winter 2015

volume 79 number 1

THE ENGINEERING DESIGN GRAPHICS Journal

Engineering Design Graphics Journal (EDGJ)
Winter 2015, Vol. 79, No. 1
http://www.edgj.org

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 and Biwu Yang, Research & Development, ECU Academic Outreach.

ISSN: 1949-9167

Message from the Chair

Kevin Devine
Illinois State University

The 69th EDGD Midyear Conference is now behind us and I appreciate the hard work contributed by many to make it a success. My hearty congratulations are extended to Diarmaid Lane and Dónal Carty, recipients of this year's Oppenheimer Award. Their presentation entitled "Micro to Macro… Investigating the Complex Cognitive Processes in Forming and Externalizing Visual Imagery" was certainly worthy of the award. The quality of the presentations and comradery among attendees is something I always look forward to at the midyear conference. I also find value in the off-site social events and tours that are often part of the mid-year conferences. By attending midyear conferences I have seen aircraft carriers and submarines being built in Virginia, diesel locomotives being built in Pennsylvania, and medical devices being manufactured in Massachusetts. This year we were treated to a tour of a Caterpillar manufacturing facility, where in addition to seeing their huge mining trucks being built, several design engineers spoke with the group about product design practices used at Caterpillar. The technical insights we gain from activities such as these, as well as the relationships we forge with our colleagues, make these events time well-spent.

In my last "Message from the Chair", I outlined some of the important changes in EDGD leadership that lie ahead for the Division. The division elections have since been held and I am very pleased with the results. Norma Veurink was elected as Vice Chair, Heidi Steinhauer will be our Secretary/Treasurer, and AJ Hamlin will become our Director of Publications. Both Norma and AJ have been in leadership positions with the EDGD for several years and I am glad they have agreed to use their considerable talents to serve the division in new capacities. Heidi has consistently participated in division events over the last several years and we are all fortunate she has agreed to take on a formal leadership role with the division. With the addition of these three extraordinary individuals to the Executive Committee, the division leadership team is rock solid moving forward.

Please take some time now to mark January 24-26, 2016 on your calendar for the 70th Midyear Conference that will be hosted by Embry-Riddle Aeronautical University in Daytona Beach, FL. Many thanks to Lulu Sun, Heidi Steinhauer, and Diarmaid Lane for organizing what I am sure will be an enlightening, enjoyable, and warm conference. I am looking forward to spending time with you there in the Florida sunshine instead of my Midwest snow and wind.

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Message from the Editor

Robert A. Chin
East Carolina University

As Kevin noted in his message, AJ Hamlin will assume her duties as the Engineering Design Graphics Division's Director of Publications and Editor of the Engineering Design Graphics Journal during the 122nd ASEE Annual Conference & Exposition in Seattle. AJ has served as the Journal's Associated Editor and is intimately qualified to assume these duties. I know you all will provide her with at least the same level of support you've provided me during my tenure.

In my final message to the readers of the Journal and to the Division's membership, I'd like to take this opportunity to thank everybody and the various entities that supported me during my two terms as the Division's Director of Publications and in particular as the Editor of the EDGJ. I'm sure I'm going to overlook some, and for that I apologize in advance.

The online EDGJ is a reality because of the Public Knowledge Project's Online Journal System, one of several open-source applications designed to manage peer reviewed academic journals. And while OJS has its own counter plugin, which facilitates counter statistics and reporting, the EDGJ also uses a freemium web analytic service, Google Analytics, to track and report on its website traffic.

A note of thanks and appreciation needs to be extended to a colleague, Biwu Yang, a staff member with East Carolina University's Global Academic Initiatives office, for his continuous support since the inception of the online EDGJ. I'd also like to extend a note thanks and appreciation to ECU for allowing the Division to house the Journal on one of its servers.

I also need to recognize another colleague, William Joseph Thomas, Assistant Director for Research and Scholarly Communication, Joyner Library, who's been onboard since 2009. He's been instrumental in identifying possible options and opportunities for improving the viability of the Journal. While we've come a long way, we still have a way to go to ensure the sustainability of the Journal. I know we can count on Joseph to continue providing us with the necessary guidance.

One of the initiatives that we kicked off thanks to Joseph's encouragement was that of becoming the sole source for archiving the scholarship activities of the Division. While there is still work to be done, we have made some headway by archiving past issues of the Journal. This was made possible when Kathy Holliday-Darr and Mary Sadowski scanned many of the past issues of the Journal. The patient required and arduous task

ISSN: 1949-9167

of uploading the scanned issues was accomplished by a Faizan Khaja, an ECU graduate assistant and Master of Science in Occupational Safety student. Go to http://www.edgj.org/index.php/EDGJ/issue/archive to check out the past issues that he's uploaded.

A hearty thank you needs to be extended to our current Circulation Manager and Journal Treasurer, Nancy Study. She served as the Associate Editor during the transition from the in-print edition of the Journal to the online edition and was responsible for ensuring that authors were able to upload their papers and for ensuring that the reviewers were able to complete their reviews during the transition. In order to ensure hiccups were minimized, she spent countless hours learning the system, tutoring and providing just-in-time training and did troubleshooting on behalf of authors and reviewers. Upon completion of her tour as AJ's predecessor, she brought AJ up to speed on working with the system and the reviewers and authors.

My predecessor was La Verne Abe Harris. Thanks to her patience and persistence, we were able to beginning fleshing out the online Journal with issues that she'd published. And as time permitted, we collected files from her predecessors and backfilled at the same time new issues were published.

And speaking of reviewers, the quality of the Journal and of the feature articles published is a result of our reviewers' insightful assistances. The efforts expended by our reviewers has been done quietly and more often than not go unrecognized except for their bylines—see http://www.edgj.org/index.php/EDGJ/about/displayMembership/2. In addition to completing reviews, our reviewers also help to recognize EDGJ authors with the Editors Award—see http://edgd.asee.org/awards/editors/index.htm.

From what I can tell, the online EDGJ is a reality because of Kathy Holliday-Darr's message dated Saturday, February 02, 2008 4:10 PM. The Subject line was "[et-graphics] EDG Journal: On-line vs printed". That message and the fact she was the Journal's Circulation Manager and Treasurer was probably what got the Division's membership to begin debating the merits of an online EDGJ.

Taking a vision and making it a reality requires a great deal of tenacity and stick-to-itiveness. This is where Cody Skidmore, who is currently the Help Desk Specialist at Duke University, entered the scene and who over about a two year period beginning in 2009 helped the online EDGJ gain traction.

It's been a pleasure and an honor to have worked with all the aforementioned, the six Executive Committee Chairs, the members of the Executive Committee, the readers of the Journal, and the Division's membership. There have been times, in particular at the onset, when a fine line had to be walked but thanks to everybody's willingness to engage in civil discourse, the online EDGJ is where and what it is today.

ISSN: 1949-9167

EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Mid-Year Conferences

70th Midyear Conference – January 24-26, 2016, Embry-Riddle Aeronautical University. Site Chairs - Heidi Steinhauer and Lulu Sun.

Future ASEE Annual Conferences

Year	Dates	Location	Program Chair
2015	June 14 - 17	Seattle, Washington	Ron Paré
2016	June 26 - 29	New Orleans, Louisiana	Heidi Steinhauer
2017	June 25 - 28	Columbus, Ohio	
2018	June 24 - 27	Salt Lake City, Utah	
2019	June 16 - 19	Tampa, Florida	
2020	June 21 - 24	Montréal, Québec, Canada	

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: Norma L. Veurink

Norma L. Veurink is a Senior Lecturer in the Engineering Fundamentals Department at Michigan Technological University where she teaches introductory engineering courses which include engineering graphics. She teaches a spatial visualization course designed for engineering students with poor spatial visualization skills. Ms. Veurink manages several summer programs that introduce middle and high school students to engineering. She is active in the American Society for Engineering Education and the American Society of Civil Engineers. Her research interests include spatial visualization, engineering education and first-year programs.

For Secretary-Treasurer: Heidi Steinhauer

Dr. Steinhauer has taught at Embry-Riddle Aeronautical University since 1997. Currently, she is an Associate Professor and the Department Chair of the Engineering Fundamentals Department. She teaches: Introduction to Graphical Communication, Introduction to Engineering Design, Spatial Visualization Development, Advanced 3D Modeling, Additive Manufacturing, and Design for Manufacturing and Assembly.

Her research interests include the development of engineering curriculum that utilize the power of 3D modeling to foster deeper learning by providing students a scaffold to successfully implement an interdisciplinary approach, and the effect of engineering

ISSN: 1949-9167

design skills on student learning and academic success in the engineering field, specifically its impact on the recruitments, retention, and success of women.

Dr. Steinhauer has been integral in the development of several instrumental retention and outreach programs at Embry-Riddle. In 2006 she co-founded the ERAU Womens' Baja SAE Team and in 2007 she co-founded the College of Engineering's FIRAT Program, a coaching program geared toward the success of women in engineering. In 2009 and 2010 she was the co-director for the GEMS summer camp. She has also been the faculty advisor for Project Piquero, which developed an UAV to police for illegal shark finning in the Galapagos Islands.

She has authored over 20 journal and conference papers and has been funded as a PI on several NSF grants. Steinhauer, a three time recipient of Embry-Riddle Women's Vision award in 2007, 2009, and 2011 and also has received the ABET Diversity Award in 2010. She is an active member in the Society of Automotive Engineers, SAE, American Society for Engineering Education, ASEE, Women in Engineering Program Advocates Network, WEPAN, and the American Education Research Association, AERA.

Dr Steinhauer received her B.S. in Aircraft Engineering and her M.S in Systems Engineering, and her Ph.D. in Engineering Education from Virginia Tech.

For Director of Publications: AJ Hamlin

AJ Hamlin is a Senior Lecturer in the Department of Engineering Fundamentals at Michigan Technological University, where she has taught first-year engineering courses and a course to develop spatial skills since 2001. AJ received a BS in Environmental Engineering in 1993, a MS in Civil Engineering in 1995, and a PhD in Engineering, Environmental in 2002 from Michigan Tech. She also completed an NRC Post-Doctoral Fellowship at NASA Langley Research Center.

AJ's research interests include spatial visualization skills and engineering education. AJ has been an active member in ASEE since 2006, and has presented papers at annual conferences, EDGD midyear meetings, FIE, and the First Year Engineering Experience Conference. As a co-author, AJ is the recipient of the EDG Journal Editor's award. AJ has served as Site co-chair and Program co-chair for the 65th Midyear conference. AJ has been associate editor of the EDG Journal since 2011.

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http://www.edgj.org

ISSN: 1949-9167

Pictorial Visual Rotation Ability of Engineering Design Graphics Students

Jeremy V. Ernst
Virginia Tech

Diarmaid Lane
University of Limerick

Aaron C. Clark
North Carolina State University

Abstract

The ability to rotate visual mental images is a complex cognitive skill. It requires the building of graphical libraries of information through short or long term memory systems and the subsequent retrieval and manipulation of these towards a specified goal. The development of mental rotation skill is of critical importance within engineering design graphics. It promotes the ability to comprehend complex engineering drawings, communicate design ideas through freehand sketching, and develop CAD modeling strategies. Considering this, exploratory development research was conducted in efforts to investigate student ability levels measured by parallel pictorial items of an existing geometric mental rotation measure. Images of rotated general consumer objects were captured and composed in a corresponding format to that of the Purdue Spatial Visualization Test: Visualization of Rotations. An expert review panel from engineering/technical graphics was convened to analyze consistency of format, rotation, and solutions of the corresponding pictorial items instrument. A group of post-secondary Engineering Design Graphics students were randomly administered the Purdue Spatial Visualization Test: Visualization of Rotations where the remainder of the group was administered the pictorial item instrument. The developed pictorial instrument represented orientation familiarity, while geometric forms in the Purdue Spatial Visualization Test: Visualization of Rotations represented unfamiliar structures. Comparative analyses were conducted and differences identified pertaining to student abilities in mental rotation of geometric forms and pictorial visual rotation abilities. Summary statistics, frequency analyses, and hypothesis testing uncovered that student mental rotation abilities of geometric forms collectively exceed that of pictorial rotation ability.

Introduction

Contemporary curriculum policy and planning largely focuses on the development and promotion of numeracy, literacy and articulacy skills (Mosely et al, 1999). However, research has identified the importance of graphicacy across the education system in developing well-balanced human citizens (Danos, 2001; Fry, 1981). *"Graphics"* are the representation of visual images with the purpose of communicating some information. Representations differ vastly in their purpose, mode of creation, and in their level of abstraction (Grignon, 2000). They can be in the mind (internal) or they can be physically perceivable (external).

ISSN: 1949-9167

The ability to mentally rotate and manipulate geometry is of fundamental importance in terms of being able to graphically communicate. Keen spatial skill is a strong indicator of achievement and attainment in science, technology, engineering, and mathematics fields (Uttal et al, 2013). These abilities are significant for an assortment of reasons, including “effective education in the science, technology, engineering, and mathematics (STEM) disciplines” (Uttal et al, p. 352). Predominantly, previous academic studies concentrated on spatial ability but did not offer attention to the circumstances under which spatial skill was developed or the transfer of those abilities to untrained areas (Miller & Halpern, 2013; Marunic & Glazar 2013). Within STEM education, however, engineering design graphics literature has a concentrated focus of exploratory and experimental research pertaining to spatial and visual skill development, paired with efforts to enhance mental rotation abilities for students. In a 2000 study, Branoff highlighted a criticism of traditional mental rotation measures in their use of “isometric projections for the display of three-dimensional objects”, (p. 15) as well as further introducing the concept of object familiarity and unfamiliarity as an influential variable within visualization measurement. The influence and/or diagnostic impact that object familiarity has on mental rotation measure is largely undetermined.

Spatial Skills Overview

Visuo-spatial skills are of fundamental importance for successfully overcoming and solving many problems in everyday life. The ability to generate, remember, retrieve and manipulate spatial relations in visual imagery (Lohman, 1994) is a complex cognitive skill which is of particular interest to researchers within the STEM education community and beyond (Sorby, 2009, Wai et al., 2009). For decades, several longitudinal studies (Super & Bachrach, 1957) have investigated the nature of spatial ability as a psychological attribute in young adolescents. These studies found that spatial ability was a prominent attribute among adolescents who subsequently were successful in achieving advanced educational credentials and employment in STEM disciplines. An eleven year longitudinal study entitled Project TALENT by Wai et al. (2009) further highlights this.

Figure ***1*** shows the proportion of each STEM degree group as a function of spatial ability, where spatial ability scores were categorized on a nine point (stanine) scale with 1 being the lowest scoring category and 9 the highest. These findings clearly show that spatial ability is an important factor in achieving advanced qualifications within STEM disciplines. Forty-five percent of STEM Ph.D. graduates were in stanine 9 on spatial ability eleven years earlier, while ninety percent were in stanine 7 or above.

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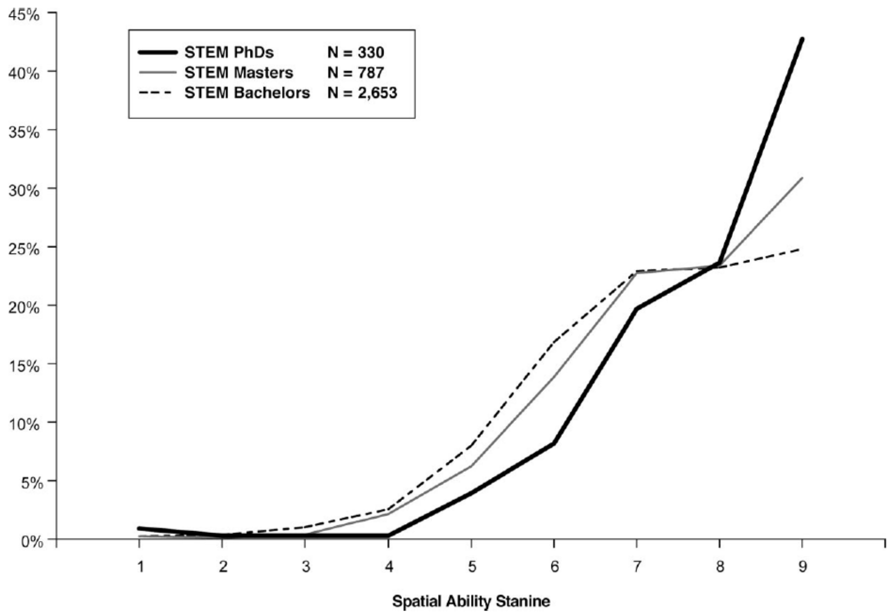

Figure 1. **Proportion of each STEM degree group as a function of spatial ability (Wai et al, 2009).**

While spatial ability as a psychological, innate attribute is a clear indicator of success within STEM disciplines, it is important to acknowledge that spatial skills can be developed through appropriate and purposeful intervention. Several longitudinal studies by researchers such as Sorby et al. (2009, 1999) have shown that the implementation of a specially designed course aimed at developing spatial skills in first year engineering students had a positive impact on student success in their degree studies, especially for women. Therefore, if pedagogical interventions that focus on spatial skill development have such a positive impact on students, how can spatial ability be validly measured in order to inform the design of these instructional activities?

Measuring Spatial Skills

It is somewhat difficult to establish absolute definitions on what exactly constitutes spatial ability from the existing body of associated research literature. For example, Maier proposed that there are five components that make up spatial skill (Sorby, 1999), while McGee (1979)believed that there are two distinct categories of 3-D spatial skills which include spatial visualization and spatial orientation. Essentially, spatial visualization is the mental movement of an object in space, while spatial orientation involves the mental modification of a viewing direction.

Over several decades of research, many different types of tests have been used in an attempt to establish the psychological attributes of visual cognition. These tests have ranged from Finke's (1988) experimental tests on visual synthesis in mental imagery, Ekstrom's (1976) range of cognitive tests that measure attributes such as figural fluency and perceptual speed, and The Differential Aptitude Test; Space Relations (Bennett et

ISSN: 1949-9167

al., 1973). Contemporary research studies associated with the evaluation of spatial skills have converged on a select number of tests. This includes the Spatial Composite Test: This test was designed and administered by Wai et al. (2009) as part of an 11 year longitudinal study of 400,000 participants who were drawn from a stratified sample of U.S. high schools (Grades 9-12). The Spatial Composite Test was composed of four measures including; three-dimensional spatial visualization, two-dimensional spatial visualization, mechanical reasoning and abstract reasoning. We feel that this test is worth mentioning due to the nature of the longitudinal study, large number of participants, and the findings (some of which were illustrated in
Figure ***1***).

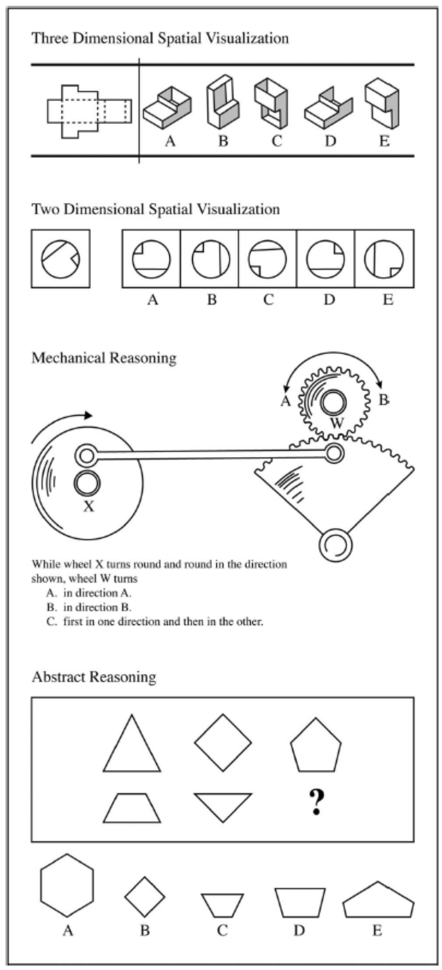

Figure 2. **Spatial Composite Test developed and administered by Wai et al. (2009).**

The Mental Rotation Test is another test for evaluating spatial skills. This test was initially developed by Shepard and Metzler (1971), and its purpose is to evaluate participants' ability to determine whether two pairs of perspective line drawings of objects were congruent or not. Each object is composed of ten solid cubes attached face to face to form a rigid structure with three right-angled bends. The test is widely used as a measure of the spatial visualization factor and has been adapted and redrawn by researchers such as Vandenberg and Kuse (1978) and Peters et al. (1995). Figure 3 shows an example of two questions from Vandenberg and Kuse (1978). Each question consists of a criterion figure, two correct alternatives, and two incorrect configurations which are referred to as distractors.

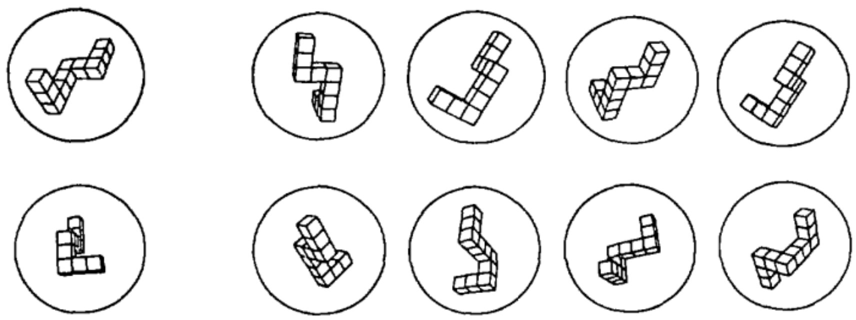

Figure 3. **Examples of Mental Rotation Test questions from Vandenberg and Kuse (1978).**

The fourth test for evaluating spatial skills is the Mental Cutting Test (MCT). The test was originally developed for university entrance examinations in the USA. The MCT measures the ability to recognize the spatial form of an object that has been cut by an imaginary plane (Sorby, 1999, Nemeth, 2007). It is composed of 25 problems consisting of relatively complicated and sometimes truncated solids. The criterion solids are all presented in a perspective drawing. Students are required to choose the correct resultant cross-section from five given alternatives, which are presented in an orthogonally. A sample question from the MCT test is shown in Figure 4 where the correct answer is 2.

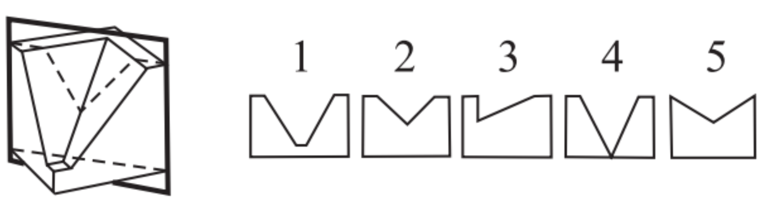

Figure 4. **Sample question from the Mental Rotation Test (CEEB, 1939).**

Finally, the Purdue Spatial Visualization Test – Visualization of Rotations (PSVT:R) is possibly the most widely used measure of spatial visualization ability across the STEM domain. Developed by Guay (1977), this paper based test consists of 30 unfamiliar objects. The test-taker is provided with a sample rotation and is then required to rotate the target object by the same amount. A sample question from the test is shown in Figure 5 where the correct answer is B.

ISSN: 1949-9167

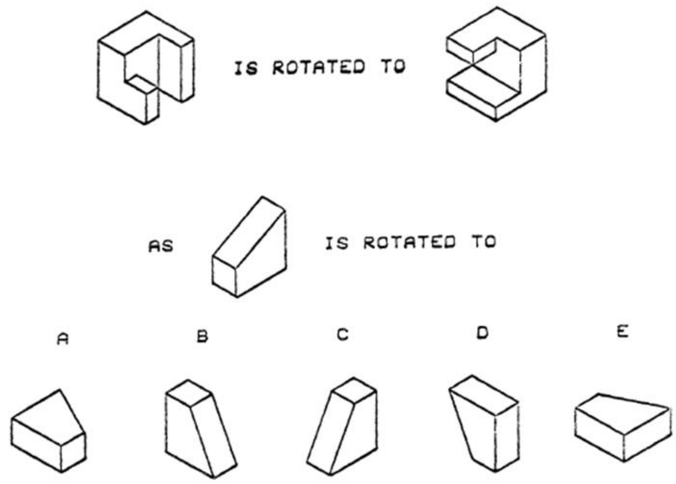

Figure 5. **Sample question from the Purdue Spatial Visualization Test – Rotations (PSVT:R) (Guay, 1977).**

Cognition and Object Familiarity

Visual representations used in spatial tests are generally line drawings of rigid, regular geometric solids which are sometimes sliced, truncated or compounded with other geometric solids. The objects generally consist of a number of flat surfaces with clearly identifiable vertices and no concavities. Research in cognitive psychology suggests that test-takers would probably form an image of the target geometry in the visuo-spatial sketchpad (Baddeley, 1998) of short term memory and subsequently manipulate the image in accordance with the test instructions. The cognitive literature also suggests that test-takers would probably engage a mixture of low-level, intermediate, and high-level processes to initially make sense of the image presented and interpret interrelations within the geometries (Stillings, 1995).

Following from this, it is worth describing how human beings interpret visual images of familiar objects. Human beings are capable of encoding all sorts of information in long term memory. Depending on the level of initial processing, chunks of information can be easily retrieved and are very clear while other information can be difficult to remember and can be vague in nature. In terms of graphical imagery, representations are encoded in long term memory through events such as haptic manipulation of objects over a long period of time.

Stillings (1995) described how identification of objects brings with it highly detailed information and an intimate understanding of their parts. The literature concerning visual cognition suggests that different memory systems are used when processing visual representations. Therefore, it is logical to ask the following question: Would there be an effect on scores in spatial tests if familiar everyday imagery (of which test takers would have a general knowledge) replaced the typical abstract representations of

ISSN: 1949-9167

regular geometries present in existing tests? This will form the focus of the next section of this paper.

Research Questions

To further explore object familiarity, a study was formed to examine paired engineering design graphics student mental rotation outcomes using traditional geometric form instrumentation and pictorial-based instrumentation of identical constructs. There was one principal research question guiding this mental rotation study: Does object familiarity provide for greater visual rotation attainment? This question was investigated through an exploratory development research study conducted in efforts to investigate student ability levels measured by parallel pictorial items of an existing geometric mental rotation measure.

Methodology

To begin, the research team met and formalized the investigational query, where they subsequently formulated a proposed research method. The full research protocol was generated and submitted for and received Institutional Review Board approval. A single instructor of 102 students in an initial technology teacher education program at the University of Limerick, Ireland, served as proctor for participants for this exploratory development study. Particular focus in this undergraduate program is in the development of core graphical competencies including graphical communication skills, understanding of geometric principles, and spatial visualization skills.

The study constituted two sections of introductory course offerings affiliated with engineering design graphics concepts and applications. The instructor/proctor randomly determined which instrument would be administered to which section. The Purdue Spatial Visualization test Visualization of Rotations (PSVT-VOR) was administered to the 52 course participants in Section 001, while the Pictorial Visual Rotation Test (VRT) was administered to the 50 course participants in Section 002.

The PSVT-VOR employed in the present study is one element of the Purdue Spatial Visualization test battery (PSVT) (Guay, 1977). The test measured students' ability to mentally rotate geometric objects depicted in drawing in three-dimension space. A standard time limit of 20 minutes was given for the test, which consisted of 30 items of increasing difficulty (Branoff, 2000). The directions of the PSVT-VOR test instructed the students to study how the key object in the top line of the question is rotated, and from among the five response options select the one that corresponds to the rotation of the depicted key object (Bodner & Guay, 1997). The PSVT battery provides a valid measure of cognitive abilities (Bodner & Guay, 1997).

The second instrument relied on rotational sequences of acquainted consumer/household objects to construct a metric for object familiarity (see Figure 6 for PSVT-VOR and PSVT comparison). Images of these objects were captured in parallel

  ISSN: 1949-9167

format to the established PSVT item sequences and response choices. A single key object was identified, just as was developed for the PSVT instrument. An expert review panel of post-secondary educators, that were members of the Engineering Design Graphics Division of the American Society for Engineering Education, was convened to analyze consistency of format, rotation, and solutions of the corresponding pictorial items instrument. A call for panel participation was posted on the Engineering Design Graphics Division Listserv where participants self-identified background and expertise in visualization and PVST-VOR. There were a total of four reviewers volunteering to assist in the review process. Feedback was obtained and incorporated based on diagnostic usability, image clarity, rotational accuracy, and uniformity in terms of PSVT metric consistency.

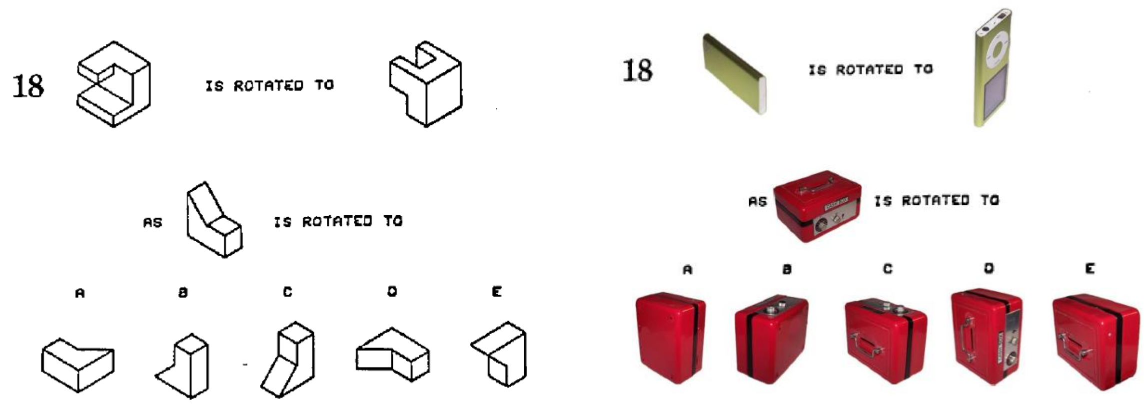

Figure 6. **PSVT-VOR and Pictorial VRT item comparison.**

The developed Pictorial VRT represented orientation familiarity, while geometric forms in the PSVT-VOR represented unfamiliar structures. Comparative analyses were conducted and differences identified pertaining to student abilities in mental rotation of geometric forms and pictorial visual rotation abilities.

Findings

Table 1 shows the summary statistics of the two visual rotation metrics. The average Pictorial VRT score (19.36 of a possible 30) for the 50 participants is lower than the average of PSVT-VOR scores (23.21 of a possible 30) for the other 52 participants. The variance (20.684) and standard deviation (4.548) of Pictorial VRT scores are low in comparison to the variance (22.837) and standard deviation (4.779) of PSVT-VOR scores indicating a slightly smaller spread of Pictorial VRT scores. The standard error (0.643) of Pictorial VRT scores is lower than that of Purdue SVRT indicating a smaller fluctuation in score values from participant to participant for the Pictorial VRT. The medians of both tests exhibit minimal deviance from the means respectively suggesting a somewhat symmetrical score distribution for both tests. The same range on both tests reiterates the comparable degree of difference in variability of participants between the

ISSN: 1949-9167

two tests. Figure 7 and Figure 8 represent the number of occurrences for PSVT-VOR scores and Pictorial VRT scores.

Table 1
Summary Statistics

Assessment	n	Mean	Variance	Std.Dev.	Std.Err.	Median	Range
PSVT-VOR	52	23.21	22.837	4.779	0.663	24	18
Pictorial VRT	50	19.36	20.684	4.548	0.643	19	18

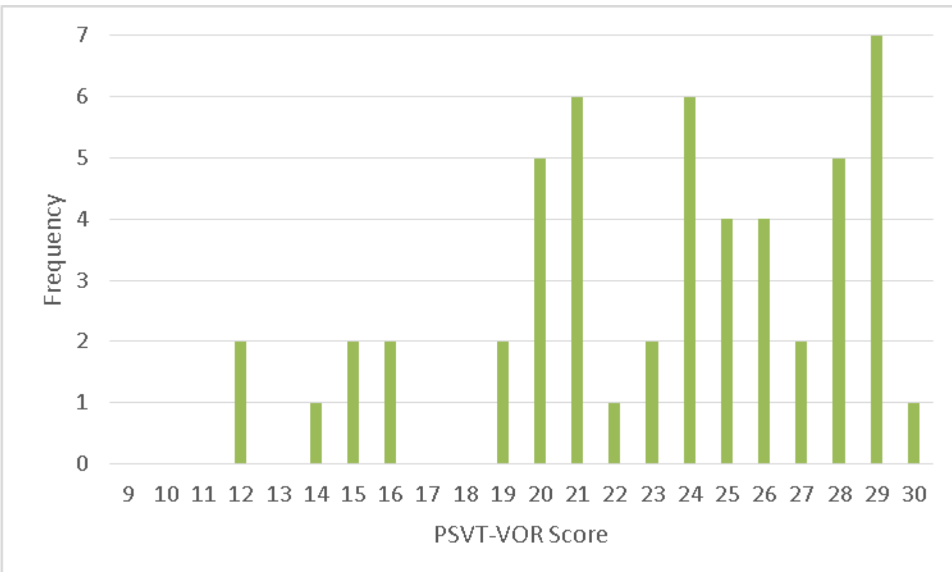

Figure 7. **PSVT-VOR Histogram.**

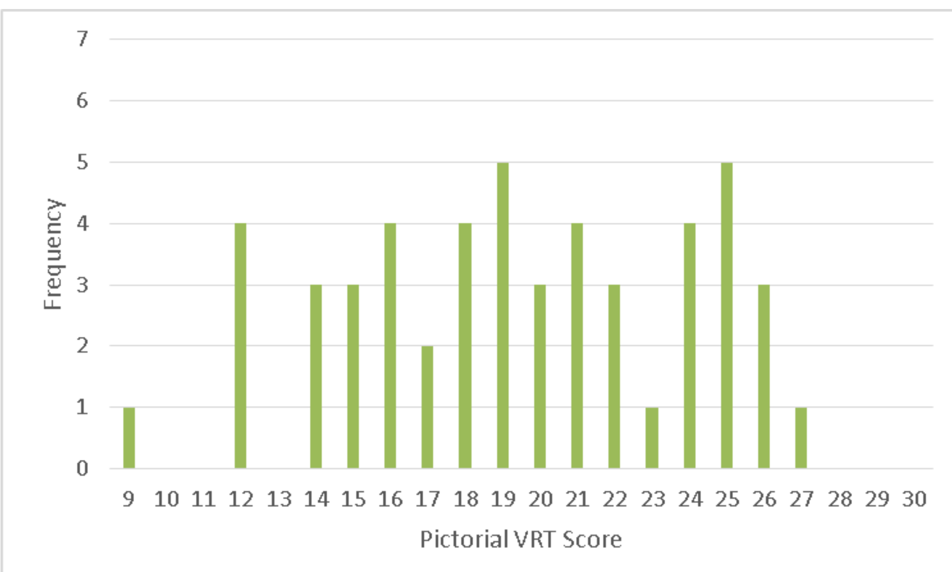

Figure 8. **Pictorial VRT Histogram.**

The primary hypothesis was non-directional provided the experimental nature of the study and the lack of basis for a directional hypothesis. A single null hypothesis was evaluated: There is no difference in the score distributions of PSVT-VOR and Pictorial VRT. This hypothesis was evaluated in Table 2 using the nonparameric Mann-Whitney U-test. Due to the sampling methodology in that two single groups of students were selected to represent the engineering graphic student population, a Gaussian population cannot be assumed. In this case, a Mann-Whitney U test, which "is often thought of as the nonparametric analogue of the t test for two independent samples"(Howell, 2013, p.668), was adopted to compare the means of the scores from two unpaired groups, Purdue SVRT and Pictorial VRT. The test statistic for the Mann-Whitney U-test was compared to the designated critical value table. The critical alpha value was set at 0.05 for this investigation. The p-value for the test (<0.0001) uncovered that the null hypothesis was rejected. The result suggests that the collective outcome scores of the PSVT-VOR is significantly different than the score of Pictorial VRT. Summary statistics, frequency analyses, and hypothesis testing uncovered that student mental rotation abilities of geometric forms collectively exceed that of ability of pictorial rotation ability.

Table 2
Mann-Whitney U-test

Purdue SVRT (n)	Pictorial VRT (n)	Diff.Est.	Test Stat.	P-value
52	50	0	717.500	<0.0001

Conclusions

This study was conducted with the premise that forms of assessment can be extended or built upon to reflect the needs and values of a discipline. Specifically, the researchers wanted to determine if using actual captures of everyday objects (i.e. Pictorial VRT), would lead to student demonstration of higher proficiency on visual-based tests. As the findings indicate, it was just the opposite; students that participated in this study scored higher using the traditional geometric or isometric drawing test. Prior to the exploratory study, the researchers held the conception that through increased presence of visual cues participants would be assisted in determining proper rotation and orientation. However, little research has been previously conducted in determining the level of surface topology needed to heighten outcomes in the visual rotation of objects.

Based on the study findings, the authors offer the following recommendations. First, comparative analyses uncovered that students that took part in the study demonstrated existing levels of mental rotation ability proficiency with the geometric forms found in the PSVT-VOR. Early on in the participants' university studies, they learned about projection systems and principles associated with descriptive geometry with particular focus on cubes, rectangular prisms, pyramids, cones, and spheres. However, there is rarely a focus placed on the purposeful rotation and manipulation of everyday objects.

Perhaps the students are influenced by what they observe in everyday media; for example, they will rarely see an iPhone turned upside down in a television commercial. Also, the participating students completed some spatial visualization instruction previous to this module and some of the developmental tasks would have been similar in nature to the PSVT-VOR. It would be interesting to investigate whether object familiarity and general interest with particular objects had an influence on performance. The second major deduction and recommendation lends itself to the pedagogy that engineering design graphics teachers use in the classroom. It could be that students are directly influenced by the geometric forms commonplace in their coursework and are not as proficient in articulating classroom-based study and exercises to everyday objects. If this were the case, it would argue to enhance transferability of skill through the inclusion of more real-world images throughout engineering design graphics curricula. The final supposition and recommendation is that the role of graphics related background instruction, visual skill development, and the use of computer graphics software needs to be considered and factored in investigations related to visualization and mental rotation.

Further research in the use of alternative visual-based tests with familiar and unfamiliar properties is suggested. Overall, more research is needed in what are best practices for using projection and computer technology to enhance students' learning of visual-based materials, as well as test their visual skills and abilities. Finally, research is needed on how we can more accurately diagnose student visual abilities, knowing that they will most likely use three-dimensional modeling and printing, as well as image processing and simulation, as major components within their careers. An industry-modeled and/or field-based course of study within engineering design graphics has potential to enhance the necessary trajectory for visual skill preparedness for the workplace. This has implicit impacts for the engineering design graphics classroom specific to the development, promotion and assessment of visual cognition and visual synthesis in mental imagery.

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Note

The preliminary results of this study were presented at the 2014 ASEE Annual Conference in Indianapolis, IN.

Acknowledgements

The authors thank Songze Li, Zac Elmore, Kevin Sutton, Barry Potter and the Engineering Design Graphics Division of ASEE for their assistance during the research and development phases of this work.

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Engineering Design Graphics Journal (EDGJ)
Winter 2015, Vol. 79, No. 1
http://www.edgj.org

ISSN: 1949-9167

Evaluation of Static vs. Dynamic Visualizations for Engineering Technology Students and Implications on Sectional View Sketching: A Quasi-Experimental Study

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The benefit of using static versus dynamic visualizations is a controversial one. Few studies have explored the effectiveness of static visualizations to those of dynamic visualizations (e.g. videos or animations). As well, the current state of research literature remains somewhat unclear (Kuhl, Sheither, Gerjets & Edelman, 2011). During the last decade there has been a lengthy debate about the opportunities for using animation in learning and instruction. More specifically it has been shown that dynamic visualizations often provide no advantages over static visualizations (Malone & Lepper, 1987). If advantages were shown, it was due to the fact that more information was available in the animated version than in the static version. Hegarty and Waller (2005) suggest that individuals with high spatial abilities benefit from dynamic visualizations because they already have effective mental models to process 3D information versus individuals with lower spatial abilities, who lack these effective mental models. Given this controversy, the focus turned to the question of when dynamic displays are more effective in learning than static ones (Hegarty, 2004).

For this study, the following was the primary research question:

Is there a difference between the type of visualization presented to engineering technology students (3D PC static, 3D PC dynamic, or 3D printed dynamic) and their ability to correctly create a sectional view sketch of the presented object?

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

H_0: There is no difference between the type of visualization presented to engineering technology students (3D PC static, 3D PC dynamic, or 3D printed dynamic) and their ability to correctly create a sectional view sketch of the presented object.

H_A: There is an identifiable difference between the type of visualization presented to engineering technology students (3D PC static, 3D PC dynamic, or 3D printed dynamic) and their ability to correctly create a sectional view sketch of the presented object.

ISSN: 1949-9167

Review of Literature

Spatial Ability

Spatial ability is developed through spatial cognition and is described as the ability to form and retain mental representations of a given stimulus, a mental model, and can also be used to determine if mental manipulation is possible (Carroll, 1993; Höffler, 2010). This type of ability has been recognized as an individual ability, somewhat autonomous of general intelligence (Hoffler, 2010). The role of spatial ability relates to an individual's ability in "searching the visual field, apprehending the forms, shapes, and positions of objects as visually perceived forming mental representations of those forms, shapes, and positions, and manipulating such representations 'mentally'" (Carroll, 1993, p. 304). In addition, 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; Orde, 1997; Pak, 2001; Lajoie, 2003).

Spatial Ability used in Engineering Education

Spatial ability has been identified as having a positive correlation with learning achievements (Mayer & Sims, 1994; Mayer, Mautone & Prothero, 2002). The use of physical object manipulations, freehand sketching on paper, and computer-aided sketching can improve the spatial ability of freshmen engineering students (Martín-Gutiérrez, Saorín, Contero, Alcañiz, Pérez-López & Ortega, 2010). The early years of Engineering Design Graphics (EDG) (1920s-1940s) were based on the development and application of spatial ability testing in curricula. During this time, the focus weighed heavily on using multi-view drawings to enhance a learner's visualization ability. To date, three phases of research in engineering education can be defined in relation to spatial ability. First, from 1901-1938, the efforts were focused on identifying visual tasks, and specifically, a single spatial factor. The second phase, from 1938-1961, focused on identifying several spatial factors: the ability to recognize spatial configurations and the ability to mentally manipulate configurations (Strong & Smith, 2001). The third phase, from 1961-1982, attempted to further separate spatial factors, such as age, sex and experience. A fourth phase of study is still emerging in the field of engineering graphics. This phase focuses on the effects of computer technology on spatial visualization skills, as well as assessment instruments used to measure these skills (Strong & Smith, 2001). Spatial abilities, specifically visualization, play a critical role in the success of a variety of professions, such as engineering, and technical, mathematical, and scientific professions.

Visualization

The term spatial visualization has often been used interchangeably with "visualization" and "spatial ability" (Braukmann, 1991). Visualization involves the mental transformation of an object through a sequence of alterations. 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) define 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). In the past two decades there has been an increased focus and sense of importance on spatial visualization in journal articles, as well as in conference proceedings (Miller & Bertoline, 1991). In a research study conducted on the increases in 3D modeling, Branoff & Dobelis (2012) asked whether or not students could still read and interpret engineering drawings. In addition, they questioned whether the ability to read these drawings related to spatial visualization ability. In the study, Branoff & Dobelis (2012) discovered a relationship exists between reading engineering drawings and spatial visualization ability. Along with this recent research, scholars in engineering education, the U.S. Department of Labor, and major industry representatives have called for the improvement of spatial visualization ability in engineering and technology students (Ferguson, Ball, McDaniel, & Anderson, 2008).

Improving spatial literacy in engineering and technology students is a key factor in their success (Ferguson, et al., 2008). Research has revealed 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). While there is a vast library of research on spatial visualization, few research studies have explored the effectiveness of static versus dynamic representations and its correlation to a learner's spatial ability (Froese, Tory, Evans & Shirkhande, 2013; Höffler & Leutner, 2011).

Static Visualizations

Research has shown that learners with high spatial ability have the opportunity to build a personal mental model when presented with static visualizations, such as non-transient static pictures (Höffler, 2010). Unlike with dynamic visualizations, static visualizations do not permit complete visualization. Instead, they use static indicators, such as shading or arrows, to symbolize the information presented (Lewalter, 2003). Static visualizations present learners with less information, therefore requiring a higher cognitive load for processing (Lewalter, 2003; Lowe, 2004). According to Garg (1999), people with low spatial ability are disadvantaged when using animation and performed better when presented with static views. In addition, research indicates that static visualizations present learners with certain benefits, such as computational offloading and graphical constraining (Larkin & Simon, 1987; Stenning & Oberlander, 1995).

Dynamic Visualizations

Dynamic visualizations and 3D animations are assumed to provide an environment that aids in changes and improvements in a student's incomplete mental model (Wu & Shah, 2004). Today, the introduction of computer-based design tools (CAD) and dynamic visuals are used in place of, or in addition to, static visuals, such as pictures. Static and dynamic representations require different cognitive demands for learners when creating a mental representation (Lewalter, 2003). However, it remains debatable whether or

ISSN: 1949-9167

not 3D models or dynamic visualizations actually enhance the learning process (Huk, 2006; Lewalter, 2003). While some researchers have indicated the possibility of dynamic visualizations aiding in learning and improving spatial ability, there have been no definitive findings suggesting spatial ability may actually act as an enhancer, especially in learners with low spatial ability (Höffler, 2010; Huk, 2006; Hegarty and Kriz, 2008; Mayer and Sims, 1994). Höffler (2010) suggests dynamic visualizations have “a compensating effect for low spatial ability learners” (p. 266). Furthermore, Hegarty & Kriz (2008) suggest animations may act as a “cognitive prosthetic” for those learners possessing low spatial ability. Hays (1996) found a statistically significant interaction of spatial ability with learners possessing low spatial ability. In this study, the learners receiving animation made greater gains than those receiving no animations.

Comparing Static vs. Dynamic Visualizations

Recently, static versus dynamic visualizations have been the focus of research to determine which one provides a better solution for learning (Froese, et al., 2013). There has been little empirical evidence suggesting the influence of spatial ability in static versus dynamic visualizations (Höffler & Leutner, 2011). Given the lack of evidence concerning a preference for one format or the other, research is now pointing to when and where the appropriate model (static vs. dynamic) is best suited for a particular learner, specifically taking into consideration the prior knowledge of the learner (Froese, et al., 2013; Höffler, Prechtl & Nerdel, 2010). A factor influencing static versus dynamic visualizations is the individual differences of the learner in knowledge or skills, such as spatial ability, which may play a critical role in determining which method is best for the learner (Höffler & Leutner, 2007). Furthermore, the instructional domain may also play a critical role in the effectiveness of static versus dynamic representations (Höffler & Leutner, 2007). Froese, et al. (2013) conducted a study to determine the effectiveness of static visualizations versus dynamic visualizations. Findings suggest that while visualization helps learners to improve 3D task performance, the use of dynamic visualizations provides no real benefit, especially to those classified as having high spatial abilities (Froese, et al., 2013).

Methodology

A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability during the summer of 2014. The study was conducted in an engineering graphics course, MET 120 (Computer Aided Drafting), offered at Old Dominion University as 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.

ISSN: 1949-9167

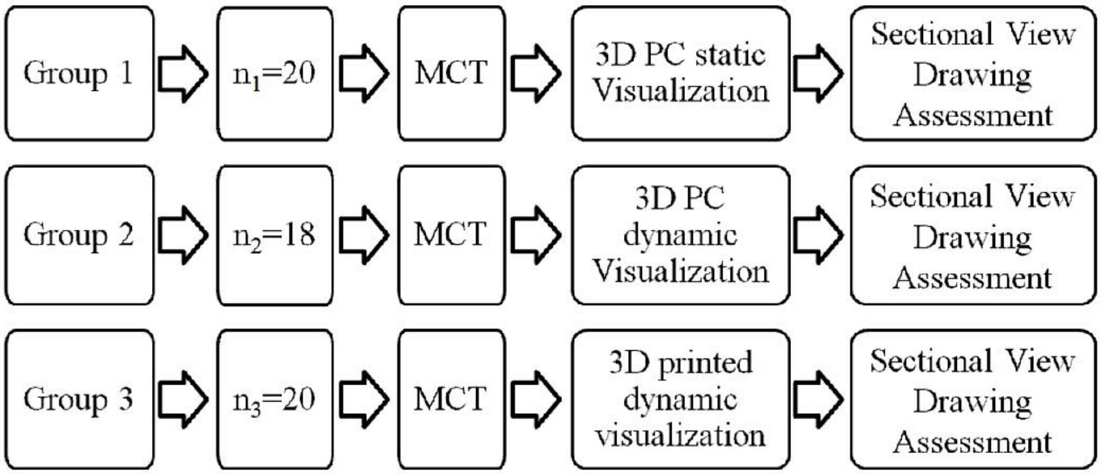

***Figure 1*. Research Design Methodology.**

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 summer semester of 2014 were divided into three groups. The three groups (*n1*=20, *n2*= 18 and *n3*=20, with an overall population of *N* = 58) were presented with a visual representation of an object (visualization) and were asked to create a sectional view. The first group (*n1*) received a static 3D PC generated octahedron visualization with no ability to rotate the visual object (see Figure 2). The second group (*n2*) received a dynamic 3D PC generated visualization of the octahedron inside a gimbal that continually rotated the visualization (octahedron) in different views (see Figure 3). The third group (*n3*) received a dynamic 3D printed octahedron, created by a 3D rapid prototyping machine, inside a gimbal that continually rotated the visualization in different views with the use of a motor in the bottom (see Figure 4). In addition, all groups were asked to complete the Mental Cutting Test (MCT) instrument 2 days prior to the completion of the sectional view drawing in order to identify the level of visual ability and to show equality between the three groups. According to Nemeth and Hoffman (2006), the MCT 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 et al. to measure spatial abilities in relation to graphics curricula (CEEB, 1939).

ISSN: 1949-9167

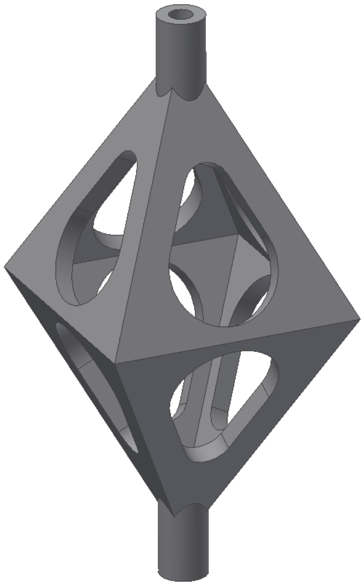

Figure 2. **Octahedron 3D Static Computer Generated Visualization.**

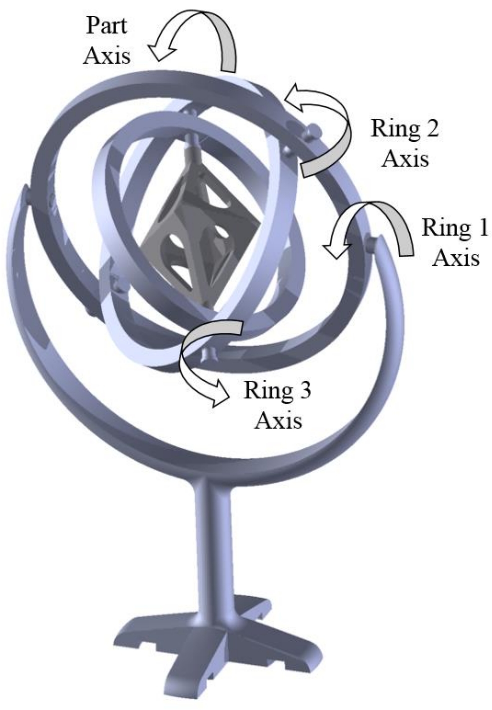

Figure 3. **Octahedron 3D Dynamic Computer Generated Visualization.**

ISSN: 1949-9167

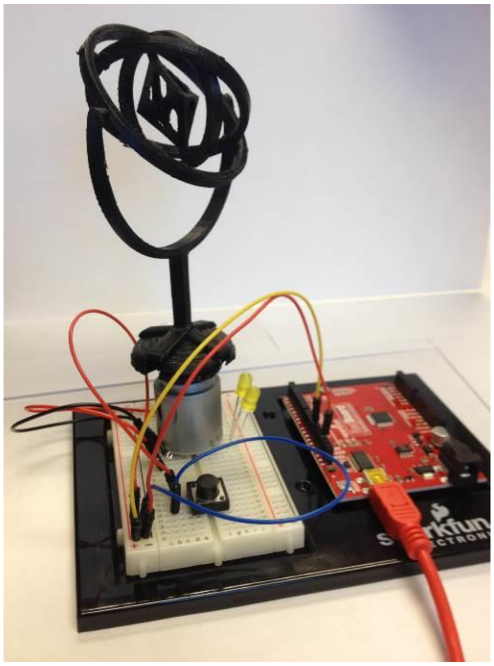

Figure 4. **Octahedron 3D Printed Solid Dynamic Visualization.**

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 in 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 quantity in the section (e.g. the length of the edges or the angles between the edges) (CEEB, 1939).

Upon completion of the MCT, the instructor of the course placed the static 3D octahedron, dynamic 3D PC generated visualization, and dynamic 3D printed visualization in a central location in the classroom. The three groups were positioned in three different rooms, and then the students were asked to create a sectional view of the octahedron (see Figure 5). This process took 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 in group 1 (static) were able to approach the visualization and observe from a close range, but had no ability to change the view through rotation. However, students placed in groups 2 & 3 (dynamic) had the privilege of close observation, in addition to having the ability to change the view through rotating the visualization by using the mouse or by rotating the gamble.

  ISSN: 1949-9167

The engineering drawing used in this research was a sectional view of the octahedron (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 an imaginary cut through the object and removing a portion, the inside features can 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.

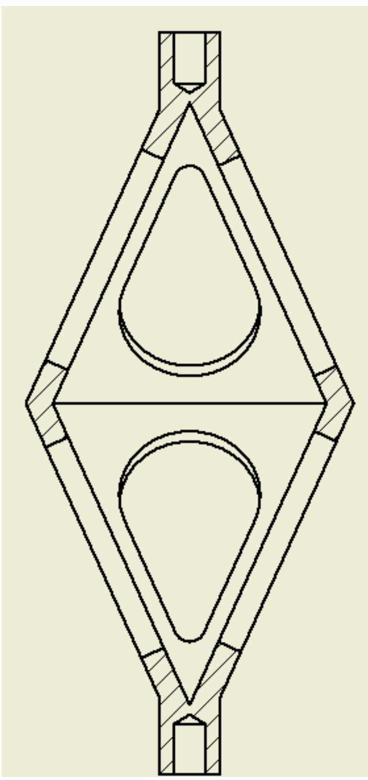

Figure 5. **Sectional View of Octahedron.**

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

ISSN: 1949-9167

before selecting alternatives. The maximum score that could be received on the MCT was 25. As seen in Table 1, n1 had a mean of 13.10, n2 had a mean of 13.22, and n3 had a mean of 14.55. A one-way ANOVA was run to compare the mean scores for significant differences between the three groups. There was no significant difference between the three groups as far as spatial ability, according to the measurements 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 PC Static	20	13.10	4.553	1.018	10.97	15.23
3D PC Dynamic	18	13.22	5.024	1.184	10.72	15.72
3D Solid Dynamic	20	14.55	4.729	1.057	12.34	16.76
Total	58	13.64	4.727	0.621	12.40	14.88

Table 2
MCT ANOVA Results

Quiz	*SS*	*df*	*MS*	*F*	*p*
Between Groups	25.535	2	12.768	0.563	< 0.573
Within Groups	1247.861	55	22.688		
Total	1273.397	57			

* Denotes statistical significance

Analysis of Drawing

The second method of data collection involved the creation of a sectional view drawing. As described previously in the paper, a 1-6 Likert scale rubric was used to evaluate the sectional drawing. As shown in Table 3, the group that used the 3D static visualization as a visual aid (n =20) had a mean observation score of 4.035. The groups that used the 3D computer generated dynamic visual (n = 18) and the 3D printed solid dynamic visualization (n = 20) had higher scores of 5.450 and 5.205, 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 significant, $F(2, 55) = 6.525$, $p < 0.003$. 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 a statistically significant difference between the 3D Static vs. 3D Solid ($p < 0.017$, $d = 1.58$) and the 3D Static vs. 3D PC ($p = 0.004$, $d = 0.99$), with 3D Static vs. 3D PC being significantly lower in both cases.

ISSN: 1949-9167

Table 3
Sectional View Drawing Descriptive Results

	N	*Mean*	*SD*	*Std. Error*	*95% Confidence Interval for Lower Bound*	*Upper Bound*
3D PC Static	20	4.035	1.7860	0.3994	3.199	4.871
3D PC Dynamic	18	5.450	0.7853	0.1851	5.059	5.841
3D Solid Dynamic	20	5.205	1.0918	0.2441	4.694	5.716
Total	58	4.878	1.4264	0.1873	4.503	5.253

Table 4
Sectional View Drawing ANOVA Results

Quiz	*SS*	*df*	*MS*	*F*	*p*
Between Groups	22.241	2	11.120	6.525	0.003*
Within Groups	93.740	55	1.704		
Total	115.981	57			

* Denotes statistical significance

Table 5
Sectional View Drawing Tukey HSD Results

Visual Aids (1 vs. 2)	Mean Diff. (1-2)	Std. Error	*p*
3D PC Dynamic vs. 3D Solid Dynamic	0.2450	0.4242	0.833
3D PC Static vs. 3D Solid Dynamic	-1.1700	0.4128	0.017*
3D PC Static vs. 3D PC Dynamic	-1.4150	0.4242	0.004*

* Denotes statistical significance

Discussion

This study was done to determine the positive impacts of dynamic and static visualizations, as well as to identify whether the type of visualization presented to engineering technology students enhances their ability to correctly create a sectional view sketch of the presented object. In particular, the study compared the use of different visual models: a 3D printed solid dynamic visualization, a 3D computer generated dynamic visualization, and a 3D printed static visualization. Even though a statistical significance was seen for particular types of visualizations, there were no

ISSN: 1949-9167

significant positive effects between the students who received treatment via the 3D computer generated dynamic visualization and the students that received treatment from the other two types of visualizations. The literature review supports that the use of animation in instruction has failed to confirm its superiority over static visualization in improving learning (Catrambone and Fleming Seay, 2002; Hasler et al., 2007; Hegarty et al., 2003; Hegarty et al., 2002; Hegarty et al., 1999; Szabo and Poohkay, 1996; Tversky et al., 2002). This small quasi-experimental study can only provide information related to change in the ability to correctly create a sectional view sketch of a presented object and cannot claim a general spatial visualization ability improvement.

Results found in a previous study conducted by Katsioloudis, Jovanovic & Jones (2014) showed the 3D PC static visualization to be the dominant one, as far as spatial ability enhancement. This could be explained because more student participants had relatively high spatial abilities, thus the use of dynamic visualizations was a significant enhancement. Froese et.al. (2013) compared static and dynamic visualization techniques for training people to complete OPT tasks and to explore whether spatial ability influences the choice of the technique. The results of the study suggest that an OPT training program focusing on static steps is most likely to be effective for people with a wide range of spatial abilities, since the participants used in the specific study did not have any previous experience with spatial tools (Froese, et. al., 2013).

Conclusion

The study compared the difference between the type of visualization presented to engineering technology students (3D PC static, 3D PC dynamic, or 3D printed dynamic) and their ability to correctly create a sectional view sketch of the presented object. No significant positive evidence was identified in the study to justify the use of a specific visualization versus any other. In order to have a more thorough understanding of the use of 3D static and dynamic visualizations in the classroom, and to understand the implications for student learning, it is imperative to consider further research.

Future Plans

Future plans include, but are not limited to:

- Repeating the study to verify the results by using additional types of visualizations.
- Repeating the study using a different population such as technology education, science or mathematics students.
- Repeating the study by adding visual cues during the display of 3D objects, including shadows, lighting and size.
- 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).

ISSN: 1949-9167

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ISSN: 1949-9167

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