integrates the information from these two perspectives to create the perception of 3-D space. Thus, stereoscopic technology creates the illusion that on-screen objects have depth and presence beyond the flat image projected onto the screen. Viewers can perceive distance and spatial relationships between different object components more realistically and accurately than with conventional visualization tools (e.g., traditional CAD tools). In industry, several major companies have integrated stereoscopic technology into their design processes to improve product quality, for example, Ford, Motorola, Harley Davidson, BMW, and GE (StereoGraphics Corp., 1999).

Prices for stereoscopic systems can vary from one dollar to half million dollars. The capacity of the systems also varies from serving one viewer to serving a large classroom. Most prior educational stereoscopic applications have only been used for small groups or individual viewers, not for large classroom settings. With advances in hardware and software, most PC computers now have the capability to support stereoscopic viewing. Thus, stereoscopic viewing has now become affordable for large classroom use.

Low-cost Stereoscopic Technology

Low-cost stereoscopic technology uses inexpensive devices such as PC workstations and 3-D glasses, combined with stereoscopic-enabled software applications, to partially immerse viewers in a virtual scene. Currently, most PC workstations have stereoscopic graphic display capability built into their graphics card chip sets. Therefore, with plug-in software for separating right-eye and left-eye and images, PC applications can now display stereoscopic views.

PC-based stereoscopic systems typically use one of several types of special viewing glasses to selectively send the right- and the left-eye images to the correct eyes. Depending upon the type of glasses used, stereo systems can be classified into active or passive stereo systems. “active” systems use glasses with electronic components; “passive” systems use glasses without electronic components. In active stereo systems, stereo images are presented by rapidly alternating the display of right-eye and left-eye images, while alternately masking the right and left eye using synchronous shutter eyewear, such as LCD shutter glasses.

Passive anaglyphic stereo systems are the most common and basic type of stereo systems. They are popular because they are very inexpensive, and cost is often a critical factor in public environments. One pair of red-blue anaglyphic glasses only costs about (U.S.) 80¢. Passive anaglyphic systems create a different colored image for the right and left eye. Users then view the images using anaglyphic paper glasses made from colored filters (e.g., blue for the right eye and red for the left eye).

One advantage for the anaglyphic stereo images is that they can be projected onto a big screen using regular LCD projectors without any special hardware. Thus, anaglyphic stereo systems can be easily implemented by most users for use with large audiences. However, image quality in passive anaglyphic systems is relatively poor, and they can only display gray-colored images. The lack of colored viewing capability is one of the major drawbacks of anaglyphic passive stereo systems.

Another method for passive stereo viewing is based on the principle of light polarization. With oppositely polarized filters attached to two projectors and matching filters in a pair of glasses, right- and left-eye images can be separated, and multiple colors can be preserved. However, polarized stereo systems are relatively expensive because they need special projectors for polarizing the left- and right-eye images. Polarized projectors usually cost about (U.S.) $5-10K.

Stereoscopic technology in education

In prior educational studies, stereoscopic technology has been considered an effective learning and educational tool for helping students understand abstract information and complex models. For example, Haufmann, Schmalstieg, and Wagner (2000) used a stereoscopic environment in mathematics and geometry education, especially in vector analysis and descriptive geometry. Bell and Fogler (1998) used stereo models to help students understand molecular mechanisms.

Many instructors have used anaglyphic technology, since it is very empirical, to enhance instructional delivery, especially in the geosci-

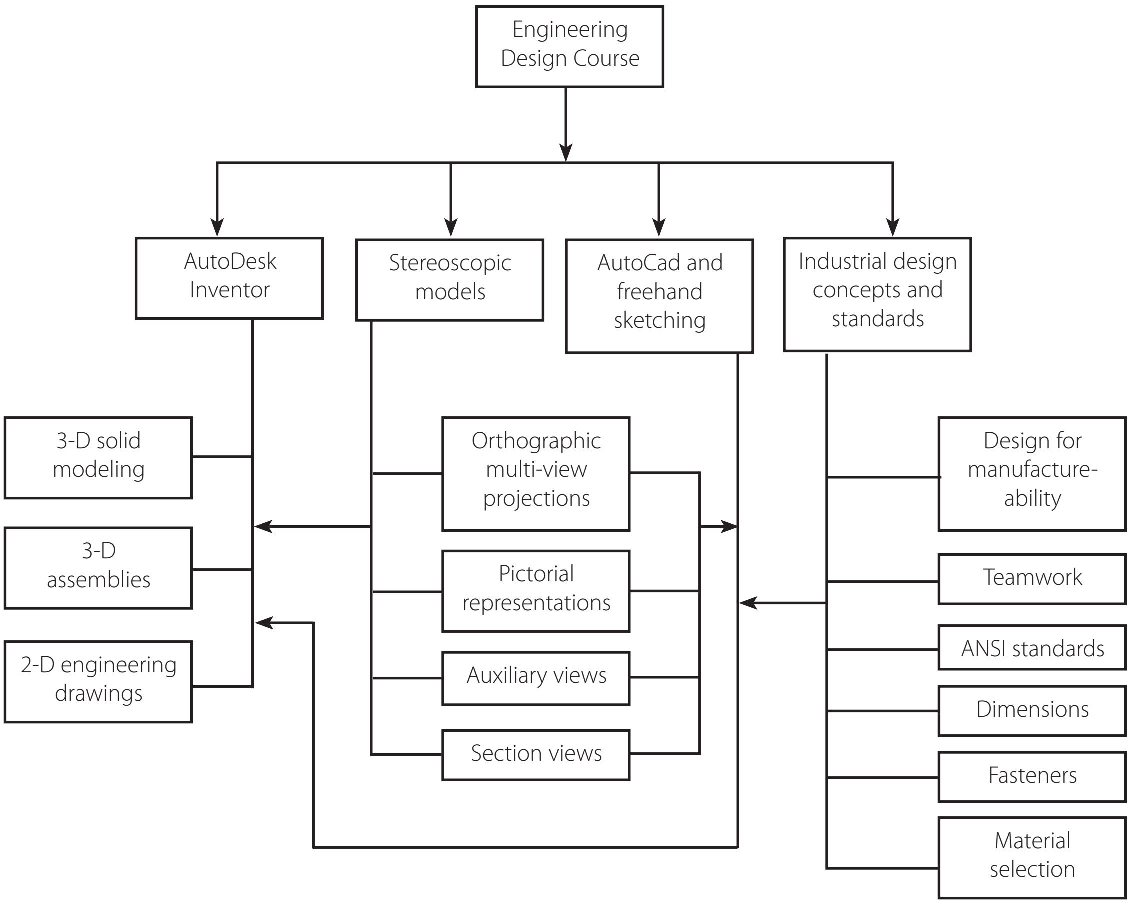

Figure 1. Integrating stereoscopic models into an entry-level design course

ences and biology (Lynn, 1993; Perkins, Hashmi, & Jordan, 1993). In addition, anaglyphic technology is an excellent basic tool for teaching students how stereoscopic images are created. However, although low-cost anaglyphic stereoscopic technology has existed for many years, in prior studies, most images were printed on paper. For example, Pearce (1985) introduced red-green color stereo images, printed on paper, into descriptive geometry instruction. As a result, the viewers could not orient or manipulate the models to look at different views.

Okamura and Lieu (1993) wrote a computer program to generated red-green anaglyphic images, on computer monitor screens, for enhancing descriptive geometry instruction. They concluded that their low-cost stereoscopic viewing system was ideal for educational use. The initial response from students was positive. Students liked the concept of having 3-D stereo models as well as a new, interesting way of learning. However, they did not collect any formal qualitative or quantitative survey results. After the study given by Okamura and Lieu, little literature exists concerning using computer-generated anaglyphic stereoscopic images in design and graphics education. Reasons for the lack of continued research or follow-up studies may have been the technical difficulty involved in developing stereoscopic viewing algorithms and displaying stereo models on computers. However, recently, stereoscopic viewing software and hardware has become more available, due to a growing stereoscopic virtual reality gaming industry. Some free stereoscopic software tools are even available in downloadable form on the Internet. Now, since more low-cost stereoscopic software and hardware tools are available, research concerning the effectiveness and cost-effectiveness of integrating computer-generated stereo images into large classroom, for full-time instructional

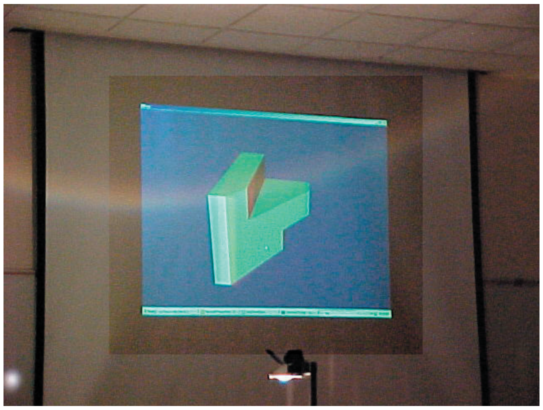

Figure 2 Stereoscopic models projected on a big screen at the front of the classroom

use, and pedagogical issues related to integrating the tools into design and graphics education can be completed.

Methodology

In this study, computer-generated anaglyphic stereo models were integrated into to an introductory design course, during the Spring 2003 semester, to help students visualize 3-D graphic models. Thirty-two students were in the class. Mental Rotation Test (MRT) scores were compared with results from the Fall 2002 semester, in which the same models were used and displayed in the classroom, but without stereoscopic viewing. A student survey concerning using stereo models was also conducted during the Spring 2003 semester.

The shaded blocks in the course map shown in Figure 1 describe how stereo models were integrated into the existing course. Example models from an engineering graphics workbook were created using Autodesk Inventor, before the pilot test lectures, which covered multi-view projections, pictorial views, auxiliary views, and section views. Free software was downloaded from OpenSceneGraph Professional Services (http://openscenegraph.sourceforge.net/) to translate the CAD models into red-blue anaglyphic stereo models. The software tool allows viewers to orientate, zoom, and translate the models. The red-blue stereoscopic tools were used in lectures, with free-hand sketching, to help students understand 3-D concepts and the relationships between different views.

During lectures, the instructor first projected the red-blue stereo models onto a big screen at proper times (Figure 2). The instructor also

Figure 3 Students experiencing stereoscopic instruction

manipulated the models to different orientations to show the different object views. Students wore the anaglyphic 3-D glasses for viewing the stereoscopic images (Figure 3). After students acquired spatial knowledge of a 3-D model, by stereoscopic viewing, they were asked to free-hand sketch projection views of the object.

The Mental Rotation Test (MRT) (Vandenberg & Kuse, 1978) was administered to evaluate students' visualization abilities. Testing occurred at the beginning and end of two different semesters. MRT scores from the two semesters were compared using two-sample t-tests. A statistical significance level of $p = 0.05$ was used for comparing sets of MRT scores. MRT scores from the beginning and end of each semester were also compared, within groups. During Fall 2002, traditional CAD tools were used during classroom lectures. The instructor projected the same models on the screen, but without stereoscopic viewing capability. During Spring 2003, passive anaglyphic stereoscopic tools were used during classroom lectures. A questionnaire was also administered, at the end of the Spring 2003 semester, to collect

MRT Scores		N	Mean	Standard Deviation	Mean Difference	Standard Deviation
(1) Fall 2002 (without stereo models)	Pre-test	35	18.06	6.30	9.31	4.80
	Post-test	35	27.37	6.93		
(2) Spring 2003 (with stereo models)	Pre-test	27	18.44	7.01	8.70	4.92
	Post-test	27	27.15	6.92		

Table 1 Pre-test and post-test MRT scores

students' comments about using the stereo models. The purpose of the questionnaire was to identify issues and concerns students had about viewing stereo models.

Results

MRT Results

MRT results for the pilot study are shown in Table 1. Results indicate that there was a statistically significant increase in students' visualization skills during both semesters, with a mean difference between pre-test and post-test scores of approximately 9 points on the MRT (p= 0.05). The pilot study results do not indicate a statistically significant difference between using traditional CAD tools and passive stereoscopic tools for classroom lectures. However, several uncontrolled factors still need to be taken into consideration (e.g., image quality, exposure time, and personal interaction with the stereo models).

Survey Results

A survey was developed to both quantitatively and qualitatively measure student perceptions related to their stereoscopic experiences, with a series of statements using a five-point Likert scale. The scale used was:

1. Strongly Disagree
2. Disagree
3. Not sure
4. Agree
5. Strongly Agree

The results of the survey are presented in Table 2. Each student was asked to rate 15 questions concerning usefulness and satisfaction with using the stereo models to enhance their learning. Overall, the results lead to two observations.

First, the students' opinions tended to be somewhat divided, and balanced about the mean on the Likert scale. This can be seen from the result mean values, which were all very close to 3 (not sure). However, overall, students' opinions appear to be slightly positive. For the eight statements that measure positive feelings about the stereoscopic tools, the average student response is 3.23. For the seven statements that measure negative feelings about the anaglyphic stereoscopic tools, the average student response is 2.44. Students gave the strongest average response overall (3.56) to Statement 9, " The three-dimensional models helped me to learn."

Second, although the students' opinions were divided, there were few extreme opinions. This can be seen from the relatively low percentages for responses in the "strongly disagree" and "strongly agree" categories. The results may indicate that the students did not have had enough exposure to stereoscopic technology to develop strong opinions about the effectiveness of stereoscopic tools for learning, or that they did not have a strong basis for comparison (did not have significant prior experience learning design and graphics materials using other methods).

In the second part of the questionnaire, students were asked about the "effectiveness", "strengths", and "weaknesses" of the stereo models in an open-ended question format. Positive comments about the effectiveness of the stereo models included: "stereoscopic models helped me get an overview of what the object really looked like," "We are actually able to see the model and understand the 3-D perspective," "It gave a better view of 3-D models than the 2-D book," "It was interesting, fun, and I could see the 3-D forms better", and "They helped visualize the object". Other than the positive comments, some students gave some negative comments about the effectiveness of the stereo models which include: "Not very - helped see the solid view", and "the glasses didn't help at all."

Question	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	All Students Mean N=32
1. I found the stereo models motivated me to learn.	6.3	21.9	37.5	34.4	0 %	3.00
2. The stereo models used in class were boring and uninteresting.	9.4	34.4	21.9	25.0	9.4	2.91
3. The stereo models were enjoyable and educational.	3.1	21.9	28.1	40.6	6.3	3.25
4. The stereo models were not easy to understand.	12.5	34.4	31.3	18.8	3.1	2.66
5. I could learn faster using stereo models than using the engineering graphics workbook.	3.1	12.5	43.8	28.1	12.5	3.34
6. I cannot see the stereoscopic view of the stereo models.	6.3	28.1	40.6	15.6	9.4	2.94
7. I could not clearly understand the material presented in the stereo models.	3.1	50.0	18.8	18.8	9.4	2.81
8. I believe that the stereo models would be excellent educational tool.	3.1	31.3	15.6	46.9	3.1	3.16
9. The three-dimensional models helped me to learn.	3.1	12.5	21.9	50.0	12.5	3.56
10. I believe that I could learn more in an introductory graphics course if stereo models such as these were available.	0 %	28.1	40.6	28.1	3.1	3.06
11. The simulated graphics of the stereo models enhanced educational value.	0 %	21.9	37.5	34.4	6.3	3.25
12. Viewing a stereo model makes me feel dizzy.	21.9	28.1	12.5	18.8	18.8	2.84
13. The stereo models were not an effective way to learn about engineering drawing.	18.8	21.9	25.0	31.3	3.1	2.78
14. I would appreciate the interaction with the stereo models.	0 %	15.6	43.8	40.6	0 %	3.25
15. The stereo models did not help me learn engineering graphics.	9.4	34.4	28.1	21.9	6.3	2.81

Table 2 Usefulness and satisfaction with the stereo models

Comments about the “strengths” of the stereo models include: “Help visualize the object better”, “Fun, Motivate”, “Not as boring”, “Great view”, “Better interpretation, fun”, “Better 3-D view”, “Works well”, “Good visualization tool”, “Gives you another perspective view”, and “Easier to understand our models”.

Some participants put valuable comments in the “weaknesses” section. Their responses were related to specific aspects of the technology or to particular individual differences. The comments included: “Couldn’t see it well," “Dizzying, goofy glasses," “Can’t physically touch it, still computer oriented," “I can see it well through 2-D," “Contrast was not clear enough on surfaces”, and “eye hurt."

Conclusions and Discussions

This pilot-test investigates the effectiveness of integrating computer-generated low-cost anaglyphic stereoscopic models into an entry-level design course, in a large classroom setting. Geometric models were created, using a CAD tool, and then translated into red-blue anaglyphic stereo models, using a free software tool provided by OpenSceneGraph Professional Services. The computer-generated stereo models were displayed and manipulated into different orientations, at the front of a classroom, at proper times during lectures or sketching exercises to help students understand the relationships between the 2-D representations and 3-D models.

The study also introduces formal qualitative and quantitative instruments for measuring the impacts of using stereoscopic technology in education: MRT tests and student surveys. Prior related studies did not use quantitative measures to support conclusions about the impacts of stereoscopic technology in education.

In the pilot study conducted, MRT test results indicate that student visualization skills improved by similar amounts, using either a low-cost anaglyphic 3D stereo system or a traditional 2D CAD system for classroom lectures. However, qualitative and quantitative survey results indicate that most students enjoy learning design and graphics instructional materials with the aid of stereo models and that stereo models help most students to visualize 3-D objects better. In particular, most students felt that the stereo models were interesting and fun, and that they made class less mundane. The instructor also observed that students were more engaged in lectures when the stereoscopic tools were used.

The effectiveness and quality of stereo models are both greatly affected by the stereoscopic system used. In the given study, some students felt that the inexpensive anaglyphic stereoscopic system used did not always work well. Since the anaglyphic stereoscopic system used inexpensive red-blue paper glasses, models were in gray color only. Thus, the contrast was not clear on model surfaces. As a result, some students' eyes hurt, they became dizzy, or sometimes it was hard for them to see the 3-D effect.

The effectiveness of stereo models is also affected by each individual's physical reactions. In the pilot test conducted, some students felt that using stereo models was not necessary because they could visualize 3-D models quite well using 2-D graphics. Some students could not see the stereoscopic effect in the projected 3-D images, or they felt uncomfortable and dizzy using the stereoscopic glasses.

Students also stated that they would like to have opportunities to actively interact with stereo models, rather than being passive viewers in the classroom. Inviting students to manipulate the models during the lectures could further increase students' engagement in class. Providing students more opportunities to experience the new technologies through direct interaction may further improve effectiveness.

Student survey results support conclusions drawn in prior studies related to using stereoscopic tools in education, which indicated, based upon student and instructor comments, that stereoscopic technology is a useful and engaging tool for education. The investigator believes that pilot study findings and comments are positive enough to continue to explore possibilities for implementation.

Future Work

This study provides a roadmap for further implementing and refining stereoscopic technology for use in design and graphics education. Further research is needed concerning the connection between using stereoscopic visualization tools and improving concept learning and visualization skills. Different or better methods may be needed for measuring, quantitatively, the positive impact reported by students and investigators in both prior studies and the pilot study. Although the MRT results for the test semesters are similar, students' comments related to using the stereoscopic visualization tools indicated enhanced learning effects. Test instruments, other than the MRT, could be developed to better measure the apparent learning effects. Instruments that incorporate the stereoscopic viewing technology might be particularly useful.

Additional research is also needed for determining the most cost-effective stereoscopic technology for improving design and graphics education, in a large classroom setting. Other stereoscopic technologies, such as passive polarized stereo systems, CAVE, and head-mounted displays, need to be tested and compared to anaglyphic systems. Some stereoscopic systems are relatively expensive, although their image quality and degree of immersion are much better than anaglyphic systems.

Several pedagogical issues concerning how to best use stereoscopic tools to promote learning also need to be studied. For example, students might be more interested in viewing models they create. Research is also needed concerning how more hands-on opportunities, such as using stereoscopic tools for student team-design projects and presentations, impacts visualization skill development and learning. In addition, the pilot study only used relatively simple individual models. Stereoscopic technologies might be most useful for visualizing complex mechanisms and motions.

Adding haptic devices to provide force feedback could help increase the realism of the stereo models. Other factors, for example exposure time and physical comfort, that might influence learning in stereoscopic environments, also need to be considered.

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