



Stereoscopic Visualization for Improving Student Spatial Skills in Construction Engineering and Management Education

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Abstract

Spatial skills are essential in Science, Technology, Engineering, Mathematics (STEM) education. However, most educational settings are not focused on them. Spatial skills are the ability to understand and remember spatial relations among objects. Critical features in construction engineering and management (CEM) education are related to the capability of constructing mental models of building components and materials from construction drawings and specifications. Thus, it is essential for students to develop spatial skills throughout the CEM curriculum. Several studies have shown that spatial performance can be improved through practice and training. In this paper, we propose using portable stereoscopic visualization as a tool for students to practice spatial skills in CEM education. Stereoscopic visualization uses the characteristics of human binocular vision to create an illusion of astonishingly vivid depth perception, making objects appear to be in front of or behind the screen. This technique relies on presenting a stereo pair of views created by simulating the presence of two camera views corresponding to viewpoints of two human eyes, which are an independent pair of co-timed images, giving the left and right view. Computer-generated content, using computer graphics software, are typically considered the easiest method of stereo generation. In the process of stereoscopic visualization, it is required to (1) segment an image, (2) calculate and assign relative depth to each object in the image, (3) locate occlusion areas and fill them with suitable portions of other objects, and (4) present each view of the scene exclusively to each corresponding eye of the perceiver. This process creates depth and occlusion maps suitable for integration with imagery. This paper mainly describes how to develop and implement stereoscopic visualization in a portable system to help students better understand information from construction drawings.

Introduction

Students in construction engineering and management (CEM) programs have difficulty in learning quantity takeoff, estimating, and scheduling. Based on our preliminary study on what causes this problem, we identified that students taking these courses were required to use construction drawings and specifications for hands-on activities. They struggled in obtaining information from construction drawings and specifications. We believe that this might be one of major problems besetting CEM education since students coming into a CEM program typically do not have extensive construction experience. This problem directly affects the student understanding of CEM core contents associated with plan reading.

Reading construction drawings is not difficult. It only requires some basic knowledge of architectural plans (e.g., scales, lines, symbols, views, etc.) and practice. CEM programs teach students the foundational knowledge of plan reading (e.g., an understanding of scale and the interpretation of types of lines and symbols). Nevertheless, why do students struggle in understanding information from plans? To address this, a simple question, "What is the hardest

part in reading plans? Why?” was asked to students in plan reading and estimating courses. Through this question, we revealed that students have difficulty in building mental models of object configuration from two-dimensional drawings on several sheets representing different perspectives such as plan, elevation, and section views. Branoff and Dobelis¹ also advocate that it is often exasperating for students to convert the two-dimensional drawing information into three-dimensions mentally.

Several studies show that students with high spatial ability can understand and interpret drawings much faster and more accurately than those with low spatial ability.^{2, 3, 4, 5} This indicates that the ability to read drawings is directly related to spatial ability. This ability can be developed by practice or improved by some types of interventions.^{6, 7, 8}

In this paper, we propose using stereoscopic visualization in CEM education not only to improve students’ spatial ability but also provide students with a better understanding of construction assemblies and details. This paper mainly focuses on how to develop and implement such visualization in a portable computer system to assist students in building mental models of construction assemblies and details from two-dimensional drawings. The main objective of this study is to establish a baseline to determine whether future research on spatial perception and visualization is warranted in a university’s CEM education.

Spatial Skills in Construction

Spatial ability is a unique type of intelligence which can be best defined as “the ability to present the spatial world internally in your mind”.⁹ In other words, spatial ability is the capacity to mentally organize, understand, and visualize spatial relations among objects. Linn and Peterson¹⁰ describe that spatial ability consists of mental rotation, spatial perception, and spatial visualization. This ability is known as a critical skill in many fields of study, including science, technology, engineering, and mathematics (STEM) education.¹¹ Spatial ability becomes increasingly important with the advance of new computer graphics technology.

In the construction industry, architects typically use two-dimensional plans and written specifications to communicate what is to be built to construction managers. Thus, being able to understand plans and working drawings is a critical skill for all areas of construction. Students must learn how to read plans throughout the CEM curriculum since strong visual-spatial ability is required to understand details of the finished structure and perform construction work.

Mental reconstruction of three-dimensional models from a set of drawings and specifications is not an easy task for novices. As shown in Figure 1, there have been efforts at teaching students how to systematically relate multiple orthographic two-dimensional views to a corresponding three-dimensional model. However, this requires students to practice rotating each of two-dimensional views mentally and reasoning the corresponding three-dimensional appearance diagrammatically.

Critical features of spatial ability in CEM education are “the ability required to build mental models”¹¹ of building components and materials from drawings and specifications. Student spatial skills can directly affect students’ perceptions and performance on CEM core courses.

Fortunately, several studies have shown that spatial ability can be enhanced through specific practice and training.^{12, 13, 14}

Visualization in Construction Engineering and Management Education

3D technology is making a breakthrough in education. More recently, it has become part of critical instructional materials. There has been a large growth of 3D technology in CEM education over the last decade. There is some evidence that visualization helps to get students more engaged in learning.^{15, 16} Thus, visualization is an effective tool in educational settings. There are several benefits of using 3D methods, compared to teaching with 2D methods. They include:

- Students can more easily understand complex concepts.
- New concepts can be introduced in more engaging ways.
- The learning process can be more interesting and efficient.
- Students can become more focused in their learning.
- Students can learn, retain and recall with more accuracy.

3D modeling uses to help students better understand spatial relations and associate building components. Also, it facilitates the teaching of concepts that can be difficult to explain and understand. 3D technology may have great potential for CEM education. With stereoscopic visualization, students will be able to obtain and exercise a reasonable degree of basic spatial awareness and enhance their spatial skills.

Stereoscopic Visualization for Construction

Most biological vision consists of two eyes, such as human eyes. The two eyes of a human are located at slightly different horizontal positions on the head, giving slightly different images of objects on the retina. This is called *binocular disparity*²⁸ and it is processed by the visual cortex of the brain to construct depth perception.¹⁷ Binocular disparity based depth perception is called *stereopsis*.²⁷ If two objects are located at the same depth from the viewing person, their images on the retina do not generate binocular disparity. This is the case when we see a usual photograph of a scene. Even if multiple objects are on the photo, they do not generate depth perception. On the contrary, if two objects are located at different depths from the viewer, their images on the retina generate binocular disparity. This is the case when we see a real scene, not a photo, with the naked eye.

The human visual cortex can process multiple disparities on the two eyes' retinas simultaneously and instantly, and we perceive depths of the different objects with ease.¹⁸ It is also possible to induce depth perception by simulating binocular disparity without involving real objects in different depth.¹⁹ This is called stereoscopy and this perception of depth is referred to as stereoscopic depth.

Construction drawings are composed of several line types such as border line, object line, hidden line, and center line. Different types of lines denote structural differences in 3D space as shown in Figure 1. Hence, drawings are basically 2D diagrammatic representations of the 3D structure to be built.

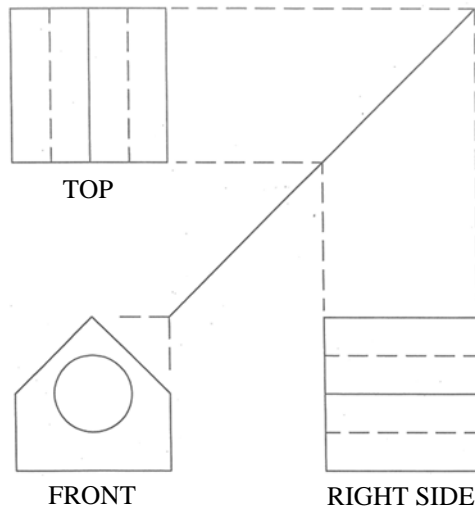


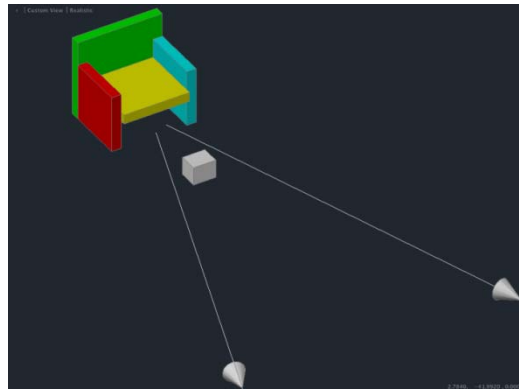
Figure 1: Orthographic Drawing

More recently, 3D models are prevailing in CEM education. However, they actually provide a 3D snapshot of a perspective view even if the perspective view can be manipulated in the 3D model by the user. In other words, a 3D snapshot is just a perspective view of the 3D structure. It does not generate a vivid depth perception, just like a photograph. For this reason, the perspective view may entails distortion of dimensions and ambiguity in depth of the structure. However, it provides the interpretation of the 3D structure. Only when the viewing angle continuously changes over time, depth perception is achieved from 3D models, which is called *motion parallex*.²⁷

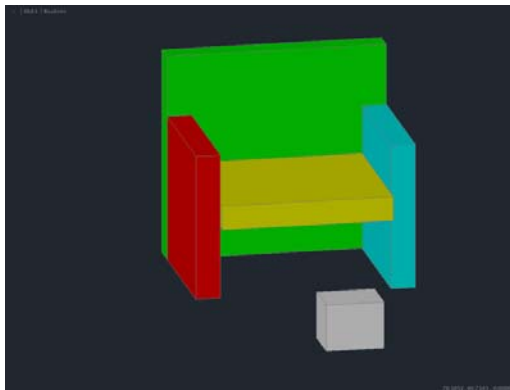
Wheatstone²⁸ first introduced stereoscopic visualization based on human perception of depth in 3D space.²⁰ Stereoscopic visualization is a promising alternative to the perspective view-based visualization, and is actively used for transfer-of-training from virtual environment to real environment.^{21, 22}

Stereopsis Mechanism

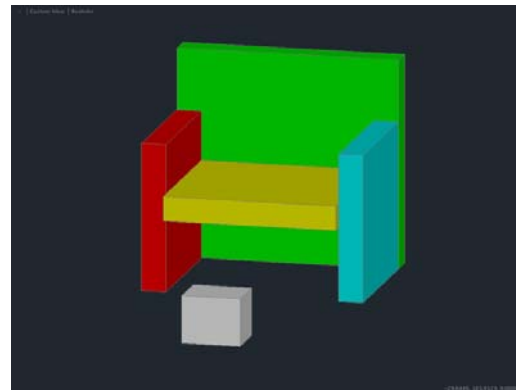
Figure 2 shows how stereopsis is achieved in human visual perception. When a person sees objects in 3D space, the two eyes converge to focus on an object of interest (e.g., the chair in Figure 2-a) and another object (e.g., the cube) appears shifted differently in the retina of left eye (Figure 2-b) versus right eye (Figure 2-c) due to binocular disparity. Even if the two eyes receive the different images respectively, our brain not only perceives a single view (Figure 2-d) from the two eyes' images but also perceives the relative depth of different objects as indicated in the grayscale depth map (Figure 2-e). Brighter part of the depth map is nearer to the viewer while darker part farther away from the viewer in the 3D space.



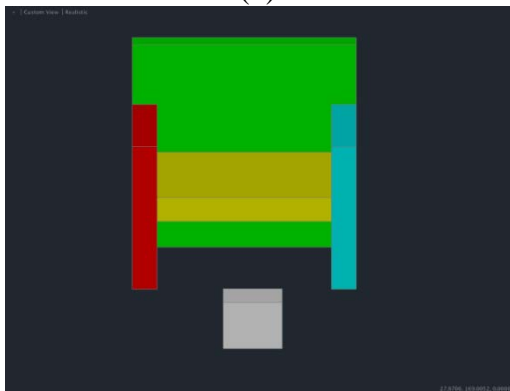
(a)



(b)



(c)



(d)



(e)

Figure 2: Stereopsis Formation Process

Stereoscopic Image Production

Using computer graphics software such as Autodesk Revit or CAD, we need to build a 3D model corresponding to construction drawings. A conventional snapshot (Figure 3-a) of the 3D model, which is actually a 2D image on a computer screen, can be viewed using computer graphics software. However, it is required for the viewer to continuously change 2D images of innumerable view angles in order for the viewer to have 3D perception.

Stereoscopic visualization can make the viewer perceive the vivid depth in a single view without changing view angles even though the viewer is not viewing real objects in the real world. When

the viewer is provided with a left-perspective image only to the left eye (occluded to the right eye) and a right-perspective image only to the right eye (occluded to the left eye), the viewer can be in a simulated form of stereoscopic visualization.

Figure 3-b shows an example of the superimposed stereoscopic image corresponding to the construction element in Figure 3-a. To create this stereoscopic image, a left-perspective image in red needs to be superimposed with a right-perspective image in cyan in a single image frame. If we extract the left-perspective image from Figure 3-b and project it only to the left eye and simultaneously extract the right-perspective image from Figure 3-b and project it only to the right eye, then the viewer will achieve stereopsis perception. This is the fundamental concept of stereoscopic image production.

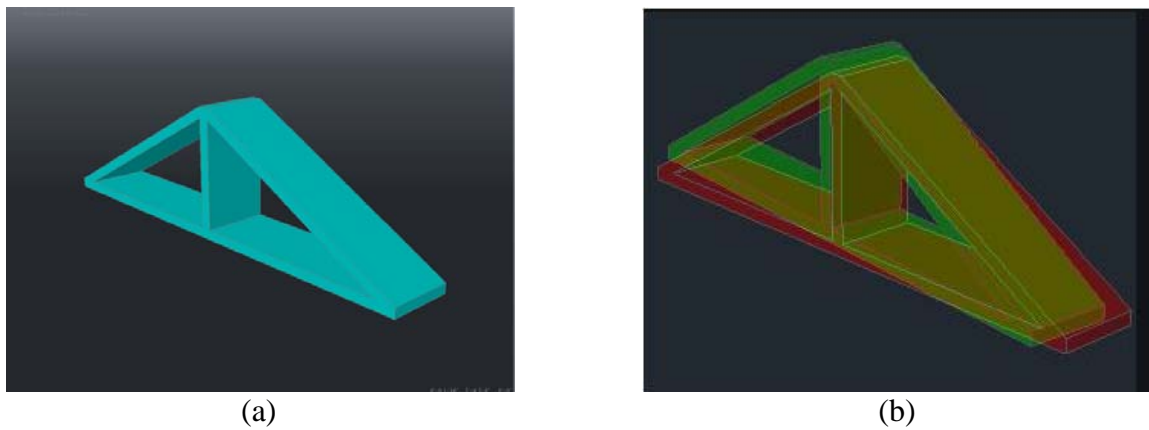


Figure 3: Sample Image for Stereoscopic Visualization

Development and Implementation of Stereoscopic Visualization

Stereoscopic Display Methods

There are several methods to display stereoscopic images to viewers. Table 1 summarizes stereoscopic display methodologies.

Table 1. Stereoscopic Display Methods Summary

<i>Method</i>	<i>Display screen</i>	<i>Binocular separation</i>	<i>Viewer requires</i>	<i>Cons</i>	<i>Cost</i>	<i>Portability</i>
Method-1	<i>Dual display</i>	Mechanical divider	Eye convergence	Slow perception	Expensive	Bulky & heavy
Method-2	<i>Single display</i>	Temporal multiplexing	3D SG glasses	Image flickering	Expensive	Requires electricity
Method-3	Single display	Orthogonal polarization	3D FPR glasses	Needs polarized display	Moderate	Can be portable
Method-4	Single display	Color-based filtering	Anaglyph glasses	Artificial coloring	Cheap	Portable

The first method uses two independent display screens to project a left-eye view image to the left eye and a right-eye view image to the right eye, exclusively. A single display screen is sometimes used with divided viewing area of the screen for the left and right images for the left and right half screen, respectively. This method requires a mechanical divider placed between the two eyes of the viewer to guarantee the exclusive view of left- and right-images to the corresponding eyes only. It also requires the viewer's eye convergence which takes time and may cause eye fatigue.

The second method uses a single display screen on which left- and right-eye views are projected alternately at fast speed (e.g., 60 frames per second). The alternation is electrically controlled (i.e., temporal multiplexing). The viewer should wear a special 3D SG (shutter glasses) that electronically shut and open left and right eye view alternately in synchrony with the display. The synchronized electronic shutter guarantees that left-eye versus right-eye views are seen by the left versus right eye exclusively through the shutter glass. This method requires battery-powered, heavy 3D SG glasses.

The third method also uses a single display screen, and left- and right-view images are superimposed on the same display screen through orthogonal (e.g., 45 and 135 degrees) polarization filters attached on the screen. Viewers wear low-cost polarized FPR (Film-type Patterned Retarder) glasses. The polarization mechanism guarantees the exclusive view of left- and right-images to the corresponding eyes, respectively. This method requires a special display screen coated with polarization filters.

The fourth method is similar to the third method in that it uses a single display screen with superimposed left- and right-view images. This method is different from the third in that the two images are in different color (e.g., red and cyan for left and right images, respectively) and viewer wears low-cost cellophane-based color-filter glasses. This method requires left- and right-view images of different color, but does not need special polarization filter on the display screen. In this study we adopt the fourth method with stereoscopic images such as shown in Figure 3-b.

Portable Stereoscopic Visualization System

A portable stereoscopic visualization system can be developed using a tablet and a laptop computer. In general, there will be two major parts including “production” and “display” in developing a stereoscopic visualization system. Figure 4 presents a portable stereoscopic visualization system overview. For “production”, 3D models for construction assemblies and details are developed from the original 2D drawings. With detailed 3D models, stereoscopic 3D images are created using two different perspective views (the left- and right- eye views). For this, calculating and assigning relative depth to a 3D object is essential. When there are multiple objects in a single image, it is also required to locate occlusion areas and fill them with suitable portions of other objects.²³ These stereoscopic images are delivered and stored in the database the internet cloud.

In terms of “display”, the stereoscopic images stored in the cloud must be accessible from the client side, which is a portable computer device like a tablet PC. This can be possible using

barcodes attached on 2D drawings. Through a camera-based barcode reader, students can get access directly to a specific stereoscopic image. Figure 3-b shows a simple image for stereoscopic visualization from a Tablet PC. In this way, students can see stereoscopic objects with 3D glasses.

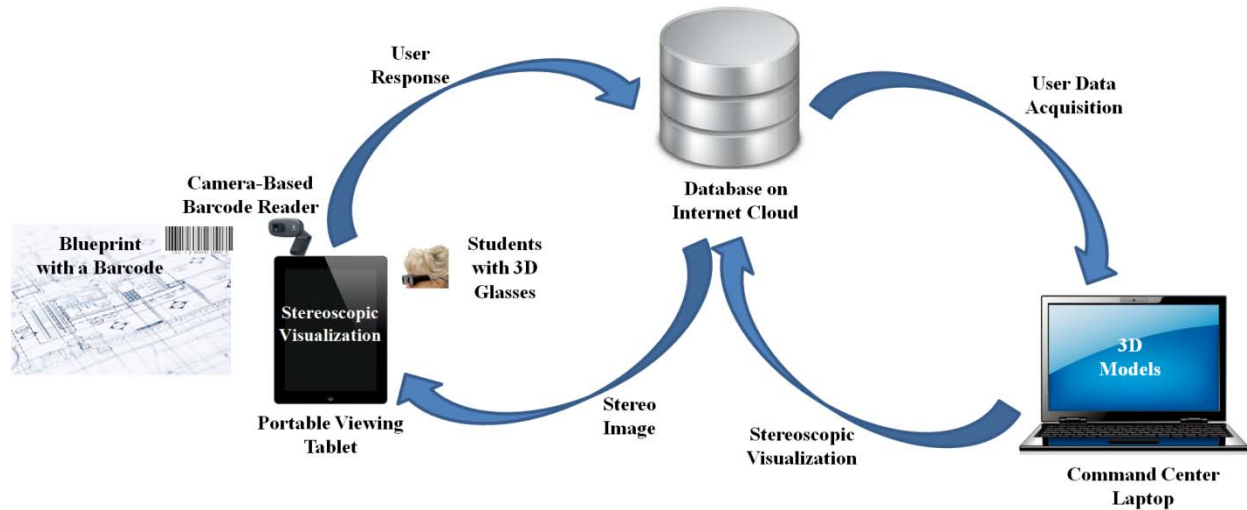


Figure 4: Portable Stereoscopic Visualization System Overview

In summary, the development and implement process of stereoscopic visualization system are as follows:

- The laptop computer generates two different snapshots of a 3D model for a given 2D drawing by simulating the binocular disparity of the model, and blend the two snapshots of different color to a stereoscopic visualization image as shown in Figure 3-b.
- The laptop computer then uploads the ID-tagged stereoscopic visualization image on a database of a secured Internet cloud server.
- The Tablet PC remotely retrieves the stereoscopic-visualization image that corresponds to the assigned 2D drawings, and projects exclusively the two snapshots from the image to the viewer's left and right eyes, respectively, through the 3D glasses.
- The viewer using the Tablet PC will perceive vivid depth of the 3D structures and enhance the interpretation of the object.

Discussions and Recommendations

The National Science Board (2010)²⁴ describes that spatial skills are required for success in the STEM education along with math and verbal skills. Spatial skills are essential for student success in CEM education. Critical features of spatial skills in CEM education are associated with constructing mental models of building components and materials from drawings and specifications. Spatial skills directly affect students' perceptions and performance on CEM core courses. A student's level of spatial performance may change over time. It can be improved by specific practice and training. We propose using stereoscopic visualization as a tool to provide

students with practice and training so that their spatial skills can be enhanced. Strong spatial skills are directly linked to success in the CEM domain along with well-developed math and verbal skills.

Colleges and universities have focused on improving retention of students, transferring from 2-year to 4-year institutions.²⁵ Currently, student retention is a national discussion.²⁶ Spatial skills help students get more engaged and motivated in the task, understand drawing information, estimate materials for a job, and establish sequences of construction activities. By harnessing student spatial skills, student retention in a CEM program may be improved.

Future Research

Again, the main objective of this paper is to establish a baseline to determine whether future research on spatial perception and visualization is warranted in a university's CEM education. There are more questions that must be addressed for this research. In near future, experiments and observational studies will follow to investigate the effects of stereoscopic visualization, compared with the effects of 3D software programs, as a part of drawing and plan reading subjects. Another future research will be associated with pedagogical strategies for using stereoscopic visualization in CEM courses. No matter what technology is integrated into teaching and learning, proper pedagogical strategies are essential in facilitating student engagement and empowering student learning.

Bibliography

1. Branoff, T. J. & Dobelis, M. (2012). The relationship between spatial visualization ability and students' ability to model 3D objects from engineering assembly drawings. *Engineering Design Graphics Journal*, 76(3), 37-43
2. Manrique, F., Niall, K. K., Sullivan, H. J. & Klein, J. (1997). Effects of spatial ability levels and presentation platform on performance of a pictured rotation task. American Educational Research Association, Chicago, IL.
3. Adanez, G. P., & Velasco, A. D. (2002). Predicting academic success of engineering students in technical drawing from visualization test scores. *Journal for Geometry and Graphics*, 6(1), 99-109.
4. Leopold, C., Gorska, R. A., & Sorby, S. A. (2001). International experiences in developing the spatial visualization abilities of engineering students. *Journal for Geometry and Graphics*, 5(1), 81-91.
5. Strong, S., & Smith, R. (2001). Spatial visualization: Fundamentals and trends in engineering graphics. *Journal of Industrial Technology*, 18(1), 1-6.
6. Hsi, S., Linn, M. C., & Bell, J. E. (1997). The role of spatial reasoning in engineering and the design of spatial instruction. *Journal of Engineering Education*, 86(2), 151-158.
7. Sorby, S. A. (2001). Improving the spatial visualization skills of engineering students: Impact on graphics performance and retention. *Engineering Design Graphics Journal*, 65(3), 31-36.
8. Martín-Dorta, N., Saorín, J. L., & Contero, M. (2008). Development of a fast remedial course to improve the spatial abilities of engineering students. *Journal of Engineering Education*, 97(4), 505-513.
9. Gardner, H. (1983). *Frames of Mind: The Theory of Multiple Intelligences*. Basic Books, New York, NY

10. Linn, M. C., & Peterson, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, 56(6), 1479-1498.
11. Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over fifty years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, 101, 817-835.
12. Sorby, S. (2009). Educational Research in Developing 3-D Spatial Skills for Engineering Students. *International Journal of Science Education*. (31)3.
13. Sorby, S. A. & Veurink, N. (2010). Are the visualization skills of first-year engineering students changing? *Proceedings of the 117th ASEE Conference and Exposition*.
14. Martín-Gutiérrez, J., et al. (2009). Do video games improve spatial abilities of engineering students? *International Journal of Engineering Education*, 25, 1194-1204.
15. McLaren, S.V. (2007). Exploring perceptions and attitudes towards teaching and learning manual technical drawings in a digital age. *International Journal of Technology and Design Education*, 18, 167-188.
16. Paas, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science*, 32(1), 1-8.
17. Qian, N. (1997). Binocular Disparity and the Perception of Depth. *Neuron*, 18, 359-368. Retrieved from <http://brahms.cpmc.columbia.edu/publications/stereo-review.pdf>
18. Parker, A.J. (2007). Binocular depth perception and the cerebral cortex. *Neuroscience*, Nature publishing group 8, 379-391
19. Nagata S. (1996). The binocular fusion of human vision on stereoscopic displays--field of view and environment effects, *Ergonomics*, 39(11), 1273-1284.
20. Gilaie-Dotan, S., Ullman, S., Kushnir, T., & Malach, R. (2001). Shape-selective stereo processing in human object-related visual areas, *Human Brain Mapping*, 15, 67-79.
21. Banton, P., Thompson, P., & Quinlan, P.T. (2001). Effect of Geometric Field of View on Stereoscopic Spatial Judgments, *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 43(3), 405-414.
22. Mourant, R.R., & Parsi, L. (2002). Training in a Virtual Stereoscopic Environment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 46 (26), 2206-2209
23. Piroddi, R. (2010). Stereoscopic 3D Technologies, Innovation in the Multi-Screen World, Snell, Retrieved from http://www.snellgroup.com/documents/white-papers/white-paper-stereoscopic_3d_technologies.pdf
24. National Science Board. (2010). Preparing the Next Generation of STEM Innovators: Identifying and Developing our Nation's Human Capital. Retrieved from <http://www.nsf.gov/nsb/publications/2010/nsb1033.pdf>
25. Lockwood, P., Hunt, E., Matlack, R., & Kelley, J. (2013). From Community College to Four-Year Institution: A Model for Recruitment and Retention, *Community College Journal of Research and Practice*, 37, 613-619.
26. The Center on Education and Work. (2008). Increasing STEM Retention for Underrepresented Students: Factors That Matter, Research Brief, University of Wisconsin-Madison. Retrieved from http://www.cew.wisc.edu/docs/resource_collections/CEW_InSTEMRetention_UWMadison.pdf
27. Howard, I. P. & Rogers, B. J. (2012). *Perceiving in Depth*. Volume 3. New York: Oxford University Press.
28. Wheatstone, C. (1838). Contributions to the Physiology of Vision. - Part the First. On some remarkable, and hitherto unobserved, Phenomena of Binocular Vision. , F.R.S., Professor of Experimental Philosophy in King's College, London. Retrieved from <http://www.stereoscopy.com/library/wheatstone-paper1838.html>