winter 2016

volume 80 number 1

THE ENGINEERING DESIGN GRAPHICS Journal

ISSN: 1949-9167

Table of Contents

ISSN: 1949-9167

Editorial Board, Advisory Board, and Review Board

Online Distribution
The online EDGJ is a reality as a result of support provided by East Carolina University; Biwu Yang, Research & Development, ECU Academic Outreach.

ISSN: 1949-9167

EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Mid-Year Conferences

71st Midyear Conference – October 16-18, 2016, Daniel Webster College, Nashua, New Hampshire.
Site Chairs – Jen McInnis and Tim Kostar, Daniel Webster College.
Program Chair – Holly Ault. For additional information, including the call for papers, see http://edgd.asee.org/conferences/71st%20Midyear%20Website/conference71.html

72nd Midyear Conference – January 2017, Jamaica
Site Chair – Sheryl Sorby.

Future ASEE Annual Conferences

Year	Dates	Location	Program Chair
2016	June 26 - 29	New Orleans, Louisiana	Heidi Steinhauer
2017	June 25 - 28	Columbus, Ohio	Theodore Branoff
2018	June 24 - 27	Salt Lake City, Utah	
2019	June 16 - 19	Tampa, Florida	
2020	June 21 - 24	Montréal, Québec, Canada	
2021	June 27 - 30	Long Beach, California	
2022	June 26 - 29	Minneapolis, Minnesota	
2023	June 25 - 28	Baltimore, Maryland	

If you're interested in serving as the Division's program chair for any of the future ASEE annual conferences, please make your interest known.

ISSN: 1949-9167

Election Results

According to the Division by-laws (see http://edgd.asee.org/aboutus/edgdbylaws.htm), the chair of the Elections Committee shall transmit the results of the election to the Chair of the Division. The Chair shall inform each candidate (including those not elected) of the results of the election for his office and shall transmit the names of the newly-elected officers to the Editor of the Journal for publication in the Spring issue of the Journal. The chair of the Elections Committee shall report the results of the election to the Division at the annual business meeting. The results for the most recent election are as follows:

For Vice-Chair: Robert A. Chin

Robert A. ”Bob” Chin is a member of the Department of Technology Systems faculty, College of Engineering and Technology, East Carolina University, where he has taught since 1986. He just completed his second term as the director of publications for the Engineering Design Graphics Division and as the *Engineering Design Graphics Journal* editor. Chin has also served as the Engineering Design Graphics Division’s annual and mid-year conference program chair, and he has served as a review board member for several journals including the *EDGJ*. He has been a program chair for the Southeastern Section and has served as the Engineering Design Graphics Division’s vice chair and chair and as the Instructional Unit’s secretary, vice chair, and chair. His ongoing involvement with ASEE has focused primarily on annual conference paper presentation themes associated with the Engineering Design Graphics, the Engineering Technology, and the New Engineering Educators Divisions and their education and instructional agendas.

For Director of Programs: Theodore Branoff

Theodore Branoff, Ph.D. is a professor and chair of the Department of Technology at Illinois State University. He taught engineering graphics, descriptive geometry, and constraint-based solid modeling courses at North Carolina State University for 28 years before moving to Illinois State University. Dr. Branoff was previously employed with Measurements Group, Inc. as a draftsman and with Siemens, Switchgear Division as a specifications draftsperson. Along with teaching courses in engineering graphics, he has conducted CAD and geometric dimensioning & tolerancing workshops for both high school teachers and industry. He has also authored textbook chapters on

ISSN: 1949-9167

conventional tolerancing and geometric dimensioning and tolerancing and authored a textbook on interpreting engineering drawings.

Dr. Branoff is currently a member of the Engineering Design Graphics Division of the American Society for Engineering Education; the Association of Technology, Management and Applied Engineering; the International Technology and Engineering Educators Association; the International Society for Geometry and Graphics; and Epsilon Pi Tau. He has served as Chair, Vice-Chair, Director of Programs, and Director of Professional & Technical Committees for the EDGD and as Co-Editor of the *Engineering Design Graphics Journal*. In addition, he served as president of the International Society for Geometry & Graphics from 2009-2012. In 2013 he was elected into the Academy of Fellows of the American Society for Engineering Education, and in 2014 he received the Distinguished Service Award from the Engineering Design Graphics Division of ASEE. In April of 2015 Dr. Branoff received the Orthogonal Medal for distinguished service in graphic science from the Technology, Engineering & Design Education faculty at North Carolina State University.

For Director of Membership: Diarmaid Lane

Diarmaid Lane received his B. Tech (Ed.) and Ph.D. in Technology Education from the University of Limerick in 2008 and 2011 respectively. He spent six years in the metal fabrication industry developing engineering craft based skills prior to pursuing his studies in technology education. He currently holds a faculty position at the University of Limerick where he teaches engineering graphics courses on undergraduate and postgraduate programs in technology teacher education.

Diarmaid has acted as program chair for both the 67th and 70th MidYear Conferences for the Engineering Design Graphics Division. He was been awarded the EDGD Chair's Award in 2010 and 2011, and the Oppenheimer Award in 2012 and 2014. His research interests are in the development of spatial cognition and graphical communication skills through freehand sketching.

As membership officer in EDGD, his goal will be to further investigate the future direction of the membership. He will also reach out to researchers in other disciplines to become involved in the division by encouraging the development of working partnerships and ultimately further strengthen the role of engineering graphics educators within the engineering education community and beyond.

Engineering Design Graphics Journal (EDGJ)
Winter 2016, Vol. 80, No. 1
http://www.edgj.org

ISSN: 1949-9167

The Chair's Award

The 2015 Chair's Award Winner is Nathan Delson and Lelli Van Den Einder of the University of California, San Diego for their paper, "Tracking Student Engagement with a Touchscreen App for Spatial Visualization Training and Freehand Sketching." Their paper appears on the following pages and can be downloaded from https://peer.asee.org/tracking-student-engagement-with-a-touchscreen-app-for-spatial-visualization-training-and-freehand-sketching

The Chair's Award recognizes the outstanding paper presented at an EDGD sponsored ASEE Annual Conference session and carries a cash award.

The award description can be found at http://edgd.asee.org/awards/chairs/index.htm

The past awardees list can be found at http://edgd.asee.org/awards/chairs/awardees.htm

Engineering Design Graphics Journal (EDGJ)
Winter 2016, Vol. 80, No. 1
http://www.edgj.org

ISSN: 1949-9167

Application of Visual Cues on 3D Dynamic Visualizations for Engineering Technology Students and Effects on Spatial Visualization Ability: A Quasi-Experimental Study

Petros Katsioloudis, Vukica Jovanovic, and Mildred Jones
Old Dominion University

Abstract

Several theorists believe that different types of visual cues influence cognition and behavior through learned associations; however, research provides inconsistent results. Considering this, a quasi-experimental study was done to determine if there are significant positive effects of visual cues (color blue) and to identify if a positive increase in spatial visualization ability for students in engineering technology courses is observed. According to the results of this study it is suggested that the use of the specific visual cue (color blue) provides no statistically significant higher scores versus the treatment that did not utilize any visual cues.

Introduction

There are several reasons for exploring the potential of color information and its effects on improving spatial visualization ability. Color is one of the fundamental properties of objects and is detected preattentively with other primary properties like brightness and line orientation (Enns & Rensink, 1991; Treisman, 1986). Even though the role of color in object constancy and depth perception is clear, the value of adding redundant color as spatial stimuli has attracted very little attention (Alington, Leaf & Monaghan, 2001). According to Mehta and Zhu (2009) a large amount of research has been done in this domain; however, the psychological processes through which color operates have not been fully explored. As a result, the field has observed certain conflicting results. To add to the related body of knowledge the following study was conducted.

The following was the primary research question:

> Is there a difference in spatial visualization ability, as measured through technical drawings, among the impacts of visual cues (adding blue color) on dynamic visualizations for engineering technology students?

The following hypotheses will be analyzed in an attempt to find a solution to the research question:

> H_0: There is no difference in spatial visualization ability, as measured through technical drawings, among the impacts of visual cues (adding blue color) on dynamic visualizations for engineering technology students.

> H_A: There is an identifiable difference in spatial visualization ability, as measured through technical drawings, among the impacts of visual cues

ISSN: 1949-9167

(adding blue color) on dynamic visualizations for engineering technology students.

Review of Literature

Spatial Ability

According to Hegarty and Waller (2005), spatial ability is a collection of cognitive skills that allow the learner to relate within his/her environment. Developed through spatial cognition, spatial ability can be described as the ability to form and retain mental representations of a stimulus, or mental model, and can be used to see if mental manipulation is possible (Carroll, 1993; Höffler, 2010). This ability has been recognized as an individual ability, somewhat autonomous of general intelligence (Höffler, 2010). According to several studies, it has been suggested that individuals with higher spatial abilities have a wider range of strategies to solve spatial tasks (Gages, 1994; Lajoie, 2003; Orde, 1997; Pak, 2001). Spatial abilities, specifically visualization, play a critical role in the success of a variety of professions, such as engineering, and other technical, mathematical, and scientific professions.

Spatial Ability used in Engineering Education

According to Contero, Company, Saorín & Naya (2006) shifting from a teacher-centered to a student-centered education paradigm in engineering education requires teachers to put an emphasis on spatial reasoning. Known as a critical engineering skill, spatial ability has been identified as having a positive correlation with learning achievements in engineering education (Mayer & Sims, 1994; Mayer, Mautone & Prothero, 2002). Ferguson (1992) defines engineering drawings as the process where a concept is taken from a learner's mind and articulated through drawings to another person's mind, thus transferring an object from a 2D to a 3D representation of the object. These physical object manipulations, done through freehand sketching on paper and/or computer-aided sketching, can improve the spatial ability of freshmen engineering students (Martín-Gutiérrez, et al., 2010). In engineering courses descriptive geometry, orthographic views, and three-dimensional modeling have all been employed as a means to improve learners' spatial abilities (Martín-Gutiérrez, Gil, Contero & Saorín, 2013). More general Spatial Visualization encompasses the mental alteration of an object through a sequence of adjustments. It is considered a key factor in the success of engineering students (Ferguson, Ball, McDaniel, & Anderson, 2008).

  ISSN: 1949-9167

Spatial Visualization

Spatial visualization can be defined as “the ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus object” (McGee, 1979, p. 893). Strong & Smith (2001) suggest a definition of spatial visualization as “the ability to manipulate an object in an imaginary 3-D space and create a representation of the object from a new viewpoint” (p. 2). Researchers in engineering education, the U.S. Department of Labor, as well as major industry representatives have called for the improvement of spatial visualization ability in engineering and technology students (Ferguson, et al., 2008). Over the past two decades there has been an increased sense of urgency on spatial visualization as a primary focus in engineering education, as reported in journal articles and conference proceedings (Marunic & Glazar, 2013; Miller & Bertoline, 1991). In a recent research study, Branoff & Dobelis (2012) discovered a relationship between reading engineering drawings and visualization ability. Sorby & Baartmans's (2000) research on an introductory course, constructed to enhance 3D spatial visualization skills, revealed statistically significant gains in scores and higher retention in first-year engineering students than those who did not take the course. In the matter of engineering student retention, research suggests positive correlations between spatial visualization ability and the retention and completion of degree requirements for engineering and technology students (Brus, Zhoa & Jessop, 2004; Sorby, 2001). In conjunction with the positive correlations related to retention for engineering students (Brus, et al., 2004; Sorby, 2001), several studies suggest that dynamic visualizations, as opposed to static visualizations, have more benefit for students with advanced spatial skills, such as engineering students (Huk, 2006; Lewalter, 2003). Wu & Shah (2004) suggest that dynamic visualizations and 3D animations offer an environment that supports a learner’s incomplete mental model.

Dynamic Visualizations

Today, with the introduction of computer-based design tools (CAD), dynamic visuals are used in place of, or in addition to, static visuals, such as pictures. Research suggests that dynamic visualizations enhance the learning process for learners with high spatial ability (Huk, 2006; Lewalter, 2003). Research has suggested that dynamic visualizations in learning may improve spatial ability in learners with low spatial ability, and may, in fact, have a compensating effect for the low spatial ability learners (Hegarty & Kriz, 2008; Höffler, 2010; Huk, 2006; Mayer & Sims, 1994). Hegarty and Kriz (2008) suggest that dynamic visualizations act as a “cognitive prosthetic” for learners possessing low spatial ability. Hays (1996) found a statistically significant interaction of spatial ability with learners who possess low spatial ability. In this study, the learners receiving animations made greater gains than those receiving no animations.

ISSN: 1949-9167

Visual Cues and Color

Cuing may also enhance a learner's experience when related to visualizations and text that allow the learner to integrate representations resulting in a deeper understanding of the representative content (Mayer, 2009). Kühl, Scheiter, and Gerjets, (2012) found that cuing significantly increased a learner's recall in spatial visualization. Lambert, Roser, Wells, and Heffer (2006) found that cuing resulted in rapid orienting by peripheral onsets, as well as target location and specific features, such as color. According to Seddon and Shubber (1984), color in spatial ability, specifically rotation, may assist learners with following the path taken by each part of the structure during rotation. In a research study of color influence on visual memory, Borges, Stepnowsky, and Holt (1977) found that recognition memory in subjects was 5-10% better for colored images than the black and white versions of the same images. Alington, et al. (2001) study suggests that color improved performance in men and women in relation to spatial visualization. Color theorists believe that color influences cognition and behavior through learned associations (Elliot, Maier, Moller, Friedman, & Meinhardt, 2007). However, research provides inconsistent results when using visual cues like color (Seddon & Shubber, 1985). For example the amount of color may have an effect on the results when comparing color versus monochrome. Too much color, however, may have an adverse effect on the subjects when comparing color versus monochrome (Seddon & Shubber, 1985).

For this specific study, the authors had to decide which color to use for the visual cue treatment groups (*n2 & n3*). Previous research has suggested that red and blue have different associations within the cognitive domain. More specifically, in a study conducted by Mehta and Zhu (2009), the colors red and blue were compared towards effects on cognitive task performance. Red is often associated with dangers and mistakes [e.g., errors that are circled with a red ink pen, stop signs, and warnings] (Elliot et al., 2007). In disparity, blue is often associated with openness, peace, and tranquility [e.g., ocean and sky] (Kaya & Epps, 2004). In addition, a study conducted by Elliot et al., (2007), revealed that significantly more participants chose the blue (66%) versus red (34%) color when the task was described to be creative [χ^2 (1) = 7.12, $P < 0.01$]. The same pattern of results emerged when the task was described to be detail-oriented, i.e., more people thought the blue (74%) versus red (26%) background color would enhance their performance even on the detail-oriented task [χ^2 (1) = 15.06, $P < 0.001$], (Elliot et al., 2007). For this specific study, we chose the color blue.

Methodology

A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability during the Fall of 2014. The study was conducted in an engineering graphics course, MET 120 (Computer

ISSN: 1949-9167

Aided Drafting), as a part of the Engineering Technology program. The participants from the study are shown in Figure 1. Using a convenience sample, there was a near equal distribution of the participants between the three groups.

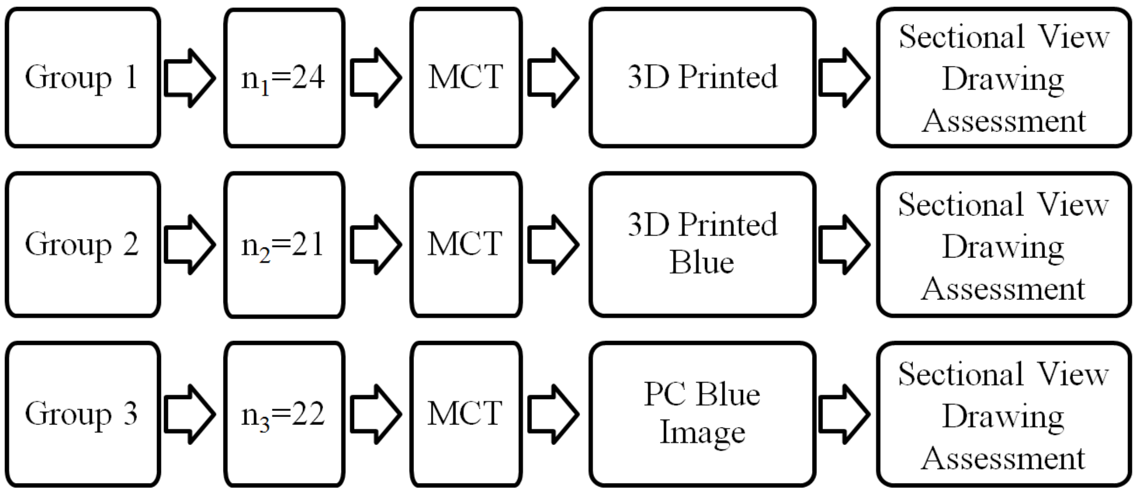

Figure 1. Research Design Methodology

The engineering graphics course emphasized hands on practice using 3D AutoCAD software in the computer lab, along with the various methods of editing, manipulation, visualization, and presentation of technical drawings. In addition, the course included the basic principles of engineering drawing/hand sketching, dimensions, and tolerance principles.

The students attending the course during the Fall Semester of 2014 were divided into three groups. The three groups (*n1*=24, *n2*= 21 and *n3*=22, with an overall population of N = 67) were presented with a visual representation of an object (visualization) and were asked to create a sectional view. The first group (*n1*) received a dynamic 3D printed dodecahedron visualization, self rotated at 360 degrees on the top of a motorized base at about 4 rounds per minute (slow rotation was used to prevent optical illusion and distortion of the original shape) during the creation of the sectional view (see Figure 2). The second group (*n2*) received the same dynamic 3D printed dodecahedron visualization, also self rotated at about 4 rounds per minute at 360 degrees on the top a motorized base at about 4 rounds per minute with students wearing blue glasses (see Figure 3); thus, it created a blue background around the visualization during the creation of the sectional view. The third group (*n3*) received a blue, shaded PC developed, dynamic 3D dodecahedron visualization, also self rotated at about 4 rounds per minute at 360 degrees at about 4 rounds per minute (see Figure 4). Since color was used as a part of the study treatment, and to prevent bias with color blind students, all participants were presented with a power point slide that had three color filled circles (red, blue and yellow) and were asked to report on a piece of

ISSN: 1949-9167

paper the three colors. No students were identified as color blind since everyone stated the correct colors.

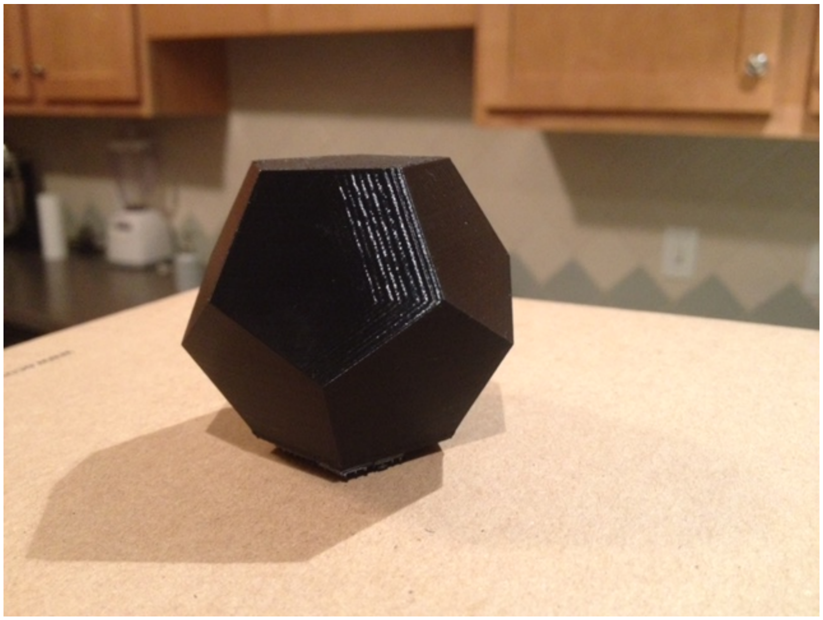

Figure 2. Dodecahedron 3D Printed Dynamic Visualization

Figure 3. Blue glasses treatment used for Group 2

ISSN: 1949-9167

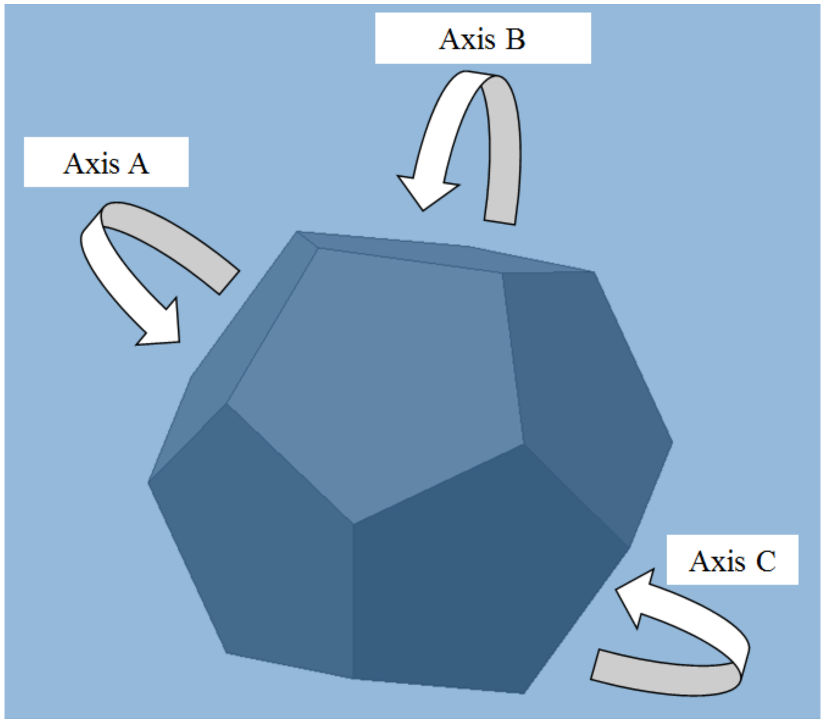

Figure 4. Blue Dodecahedron 3D Dynamic Computer Generated Visualization

In addition, all groups were asked to complete the Mental Cutting Test (MCT) (CEEB, 1939) instrument 2 days prior to the completion of the sectional view drawing in order to identify the level of visual ability and show equality between the three groups. The MCT was not used to account for spatial visualization skills in this study. Its only purpose was to establish a near to equal group dynamic based on visual ability, as it relates to Mental Cutting ability. According to Nemeth and Hoffman (2006), the MCT (CEEB, 1939) has been widely used in all age groups, making it a good choice for a well-rounded visual ability test. The Standard MCT consists of 25 problems. The Mental Cutting Test is a sub-set of the CEEB Special Aptitude Test in Spatial Relations, and has also been used by Suzuki (2004) to measure spatial abilities in relation to graphics curricula (Tsutsumi, 2004).

As part of the MCT test, subjects are given a perspective drawing of a test solid, which is to be cut with a hypothetical cutting plane. Subjects are then asked to choose one correct cross section from among 5 alternatives. There are two categories of problems in the test (Tsutsumi, 2004). Those of the first category are called *pattern recognition problems*, in which the correct answer is determined by identifying only the pattern of the section. The others are called *quantity problems*, or *dimension specification problems*, in which the correct answer is determined by identifying, not only the correct pattern, but also the

ISSN: 1949-9167

quantity in the section (e.g. the length of the edges or the angles between the edges) (Tsutsumi, 2004).

Upon completion of the MCT, the instructor of the course placed two identical models of the dynamic 3D dodecahedron for groups *n1 & n2* in a central location in two different classrooms (*n2* also received blue glasses). The instructor also projected the dynamic 3D PC generated visualization in a third room, where the three groups were asked to create a sectional view of the dodecahedron (see Figure 5). This process takes into consideration that research indicates a learner's visualization ability and level of proficiency can easily be determined through sketching and drawing techniques (Contero, Company, Saorin, & Naya, 2006; Mohler, 1997). The students placed in the first group (*n1)* were able to approach the visualization and observe from a close range. Students placed in the second group *(n2)* also had the privilege of close observation, but had to wear and keep on the blue glasses throughout the whole treatment. The computer generated dynamic visualization was presented to the third group *(n3)* on a projector and they had the same time and lighting conditions as everyone else in order to create a sectional view of it.

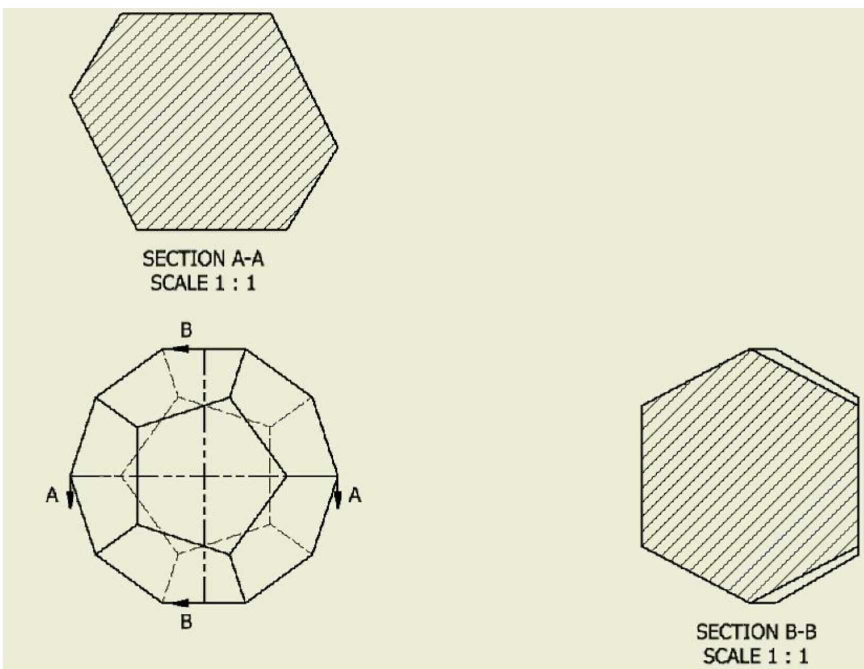

Figure 5. Sectional View of Dodecahedron

The engineering drawing used in this research was a sectional view of the dodecahedron (see Figure 5). Sectional views are very useful engineering graphics tools, especially for parts that have complex interior geometry, as the sections are used to clarify the interior construction of a part that cannot be clearly described by hidden lines in exterior views (Plantenberg, 2013). By taking

 Copyright 2016
ISSN: 1949-9167

an imaginary cut through the object and removing a portion, the inside features could be seen more clearly. Students had to mentally discard the unwanted portion of the part and draw the remaining part. The rubric used included the following parts: 1) use of section view labels; 2) use of correct hatching style for cut materials; 3) accurate indication of cutting plane; 4) appropriate use of cutting plane lines; and 5) appropriate drawing of omitted hidden features. The maximum score for the drawing was 6 points.

Data Analysis

Analysis of MCT Scores

The first method of data collection involved the completion of the MCT instrument prior to the treatment to show equality of spatial ability between the three different groups. The researchers graded the MCT instrument as described in the guidelines by the MCT creators. A standard paper-pencil MCT was conducted, in which the subjects were instructed to draw intersecting lines on the surface of a test solid with a green pencil before selecting alternatives. The maximum score that could be received on the MCT was 25 and, as it can be seen in Table 1, n1 had a mean of 14.45, n2 had a mean of 12.75, and n3 had a mean of 13.25. A one-way ANOVA was run to compare the mean scores for significant differences, as it related to special skills among the three groups. There was no significant difference between the three groups as far as spatial ability, as measured by the MCT instrument (see Table 2).

Table 1

MCT Descriptive Results

	N	Mean	SD	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound
3D Printed (n1)	24	14.45	4.564	.847	12.71	16.18
3DPrinted Blue (n2)	21	12.75	4.561	.931	10.82	14.68
PC Blue Image (n3)	22	13.25	4.046	.826	11.54	14.96
Total	67	13.55	4.412	.503	12.54	14.55

ISSN: 1949-9167

Table 2

MCT ANOVA Results

Quiz	SS	df	MS	F	p
Between Groups	40.918	2	20.459	1.053	0.354
Within Groups	1438.172	65	19.435		
Total	1479.091	67			

* Denotes statistical significance

Analysis of Drawing

The second method of data collection involved the creation of a sectional view drawing. As shown in Table 3, the group that used the 3D Printed Model, and wore the blue glasses as visual aid (*n* =21), had a mean observation score of 3.26. The groups that used the PC computer generated model, and used no blue glass visual (*n* = 24), and the PC generated blue shaded image (*n* = 22), had lower scores of 3.17 and 3.00 respectively. A one-way ANOVA was run to compare the mean scores for significant differences among the three groups. The result of the ANOVA test, as shown in Table 4, was not significant, $F(2, 62) = 6.525$, $p < 0.802$. The data was dissected further, through the use of a post hoc Tukey's honest significant difference (HSD) test. As it can be seen in Table 5, the post hoc analysis shows no statistically significant difference between the 3D printed Blue vs. PC Model ($p < 0.968$, $d = 0.96$) and the 3D Printed Blue vs. PC Blue Image ($p = 0.792$, $d = 0.263$), with PC Blue Image vs. PC Model being equal and higher than the first one in both cases (p=.792, d=.263).

Table 3

Sectional View Drawing Descriptive Results

	N	Mean	SD	Std. Error	95% Confidence Interval for Lower Bound	Upper Bound
3D Printed	24	3.17	1.465	0.299	2.55	3.79
3D Printed Blue	21	3.26	1.046	0.240	2.76	3.77
PC Blue Image	22	3.00	1.272	0.271	2.44	3.56
Total	67	3.14	1.273	0.158	2.82	3.45

ISSN: 1949-9167

Table 4

Sectional View Drawing ANOVA Results

Quiz	SS	df	MS	F	p
Between Groups	.736	2	.368	.222	.802
Within Groups	103.018	62	1.662		
Total	103.754	64			

* Denotes statistical significance

Table 5

Sectional View Drawing Tukey HSD Results

	Visual Aids (1 vs. 2 vs. 3)	Mean Diff. (1-2)	Std. Error	*p*
2 vs 1	3D Printed Blue vs. 3D Printed	.096	.396	.968
2 vs 3	3D Printed Blue vs. PC Blue Image	.263	.404	.792
3 vs 1	PC Blue Image vs. 3D Printed	.263	.404	.792

* Denotes statistical significance

Discussion

This study was done to determine significant positive effects of visual cues (color blue) and to identify a positive increase of spatial visualization ability for students in engineering technology courses. In particular, the study compared the use of different visual models: a 3D printed solid dynamic visualization with the addition of blue glasses to add blue color background around the model, a 3D computer generated blue shaded dynamic visualization, and a 3D printed dynamic visualization with no additional visual cue treatment. It was found that the use of visual cue (color blue) provided no statistically significant higher scores versus the treatment that did not utilize any visual cues.

While not statistically significant, the students who received treatment using the 3D printed Dynamic visualization, with the addition of the blue glasses visual cue, outperformed their peers who received treatment from the other two types of visualizations. Previous research supports that the effect of color on those with high spatial ability may result in little benefit, as high spatial ability learners develop mental models on shape alone. Khooshabeh and Hegarty (2008) suggested that color affects the performance of learners with low spatial ability more so than those with high spatial ability.

  ISSN: 1949-9167

Strong and Smith (2002) reported that variations in technologies used for educating students may include application of texture, color, and lighting to 3D models which may significantly impact spatial ability. In a research study by Khooshabeh and Hegarty (2008), it was determined that color affected the performance in participants with low spatial ability, but did not show any statistically significance in students who already possess high spatial abilities as in engineering courses. This is mainly due to the high spatial ability learner using more schematic spatial mental representations where as the low spatial ability learn tend to use both visual and spatial information in performing tasks (Khooshabeh & Hegarty, 2008). Due to the findings in this study and the relatively high scores recorded from the MCT given to the participants prior to the treatment, the researchers believe that the population used (engineering technology students) did not demonstrate a statistically significant difference in spatial abilities from the addition of the color, due to the fact that spatial abilities were well developed in this population.

Limitations and Future Plans

In order to have a more thorough understanding of the use of visual cues used by engineering technology students during the creation of sectional views of 3D dynamic visualizations, and to understand the implications for student learning and spatial ability, it is imperative to consider further research. Future plans include, but are not limited to:

- Repeating the study to verify the results by using additional types of visual cues.
- Repeating the study using a different population such as technology education, science, or mathematics students.
- Repeating the study by comparing male versus female students, as it has been suggested that males tend to do better on spatial ability tasks than females (Carriker, 2009).
- Repeating the study with different populations to identify whether individuals with low spatial abilities, can benefit from the use of additional visual cues, such as color.

References

Alington, D.E., Leaf, R.C., & Monaghan, J.R. (2001). Effects of stimulus color, pattern, and practice on sex differences in mental rotations task performance. *The Journal of Psychology, 126*(5), 539-553.

ISSN: 1949-9167

Borges, M.A., Stepnowsky, M.A. & Holt, L.H. (1977). Recall and recognition of words and pictures by adults and children. *Bulletin of the Psychonomic Society, 9*(2), 113-114.

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.

Brus, C., Zhoa, L. & Jessop. J (2004). Visual-spaital ability in first-year engineering students: A useful retention variable? *Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Salt Lake City, UT.*

Carroll, J. B. (1993). Human cognitive abilities: A survey of factor-analytic studies. New York: Cambridge University Press.

Carriker, A. W. (2009). *Effectiveness of 3D input on spatial abilities.* (Doctoral dissertation). Retrieved from http://repository.lib.ncsu.edu/ir/handle/1840.16/695.

CEEB. (1939). *Special Aptitude Test in Spatial Relations (MCT).* Developed by the College Entrance Examination Board, USA, 1939.

Contero, M., Company, P., Saorín, J. L. & Naya, F. (2006). Learning support tools for developing spatial abilities in engineering design. *International Journal of* Engineering Education, 22(3), 470-477.

Elliot, A.J., Maier, M.A., Moller, A.C., Friedman, R., Meinhardt, J. (2007). Color and psychological functioning: The effect of red on performance attainment. *Journal of Experiential Psychology: General, 136*(1), 154-168.

Enns, J.T. & Rensink, R.A. (1991). Preattentive recovery of the three-dimensional orientation from line drawings. *Psychological Review, 98*(3), 335-351.

Ferguson, E.S. (1992). *Engineering and the Mind's Eye*. Cambridge, Massachusetts: MIT Press.

Ferguson, C., Ball, A., McDaniel, W., & Anderson, R. (2008). A comparison of instructional methods for improving the spatial-visualization ability of freshman technology seminar students. *Proceedings of The 2008 IAJC-IJME International Conference,* Nashville, TN. ISBN 978-1-60643-379-9.

ISSN: 1949-9167

Gages, T.T. (1994). *The interrelationship among spatial ability, strategy used, and learning style for visualization problems.* (Doctoral dissertation). The Ohio State University.

Hays, T.A. (1996). Spatial abilities and the effects of computer animation on short-term and long-term comprehension. *Journal of Educational Computing Research 14*(2), 139-155.

Hegarty, M., & Kriz, S. (2008). Effects of knowledge and spatial ability on learning from animation. In R. Lowe & W. Schnotz (Eds.), *Learning with animation: Research implications for design* (pp. 3-29). Cambridge, England: Cambridge University Press.

Hegarty, M. & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence, 32,* 175-191.

Höffler, T. N. (2010). Spatial ability: Its influence on learning with visualizations-a meta-analytic review. *Educational Psychology Review*, *22*, 245–269. doi: 10.1007/s10648-010-9126-7

Huk, T. (2006). Who benefits from learning with 3D models? The case of spatial ability. *Journal of Computer-Assisted Learning, 22*, 392-404.

Kaya, N. & Epps, H.H. (2004). Color-emotion associations: Past experience and personal preference. In AIC 2004 Color and Paints, *Proceedings of the Interim Meeting of the International Color Association,* Porto Alegre, Brazil, ed. by José Luis Caivano and Hanns-Peter Struck. Porto Alegre, Brazil: Associação Brasileira da Cor, 31-34.

Khooshabeh, P., & Hegarty, M. (2008). How visual information affects a spatial task. *Proceedings of Cognitive Science Society,* Washington, DC.

Kühl, T., Scheiter, K., & Gerjets, P. (2012). Enhancing learning from dynamic and static visualizations by means of cueing. *Journal of Educational Multimedia and Hypermedia, 21*(1), 71-88.

Lambert, A., Roser, M., Wells, I, & Heffer, C. (2006). The spatial correspondence hypothesis and orienting in response to central and peripheral spatial cues. *Visual Cognition, 13*(1), 65-88.

Lewalter, D. (2003). Cognitive strategies for learning from static and dynamic visuals. *Learning and Instruction, 13,* 177-189.

Lajoie, S. P. (2003). Individual differences in spatial ability: Developing technologies to increase strategy awareness and skills. *Educational Psychologist, 38*(2), 115-125.

McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin, 86*(5), 889-918.

Marunic, G. & Glazar, V. (2013). Spatial ability through engineering graphics education.
International Journal of Technology & Design Education, 23, 703-715.

Martín-Gutiérrez, J., Saorín, J.L., Contero, M., Alcañiz, M., Pérez-López, D.C. & Ortega, M. (2010). Design and validation of an augmented book for spatial abilities development in engineering students. *Computers & Graphics, 34,* 77-91.

Martín-Gutiérrez, J., Gil, F.A., Contero, M., & Saorín, J.L. (2013). Dynamic three-dimensional illustrator for teaching descriptive geometry and training visualisation skills. *Computer Applications in Engineering Education, 21*(1), 8-25.

Mayer, R.E. (2009). *Multimedia learning (2nd ed.).* Cambridge: Cambridge University Press.

Mayer, R.E., Mautone, P. & Proterho, W. (2002). Pictorial aids for learning by doing in a multimedia geology simulation game. *Journal of Educational Psychology, 86,* 389-401.

Mayer, R.E., & Sims, V.K. (1994). For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. *Journal of Educational Psychology, 82*, 715-26.

Mehta, R. & Zhu, R. (2009). Blue or red? Exploring the effect of color on cognitive task performances. *Science, 323*(5918), 1226-1229.

Miller, C.L. & Bertoline, G.R. (1991). Spatial visualization research and theories: Their importance in the development of an engineering and technical design graphics curriculum model. *Engineering Design Graphics Journal, 55*(3),
5-14.

ISSN: 1949-9167

Mohler, J.L. (1997). An instructional method for the AutoCAD modeling environment. *Engineering Design Graphics Journal, 61*(1), 5-16.

Nemeth, B. & Hoffman, M. (2006). Gender differences in spatial visualization among engineering students. *Annales Mathematicae et Informaticae, 33,* 169-174.

Orde, B. J. (1997). Drawing as visual-perceptual and spatial ability training. *Proceedings of Selected Research and Development Presentations at the 1997 National Convention of the Association for Educational Communications and Technology,* Albuquerque, NM.

Pak, R. (2001). A further examination of the influence of spatial abilities on computer task performance in younger and older adults*. Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* 2001 45: 1551 DOI: 10.1177/154193120104502203.

Plantenberg , K. (2013). *Engineering Graphics Essentials with AutoCAD 2014 Instruction.* Mission, KS SDC Publications.

Seddon, G.M. & Shubber, K.E. (1984). The effects of presentation mode and colour in teaching the visualisation of rotation in diagrams of molecular structures. *Research in Science & Technological Education*, *2*(2), 167-176.

Seddon, G.M. & Shubber, K.E. (1985). The effects of colour in teaching the visualisation of rotations in diagrams of three-dimensional structures. *British Educational Research Journal 11*(3), 227-239.

Sorby, S. (2001). Improving the spatial ability of engineering students: Impact on grapchis performance and retention. *Engineering Design Graphics Journal, 65*(3), 31-36.

Sorby, S. A. & Baartmans, B.J. (2000). The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students. *Journal of Engineering Education, 89*(3), 301-307.

Strong, S., & Smith, R. (2002). Spatial Visualization: Fundamentals and Trends in Engineering Graphics. *Journal of Industrial Technology, 18*(1), 1–6.

Strong, S. & Smith, R.A. (2001). Spatial visualization: Fundamentals and trends in engineering graphics. *Journal of Industrial Technology 18*(1), 1-6.

Suzuki, K. (2004). Evaluation of students' spatial abilities by a mental cutting test: Review on the surveys in the past decade. *Proceedings of the 11th International Conference on Geometry and Graphics, Guangzhou, China.*

Treisman, A. (1986). Features and objects in visual processing. *Scientific American, 255*(5), 114-125.

Tsutsumi, E. (2004). A mental cutting test using drawings of intersection. *Journal for Geometry and Graphics, 8*(1), 117-126.

Wu, H.K. & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education, 88,* 465-92.

Note

Preliminary results of this study were presented at the 2016 ASEE Midyear Conference proceedings in Daytona Beach, FL.

About the Authors

Petros J. Katsioloudis is an Associate Professor, the Industrial Technology Program Leader and Chair of the Department of STEM Education and Professional Studies, Old Dominion University, Norfolk, VA. His research focuses on improving teacher and student performance in STEM education, technical visualization and enhancing the development of a national STEM-educated workforce.
Email: pkatsiol@odu.edu

Vukica Jovanovic is an Assistant Professor of Mechanical Engineering Technology Department, Frank Batten College of Engineering and Technology, Old Dominion University, Norfolk, VA. Her areas of interest include the following: Mechatronics, Product Lifecycle Management, Digital Manufacturing, Engineering Collaboration, RFID, and Assembly Systems.
Email: v2jovano@odu.edu

Mildred Jones is a graduate student in the Department of STEM Education and Professional Studies at Old Dominion University. Her research focuses on technical visualization.
Email: mjones@odu.edu