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**Effectiveness of Drafting Models for Engineering Technology Students and Impacts on Spatial Visualization Ability: An Analysis and Consideration of Critical Variables**

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**Abstract**

Results from a number of studies indicate that the use of drafting models can positively influence the spatial visualization ability for engineering technology students. However, additional variables such as light, temperature, motion and color can play an important role but research provides inconsistent results. Considering this, a set of 5 quasi-experimental studies, was conducted to identify additional critical variables. According to the results, a dynamic, 3D-printed drafting model, presented with a blue background under lighting conditions between 500–750 lux had the highest impact on spatial visualization ability of engineering technology students.

**Keywords:** drafting models, engineering technology, spatial ability, spatial visualization

A plethora of scientific works reference the demand for good spatial abilities in engineering, architecture, and almost every science career (Martín-Gutiérrez, Gil, Contero, & Saorín, 2013). Research suggests that spatial abilities are fundamental, not only in engineering and technical fields but in an estimated 80% of jobs overall. This includes but is not limited to those in medical professions, pilots, mechanics, builders, and tradespeople (Bannatyne, 2003). Although studies exploring the effects of spatial visualization for engineering technology students have been conducted (Allam, 2009; Ben-Chaim, Lappan, & Houang, 1988; Katsioloudis, Jones, & Jovanovic, 2016; Rodriguez & Rodriguez, 2016), the focus of this review was to conduct further analysis on studies using the Mental Cutting Test (MCT; College Entrance Examination Board, 1939; see also Tsutsumi, 2004).

This systematic review yielded a total of five studies that were conducted to investigate the impacts of drafting models on the effects of spatial visualization ability for engineering technology students. The data were analyzed to identify additional critical variables among the five studies. The findings seem to suggest that additional variables played an important role. Recent advances in systematic review procedures make it an ideal tool for research synthesis (Creswell, 2015). Review procedures allow opportunities for direct interference from empirical studies.

### Previous Studies

#### **Study 1: Use of Static vs. Dynamic Visualization to Create a Sectional-View Sketch**

The purpose of this study (Katsioloudis, Dickerson, Jovanovic, & Jones, 2015) was to determine significant positive effects among three different types of dynamic drafting models and to identify whether any individual type or combination contributed towards a positive increase of spatial visualization ability for students in engineering technology courses. “(Katsioloudis, Jovanovic, et al., 2015, pp. 4–5). 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” (p. 23).

**Research question and hypotheses.** The following research question guided this study:

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? (Katsioloudis et al., 2015, p. 14)

The following hypotheses were explored during the study:

H<sub>0</sub>: 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<sub>A</sub>: 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 of the presented object. (Katsioloudis et al., 2015, p. 14)

**Methodology.** “A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability during the Fall of 2015. The study was conducted in an engineering graphics course, MET 120 (Computer Aided Drafting)” “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” (Katsioloudis et al., 2015, p. 17).

**Results.** The study compared the difference between the type of visualization presented to engineering technology students (3D PC Ststic, 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 another. The results of this study confirmed what other researchers (Catrambone & Seay, 2002; Hasler, Kersten, & Sweller, 2007, Hegarty, Kriz, & Cate, 2003) have found when attempting to investigate the superiority of animation as compared to static visualization.

### **Study 2: Exploration of the Impact of Visual Cues on Dynamic Visualizations**

The purpose of this study (Katsioloudis, Jovanovic, & Jones, 2016) was 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. (p. 11)

**Research question and hypotheses.** The following research question guided this study:

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? (Katsioloudis, Jovanovic, et al., 2016, p. 1)

The following hypotheses were explored during this study:

H<sub>0</sub>: 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<sub>A</sub>: There is an identifiable 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. (Katsioloudis, Jovanovic, et al., 2016, pp. 1–2)

**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 Aided Drafting)” (Katsioloudis, Jovanovic, et al., 2016, pp. 4–5). Using a convenience sampling method,

The students attending the course during the Fall Semester of 2014 were divided into three groups. The three groups ( $n_1 = 24$ ,  $n_2 = 21$  and  $n_3 = 22$ , 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 ( $n_1$ ) received 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 . . . . The second group ( $n_2$ ) 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 . . . ; thus, it created a blue background around the visualization during the creation of the sectional view. The third group ( $n_3$ ) 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 . . . . 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 paper the three colors. No students were identified as color blind since everyone stated the correct colors. (Katsioloudis, Jovanovic, & Jones, 2016, pp. 5–6)

**Results.** Although “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” (Katsioloudis, Jovanovic, et al., 2016, p. 11). These findings are supported by previous research (Khooshabeh & Hegarty, 2008) exploring how color affects the performance of students with low spatial ability.

### **Study 3: Impact of Effective Temperature on Sectional-View Drawing**

The purpose of this study (Katsioloudis, 2017) was to determine significant positive effects related to sectional view drawing ability. In particular, the study compared the exposure of engineering technology and technology education students to three different kinds of treatments (different temperatures) and whether a significant difference exists towards sectional view drawing ability. (p. 20)

**Research questions and hypotheses.** The following research questions guided this study:

Does the difference of effective temperature have an effect on students' spatial visualization ability as measured by the MCT?

Does the difference of effective temperature have an effect on students' ability to sketch a sectional view drawing? (Katsioloudis, 2017, p. 17)

The following hypotheses were explored during this study:

H<sub>0</sub>: There is no significant effect on students' sketching ability as measured by the MCT due to a difference of effective temperature.

H<sub>1</sub>: There is no significant effect on students' spatial visualization ability due to a difference of effective temperature.

H<sub>01</sub>: There is significant effect on students' sketching ability as measured by the MCT due to a difference of effective temperature.

H<sub>02</sub>: There is significant effect on students' spatial visualization ability due to a difference of effective temperature. (p. 17)

**Methodology.** A quasi-experimental study was used as a means to perform the comparative analysis of sectional view drawing ability during the Spring of 2016. Using convenience sampling instead of random assignment of the population, made the author believe that a quasi-experimental study was the appropriate methodology to be used. The study compared three groups comprising engineering and technology education students exposed to three different effective temperatures in order to determine whether there is a significant difference in sectional view drawing ability. (Katsioloudis, 2017, p. 18)

Students attending the [engineering graphics] course during the Spring semester of 2016 were divided into three groups. The three groups ( $n_1 = 42$ ,  $n_2 = 39$  and  $n_3 = 44$ , with an overall population of  $N = 125$ ) had the same academic background related to engineering graphics coursework (freshman engineering technology and technology education students had to complete the same intro to engineering graphics course the previous semester) were presented with a 3D printed visual representation of an octagonal pyramid . . . and were asked to create a sectional view drawing of it. To generate the three distinct temperature environments, the 3D printed model used for all groups was submerged in water . . . . The independent variable in this study was the temperature of the water: 84.2°F, 93.2°F and 102.2°F for the cold,

warm, and hot treatments, respectively. Each group member received 60 seconds to “feel” the model in the water. Using only the sense of touch to receive mental data, each student had to create a sectional view of what they felt. (Katsioloudis, 2017, pp. 18–19)

**Results.** The null hypothesis that there is no significant effect on students’ spatial visualization ability, as measured by the MCT was accepted. However, the second null hypothesis that there is no effect on students’ ability to sketch a sectional view drawing due to the difference of effective temperature was rejected due to statistically significant evidence. Students that received treatment using warm water outperformed their peers who received treatment using cold and hot water temperatures, respectively. (Katsioloudis, 2017, p. 20)

#### **Study 4: The Use of Dynamic Visualizations for Engineering Technology, Industrial Technology, and Science Education Students to Create a Sectional-View Sketch**

The purpose of this study (Katsioloudis, Dickerson, Jovanovic, & Jones, 2016) was “to determine the existence of statistically significant differences between engineering technology, industrial technology, and science education students’ ability to correctly create a sectional-view sketch of the presented object” (p. 29).

**Research questions and hypotheses.** The following research question guided this study:

Is there a difference between engineering technology, industrial technology, and science education students’ ability to correctly create a sectional view sketch of the presented object? (Katsioloudis, Dickerson, et al., 2016, p. 20)

The following hypotheses were explored during this study:

H0: There is no difference between engineering technology, industrial technology, and science education students’ ability to correctly create a sectional-view sketch of the presented object.

HA: There is an identifiable difference between engineering technology, industrial technology, and science education students’ ability to correctly create a sectional-view sketch of the presented object. (Katsioloudis, Dickerson, et al., 2016, p. 20)

**Methodology.** A causal-comparative 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 . . .

required for engineering technology and industrial technology students. Three independent groups participated in this study: group one consisted of engineering technology students, group two consisted of industrial technology students, and group three consisted of science education students . . . . Students from each discipline were placed into 3 individual groups. Using a convenience sample, there was a near equal distribution of the participants between the three groups. (Katsioloudis, Dickerson, et al., 2016, p. 24)

The students attending the courses during the fall semester of 2014 were divided into three groups ( $n_1 = 23$ ,  $n_2 = 24$ , and  $n_3 = 27$ , with an overall population of  $N = 74$ ) and were presented with the same visual representation of an object (visualization) and were asked to create a sectional-view drawing. All groups received the same type of visualization (Dynamic 3D printed octahedron). (Katsioloudis, Dickerson, et al., 2016, p. 25)

All participants completed the MCT 2 days before “to identify the level of visual ability and show equality between the three groups” (Katsioloudis, Dickerson, et al., 2016, p. 25).

**Results.** “No differences were found between the sketching abilities of students who had engineering technology, industrial technology, or science education backgrounds” (Katsioloudis, Dickerson, et al., 2016, p. 29). Although this study did not yield significant results, it has furthered the research on factors impacting sketching and spatial visualization skills (e.g., Sorby, 1999).

#### **Study 5: Effects of Light Intensity**

The purpose of this study (Katsioloudis, Jones, & Jovanovic, in press) was to determine whether the different levels of light intensity, 250–500 lux, 500–750 lux, and 750–1,000 lux, significantly change the level of spatial visualization ability, as measured by the Mental Cutting Test, (MCT) and sectional drawings for engineering technology students.

**Research questions and hypotheses.** The following research question guided this study:

Will different levels of light intensity, significantly change the level of spatial visualization ability as measured by the Mental Cutting Test and sectional drawings for engineering technology students?

The following hypotheses were explored during this study:

H<sub>0</sub>: There is no effect on engineering technology students’: (a) Spatial

visualization ability as measured by the Mental Cutting Test and (b) ability to sketch a sectional view drawing, due to the different levels of light intensity: 250–500 lux, 500–750 lux, and 750–1,000 lux.

H<sub>A</sub>: There is an identifiable amount effect on engineering technology students': (a) Spatial visualization ability as measured by the Mental Cutting Test and (b) ability to sketch a sectional view drawing, due to the different levels of light intensity: 250–500 lux, 500–750 lux, and 750–1,000 lux.

**Methodology.** The three groups ( $n_1 = 38$ ,  $n_2 = 40$ , and  $n_3 = 41$ , with an overall population of  $N = 119$ ) were presented with a visual drafting model. All three groups ( $n_1$ ,  $n_2$ ,  $n_3$ ) received a 3D printed pentadecagon model, and were asked to create a sectional view sketch while the model was exposed into three different light intensities for each group (250–500 lux, 500–750 lux, and 750–1,000 lux), respectively. Since light was used as a part of the study treatment, and to prevent bias for students using glasses or contact lenses, all participants were exposed into several light intensities (varying from 250–1,000 lux) and were asked to report whether they could clearly see or not. All students were identified as having no difficulty seeing within the spectrum of the lighting conditions used in this experiment (Katsioloudis, Jones, & Jovanovic, in press).

**Results.** It was found that the different levels of light intensity provided statistically significant higher scores; therefore, the hypothesis that there is an identifiable amount of effect on engineering technology students': (a) Spatial visualization ability as measured by the MCT and (b) ability to sketch a sectional view drawing, due to the different levels of light intensity: 250–500 lux, 500–750 lux, and 750–1,000 lux, was accepted. Specifically, students whose model was exposed between 500–750 lux outperformed the other two groups (Katsioloudis, Jones, & Jovanovic, in press).

### Systematic Review

#### Methodology

A causal-comparative methodology was selected as a means to perform a systematic review of the data previously collected for each independent study. Specifically, all five studies described above used the MCT and scores received on sectional-view drawing to identify spatial visualization ability differences between pre- and post-treatment for each group respectively. The purpose of the current study was to identify whether the combination of treatments used for the five studies independently have any additional critical variables (see Figure 1).



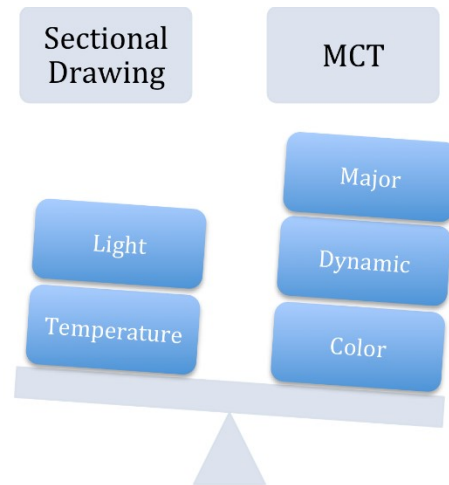


Figure 1. Meta-analysis diagram.

## Results

Data analysis involved the comparative analysis of the pre- and post-Mental Cutting Test (MCT), which was used to show equality and improvement of spatial ability between the five different study groups. The pretest results can be seen in Table 1: 23.432, 22.532, 23.450, 22.932, and 23.743, respectively. As far as the posttest, overall means were higher: 23.822, 23.532, 23.670, 24.014, and 23.839, respectively. No noticeable difference was seen for any of the groups that completed the treatment.

The second method of data collection in five studies involved the creation of a sectional-view drawing. As shown in Table 3, the average means for the five groups were 5.753, 4.932, 4.432, 4.213, 4.424, and 4.750, respectively. It was interesting to see that the average mean for the Study 1 group was 5.753, which was statistically significantly higher than the other four groups.

A one-way ANOVA was run to compare the mean scores of the graded sketches for significant differences among the five groups. The results of the ANOVA test, as shown in Table 3, were significant:  $F(0.530) = 0.039$ ,  $p < 0.05$ . The data were dissected further through the use of a post hoc Tukey's honest significant difference (HSD) test. As shown in Table 4, the post hoc analysis showed a statistically significant difference in two cases: the blue vs. temperature groups ( $p < 0.046$ ,  $d = .456$ ) and the 3D printed vs. temperature groups ( $p = .043$ ,  $d = .342$ ).

**Table 1**  
*MCT Pre- and Post-Test Descriptive Results*

Studies	N	Mean pretest	Mean posttest	SD	Std. error	95% confidence interval for mean	
						Lower bound	Upper bound
Study 1	54	23.432	23.822	2.422	0.424	23.452	23.804
Study 2	67	22.532	23.532	3.042	0.593	22.453	23.422
Study 3	125	23.450	23.670	3.524	0.522	23.529	23.602
Study 4	74	22.932	24.014	3.023	0.532	22.495	24.002
Study 5	119	23.743	23.839	2.927	0.345	23.485	23.726
Total	439	23.217	23.775	2.987	0.483	23.088	23.711

**Table 2**  
*Sectional-View Drawing Descriptive Results*

Studies	N	Mean	SD	Std. error	95% confidence interval for mean	
					Lower bound	Upper bound
Study 1	54	5.753*	1.542	.345	4.643	5.642
Study 2	67	4.932	1.422	.534	4.345	5.532
Study 3	125	4.432	1.432	.654	4.532	5.578
Study 4	74	4.213	1.568	.643	4.356	5.753
Study 5	119	4.424	1.534	.682	4.532	5.298
Total	439	4.750	2.691	.571	4.481	5.560

\* Denotes statistical significance.

**Table 3**  
*Sectional-View Drawing ANOVA Results*

Quiz	SS	df	MS	F	p
Between groups	1.642	2	0.603	0.530	0.039*
Within groups	243.428	98	2.501		
Total	252.521	100			

\* Denotes statistical significance.

**Table 4**  
Sectional-View Drawing Tukey HSD Results

Studies	Treatments	Mean Diff. (1-2)	Std. error	<i>p</i>
1 vs. 2	3D printed vs. blue	.264	.234	.125
1 vs. 3	3D printed vs. temperature	.342	.642	.043*
1 vs. 4	3D printed vs. major	.934	.753	.452
1 vs. 5	3D printed vs. light	.431	.425	.320
2 vs. 1	Blue vs. 3D printed	-.385	.643	.457
2 vs. 3	Blue vs. temperature	.0456	.643	.046*
2 vs. 4	Blue vs. major	-.643	.754	.346
2 vs. 5	Blue vs. light	.532	.345	.284
3 vs. 4	Temperature vs. major	.531	.942	.653
3 vs. 5	Temperature vs. light	.334	.233	.221
4 vs. 5	Major vs. light	.545	.234	.223

\* Denotes statistical significance.

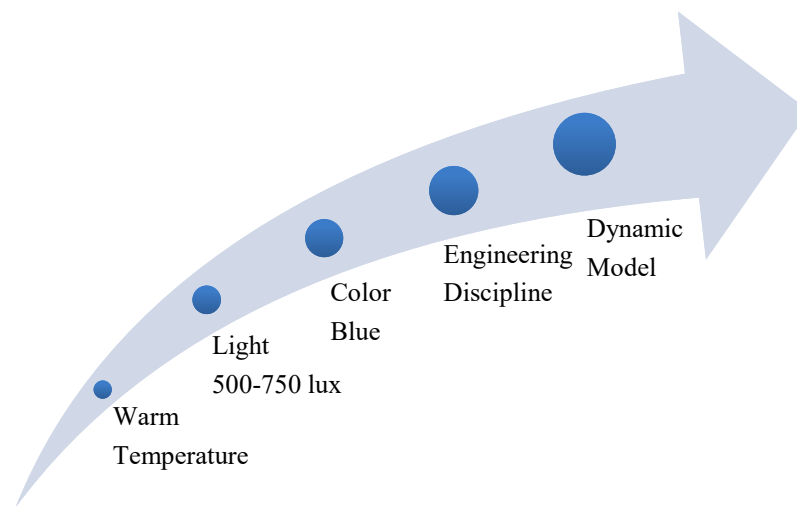
### Discussion

This study was done to determine significant positive effects related to sectional-view drawing ability. In particular, this review compared the results from five previously conducted studies in order to identify additional critical variables. All studies shared the same assessment tools: the MCT instrument and a sectional-view drawing.

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 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 (Katsioloudis, Jovanovic, & Jones, 2016, pp. 8–9).

The major results of the studies suggest that a dynamic 3D-printed drafting model presented with a blue background under lighting conditions between 500–750 lux positively impacted the spatial visualization ability of engineering

technology students (see Figure 2). As shown in Table 2, the students that participated in the temperature study were able to achieve a higher score in the sectional-view drawing, and when compared to the other five study groups, a  $p$ -value of .039,  $p < 0.05$  showed significant difference among the other means (see Table 3). Additional analysis, using the post hoc Tuckey test, showed that Studies 2 and 3 (blue vs. temperature), with a  $p$ -value of .046 ( $p < 0.05$ ), and Studies 1 and 3 (3D printed vs. blue), with a  $p$ -value of .043 ( $p < 0.05$ ), had the most significant differences among their respective means (see Table 4).



**Figure 2.** Diagram of effective spatial visualization drafting model based on a series of experimental studies.

The present results provide support for the hypothesis that when a dynamic 3D-printed drafting model is presented with a blue background under lighting conditions between 500–750 lux for Engineering Technology students, it positively impacts the spatial visualization ability of engineering technology students. This finding is consistent with previous research findings.

Focused on temperature, Filingeri, Redortier, Hodder, and Havenith (2015) “tried to identify whether the absence of humidity receptors in human skin (the sensitivity of skin wetness) is considered an output resulting from the integration of temperature (warm, hot cold) and mechanical inputs” (Katsioloudis, 2017, p. 20). Filingeri et al. found that “warm temperature stimuli have been shown to suppress the perception of skin wetness during initial contact with a wet surface” (p. 13).

This finding suggested that the temperature of warm water, versus hot and cold, allows the absence of skin wetness perception that could lead to a

more direct focus. Based on these findings, it can be assumed that the absence of the skin wetness perception could increase the amount of sensitivity data transferred to the brain that can then be translated into spatial visualization data. (Katsioloudis, 2017, p. 20)

In a study conducted by Sanger and Greenbowe (1997), the use of dynamic animations in a college chemistry class was investigated. The researchers first assessed students' conceptual understanding of salt bridges and electrochemical cells and found that many students held alternative conceptions of these topics. Computer-generated dynamic visualizations were then used as a part of the lecture to provide college general chemistry students with dynamic views of the chemical processes occurring in the salt bridge and electrolytes of an electrochemical cell system. The dynamic computer generated visualizations depicted current flow in the electro-chemical cell. According to Sanger and Greenbowe (1997), the percentage of students who held alternative conceptions after receiving the lecture using the dynamic computer generated visualizations versus those who received a no animation lecture were compared. It was observed that a significantly lower percentage of students who received the visualization-enhanced lecture showed alternative conceptions than did students who had not viewed the animations. In addition, Sanger and Greenbowe (1997) supported the theory that a detailed dynamic visualization presentation provided by computer animations helped most students overcome their alternative conceptions. The researchers indicated that the dynamic visualizations helped students visualize complicated chemical reaction processes and led them to change their alternative conceptions to scientifically more acceptable conceptions (Sanger & Greenbowe, 1997). (Katsioloudis, Dickerson, Jovanovic, & Jones, 2016. pp. 30–31)

In a study exploring the addition of blue color (Katsioloudis, Jovanovic, et al., 2016),

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. According to Khooshabeh and Hegarty (2008) it is suggested that color affects the performance of learners with low spatial ability more so than those with high spatial ability. (p. 11)

Related to the light intensity paper, it is suggested that a specific spectrum of light (500 lux up to 750 lux) could aid learning. Several studies suggested

positive correlation between lighting levels and oral reading fluency performance among middle schools students and learning in general (Mott, Robinson, Walden, Burnette, & Rutherford, 2012). The literature also supports that color and light intensity have positive effects on cognitive performance and that the level varies across different groups such as female or male students (Knez, 1995). According to Sanger and Greenbowe's (1997) study about the use of dynamic animations in a college chemistry class,

the percentage of students who held alternative conceptions after receiving the lecture using the dynamic computer-generated visualizations versus those who received a no animation lecture were compared. It was observed that a significantly lower percentage of students who received the visualization-enhanced lecture showed alternative conceptions than did students who had not viewed the animations. (Katsioloudis, Dickerson, et al., 2016, p. 30)

#### Future Plans

In order to have a more thorough understanding of spatial visualization ability and its implications for different professional disciplines and student learning, it is imperative to consider further research. Research in the area of spatial visualization could benefit from repeating the abovementioned studies included in this review by using additional types of drafting models. Although these studies focused on engineering technology students participating in engineering graphics coursework, additional studies exploring different student populations in the areas of mathematics and engineering education may offer additional insights into variables impacting spatial visualization.

Although the majority of participants were male students, additional research could be conducted exploring whether there are differences between male and female students. Further analysis exploring additional visual cues during the display of 3D objects, including shadows, construction lines, and size, could also provide additional feedback into the cause and effect of these spatial variables.

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