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.

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

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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

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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.

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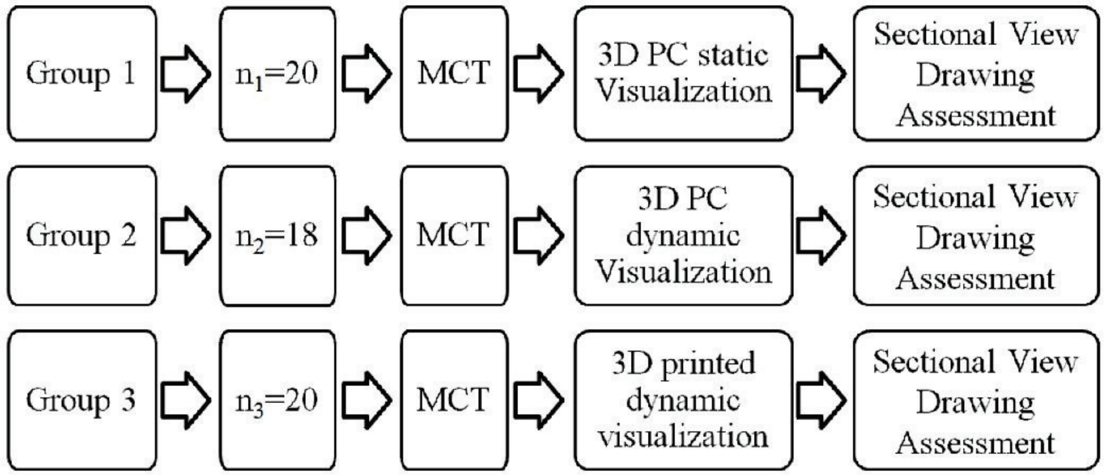

***Figure 1*. Research Design Methodology.**

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).

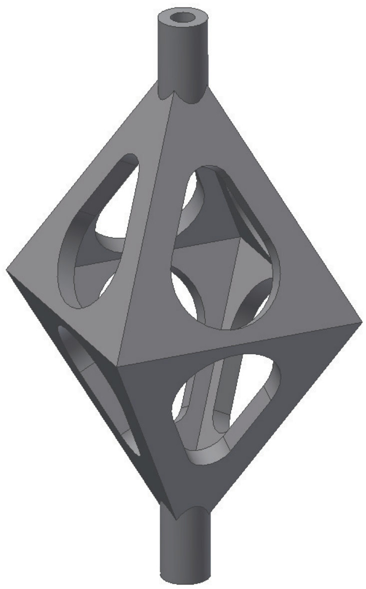

Figure 2. **Octahedron 3D Static Computer Generated Visualization.**

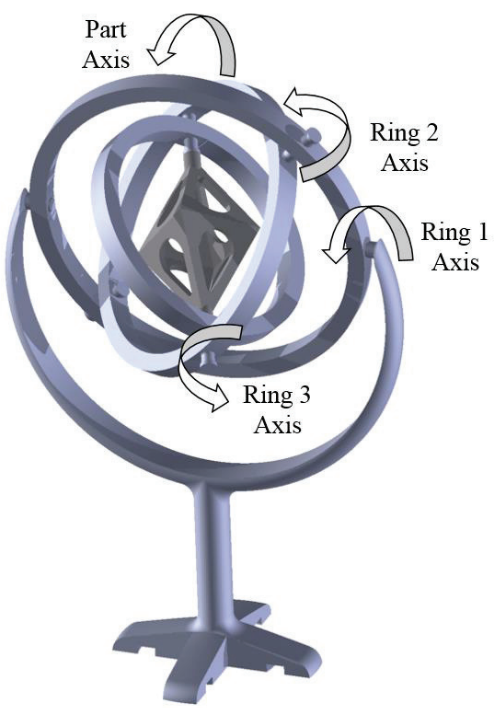

Figure 3. **Octahedron 3D Dynamic Computer Generated Visualization.**

ISSN: 1949-9167

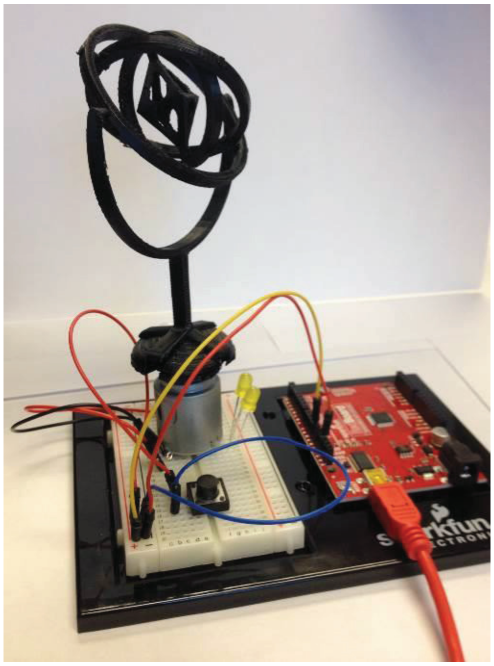

Figure 4. **Octahedron 3D Printed Solid Dynamic Visualization.**

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.

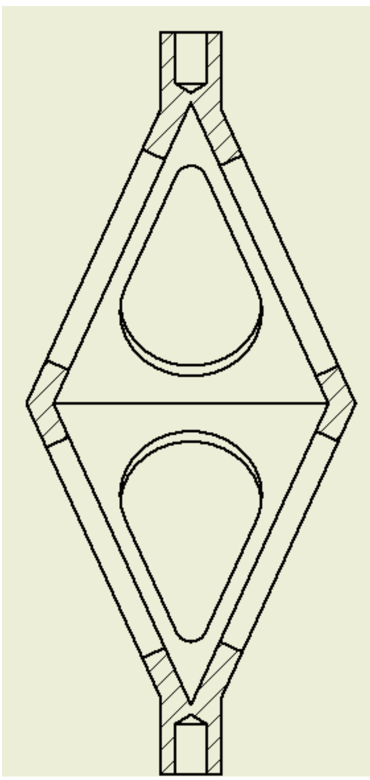

Figure 5. **Sectional View of Octahedron.**

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.

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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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