Effects of Light Reflection on Spatial Visualization Ability and implications for Engineering Technology Students

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Abstract

Results from a number of studies indicate that the type of light generated by the reflection on the surface of different types of surfaces can influence the spatial visualization ability; however, research provides inconsistent results. Considering this, a quasi-experimental study was conducted to identify the existence of statistically significant effects on spatial visualization ability as measured by the Mental Cutting Test and Sectional View drawing ability due to the impacts of light reflection. In particular, the study compared three types of light reflection; mirror, specular and diffuse and whether a significant difference exists among engineering technology students. According to the results of this study it is suggested that the type of light reflection provides statistically significant differences.

Introduction

In the natural world, the way we see objects is a consequence effect result of how the objects interact with the environment and its lighting. The world is illuminated by two types of light: Direct or Indirect. Direct light occurs from a specific light source (e.g. the sun, a lamp, overhead lighting), this is referred to as *local illumination*. When light is transmitted by bouncing off of other surfaces (e.g. a crack in a door, body of water) it is referred to as an indirect light source (Autodesk, 2015a).

When light waves strike an object it may be absorbed, reflected, or refracted. In our natural world light may also be transmitted by an object based on its transparency, color, and the material of which it is constructed (Autodesk, 2015). Absorption occurs when light stops at an object's surface appearing dark or opaque, it does not reflect or refract light. Reflection occurs when light bounces off of the surface and an equal angle as the incoming light waves (e.g. glass or mirrors). Refraction occurs when light bends at an angle and goes through an object (Autodesk, 2015b).

It is clear from the research presented in this paper that lighting on an object's surface plays a critical role in how an observer sees and mentally processes its properties. This study was designed specifically to determine the effects of light reflection on spatial visualization ability for engineering technology students as its measured by the Mental Cutting Test (MCT) and sectional view drawings.

Effects of Light Reflection in Learning

Reflection occurs when light bounces off of the surface of an object. Three types of reflection have been identified: mirror, specular, and diffuse (see Figure 1). Mirror reflec-

tion can be one of two types: concave or convex. Mirror reflection occurs in two distinct ways. First, concave mirrors (e.g. inside curve of a spoon), reflects in a straight line inward to a focal point with each light ray reflecting at the same angle as it hits the surface. Second, convex mirrors curve outwards (e.g. outside of a ball), and parallel rays of light strike the mirror and reflect outward giving a wider field of vision. (see Figure 2).

Specular reflection occurs when light reflects at the same angle as it hit the surface (e.g. smooth and shiny surfaces such as glass, water, or metal. Alternatively, diffuse reflection occurs when light hits an object with a rough surface and reflects the light in many different directions.

Light reflection in learning has an impact on the way a learner sees the object. Veiling reflection in particular is glare caused by reflection of light on a bright surface such as computer screens and whiteboards in a classroom setting. A study conducted by Fotios & Parnell (2009) suggests that veiling reflection causes a reduction in the contrast of character-to-background on computer screens and whiteboards which reduces legibility and in some cases causing contents to become completely unrecognizable.

Research conducted by Fleming, Dror, & Adelson (2003) indicate that people evaluate object characteristics more accurately under natural illumination rather than artificial light sources. Neuroimaging studies have supported the non-visual effects of light (time and intensity) on performance during cognitive tasks by regulating neu-
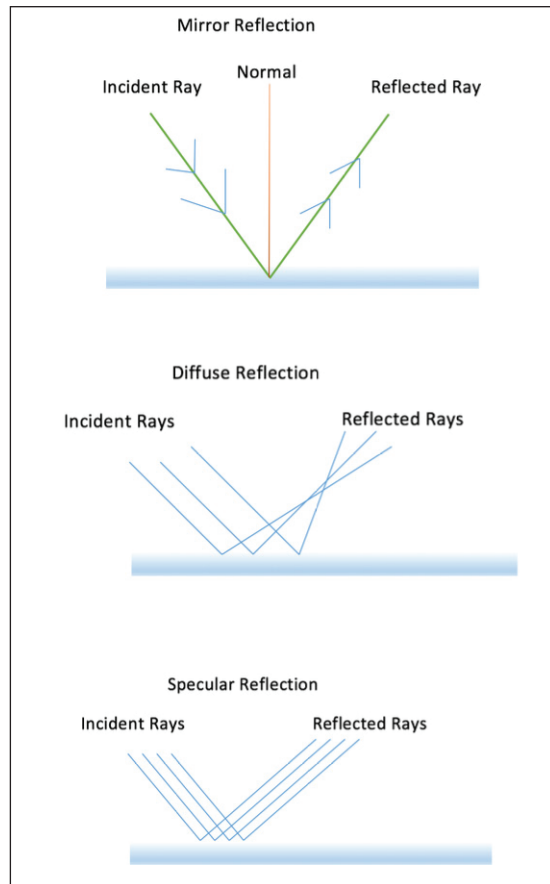

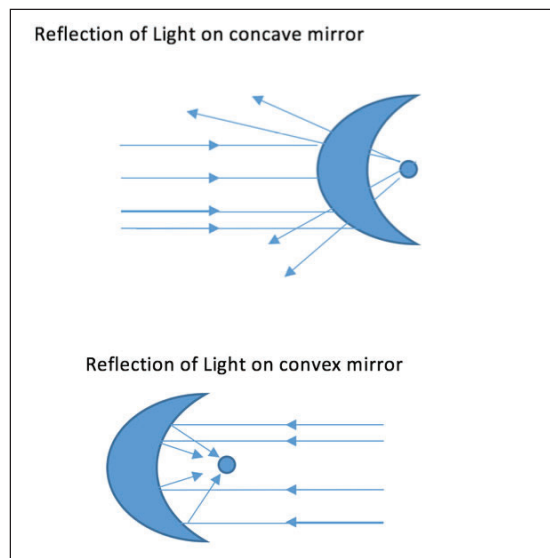**Figure 1. Three types of reflection.**

Figure 2. Mirror reflection.

ral activity (Vandewalle, Maquet, & Dijk, 2009). Furthermore, the non-visual effects of light on mood regulation and long-term memory has been confirmed by the activation of amygdala and hippocampal activation during tasks that are associated with these functions (Vandewalle, Balteau, Phillips, Degueldre, Moreau, Sterpenich, Albouy, Darsaud, Desseilles, Dang-Vu, Peigneux, Luxen, Dijk, & Maquet, 2006; Vandewalle, Gais, Schabus, Balteau, Carrier, Darsaud, Sterpenich, Albouy, Dijk, & Maquet, 2007).

Spatial Ability

Spatial ability may be described as a range of cognitive thinking skills which allow learners to relate within an environment (Hegarty & Waller, 2004). Spatial ability allows learners to shape and store mental representations of objects in order to mentally manipulate and rotate models (Carroll, 1993; Höffler, 2010). Höffler, 2010 also described this ability as independent from general intelligence. An historical perspective suggests that spatial ability has had a significant role in science including the discovery of DNA structure as well as Einstein's theory of relativity (Newcombe, 2010; von Károlyi, 2013).

Spatial skills performance is considered the gatekeeper to success in many STEM disciplines (Science, Technology, Engineer, Mathematics) (Bogue & Marra 2003; Contero, Company, Saorin, & Naya, 2006; Mohler, 2008; Sorby, 2009; Miller & Halpern, 2013; Sorby, Casey, Veurink, & Dulaney, 2013). Undergraduate engineering students in particular have numerous competencies required to achieve success in engineering programs. These essential and fundamental competencies are critical to the retention and success of students in all engineering programs. In fact, research suggests a positive correlation between spatial ability and completion of degree requirements for engineering technology students. (Brus, Zhoa & Jessop, 2004; Sorby, 2009; Mayer & Sims, 1994; Mayer, Mautone & Prothero, 2002). Furthermore, individuals with a higher level of spatial ability performance may have a broader array of strategies in spatial task problem solving (Gages, 1994; Orde, 1996; Pak, 2001; Lajoie, 2003).

Spatial Visualization

Spatial visualization is also referred to as "spatial ability" and the terms may often be used interchangeably (Braukmann, 1991). Spatial visualization of an object involves the cognitive manipulation of an object through a series of alterations (Ferguson, Ball, McDaniel, & Anderson, 2008). McGee (1979), defines spatial visualization as "the ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus object" (p. 893). Strong & Smith (2001) refer to 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).

The importance of enhancing spatial visualization ability has been a focus for engineering education researchers, industry representatives, and the U.S. Department of Labor who have all initiated a demand for a focus in these skills most specifically in engineer-

ing and technology students (Ferguson, et al., 2008). In addition, in the past twenty years conference proceedings and journal articles have reflected a fundamental focus on these skills in engineering education (Marunic & Glazar, 2013; Miller & Bertoline, 1991). As part of this initiative to improve spatial ability in students, many environmental factors have been considered with lighting being one of the lesser variables studied.

Spatial Ability and Light Reflection

The human eye contains cone cells and function to provide sharpness, detail, and color vision. Studies have shown that the amount and distribution of lighting has an impact on the level of performance in work and learning environments (Mott, Robinson, Walden, Burnette & Rutherford, 2011). Lighting in classroom environments has been found to be related to student learning in a variety of ways (Winterbottom & Wilkins, 2009). Although daylight is the preferred lighting situation, teachers prefer to have more control over lighting in classroom settings (Schreiber, 1996). As daylight changes throughout the day due to constant changes in the sun and weather, a more controlled lighting sequence may ensure a consistent environment throughout the day. (Ho, Chiang, Chou, Chang, & Lee, 2008).

The relationship of varying light directions and shadows plays a fundamental role for a learner to visualize and comprehend the characteristics of an object's shape and surface (Watteeuw, Hameeuw, Vandermeulen, Van der Peere, Boschloos, Delvaux, Proesmans, Van Bos & Van Gool, 2016). With the use of computers and other types of classroom mediums in engineering learning labs, it is important to consider light reflection and glare as a potential road block in spatial ability learning.

Research Question and Hypothesis

To enhance the body of knowledge related to light reflection for spatial visualization ability, the following study was conducted. The following was the primary research question:

> Will the different types of light reflection; mirror, specular and diffuse significantly change the level of spatial visualization ability; as measured by the MCT and sectional drawings, for engineering technology students?

The following hypotheses were be analyzed in an attempt to find a solution to the problem:

> H_0: There is no 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 types of light reflection; mirror, specular and diffuse.

> H_A: There is a significant 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 types of light reflection; mirror, specular and diffuse.

Methodology

A quasi-experimental study is an investigation that possesses all of the elements of a true experiment except that "subjects are not randomly assigned to groups" (Pedhazur & Pedhazur- Schmelkin, 1991, p. 277). In a quasi-experimental design, the researcher must identify and separate the effects of treatments from the effects of other factors which affect the dependent variable (Pedhazur & Pedhazur- Schmelkin, 1991). Quasi-experimental designs are used in natural settings with naturally occurring groups where the researcher has some control over the conditions of the experiment, and where full control is not desired or possible. (Hank & Wildemuth, 2017). The lack of control over the experiment due to the absence of random assignment is what sets quasi-experimental design apart from true experimental designs (Hank & Wildemuth, 2017). Campbell and Stanley (1963) describe quasi-experimental designs as those studies that are designed "where better design are not feasible" (p. 34). A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability during the spring semester of 2017.

Using a convenience sampling approach and lacking the element of random assignment to treatment or control the researchers felt that the quasi experimental design was the most appropriate one to use . The study was conducted in an Engineering Graphics course offered as part of the Engineering Technology program. The research design methodology is shown in Figure 3. Using a convenience sample, there was a near equal distribution of participants between the three groups.

The engineering graphics course emphasized hands-on practice using 3D Autodesk inventor 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.

The three groups ($n1$=39, $n2$= 35 and $n3$=38, with an overall population of N = 112) were presented with a visual representation of an object (visualization). All three groups ($n1,n2,n3$) received a different version of the same 3D printed model. The main difference was the finish quality of the surface (glossy, semi glossy and ruff), in order to represent the three different kinds of light reflection (mirror, specular and diffuse). Please see Figure 4. Since light reflection 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 the three different light reflections represented by different models and were asked to report whether they could clearly see or not. No students were identified as having difficulty seeing within the spectrum of the light reflections used in this experiment.
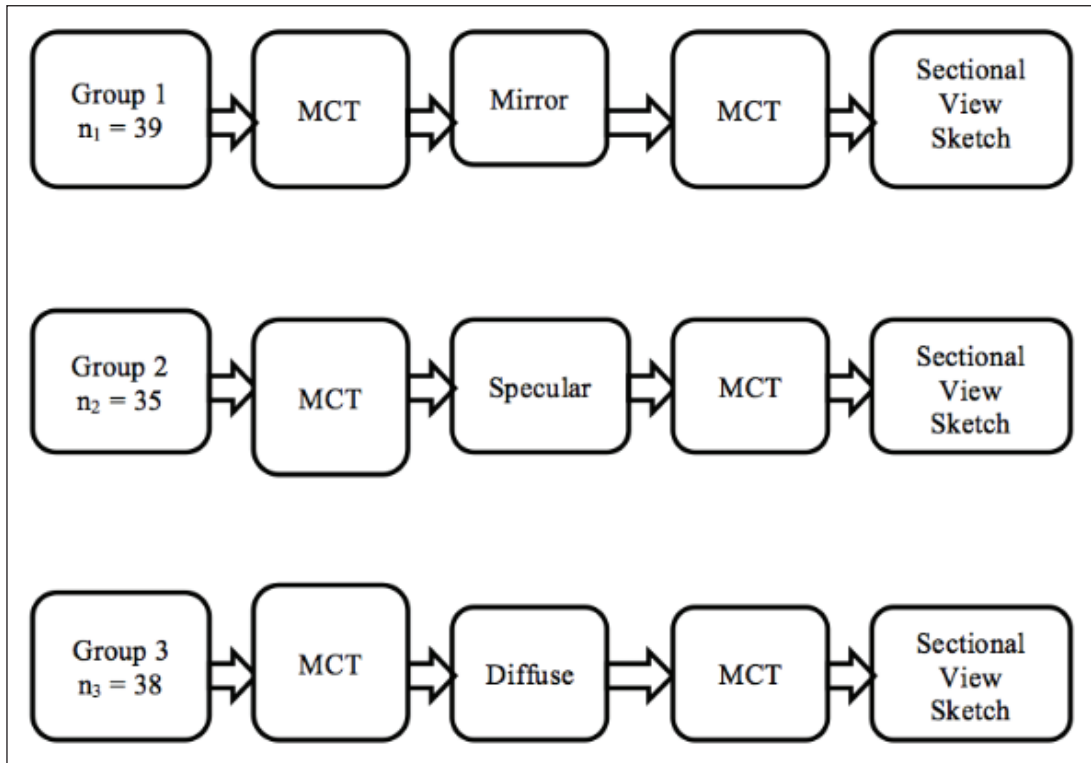
Figure 3. Research design methodology.

Figure 4. Three types of surface; glossy, semi glossy and ruff.

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

been used by Suzuki (2004) to measure spatial abilities in relation to graphics curricula (Tsutsumi, 2004).

As part of the MCT test, subjects were given a perspective drawing of a test solid, which was to be cut with a hypothetical cutting plane. Subjects were then asked to choose one correct cross section from among 5 alternatives. There were 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) (Tsutsumi, 2004).

The three groups were asked to create a sectional view of the pentagonal cylinder (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 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. This process takes into consideration that research indicates a learner's visualization ability and level of proficiency can easily be determined through sketching and drawing techniques (Contero, et al., 2006; Mohler, 1997). All students in all groups were able to approach the visualization and observe from a close range.

Figure 5. Sectional views of the pentagonal cylinder.

Data Analysis

Analysis of MCT Scores

The first method of data collection involved the completion of the MCT instru-

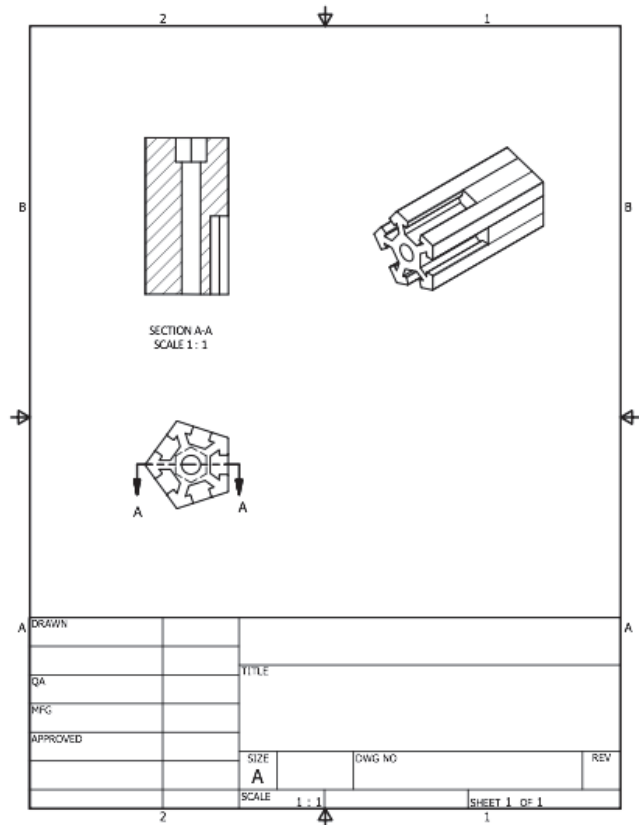ment prior to the treatment to show equality of spatial ability between the three different groups. The researchers graded the MCT instrument, as described in the guidelines by the MCT creators. A standard paper-pencil MCT pre and post were conducted, in which the subjects were instructed to draw intersecting lines on the surface of a test solid with a green pencil before selecting alternatives. The maximum score that could be received on the MCT was 25. As it can be seen in Table 1 for the pre-test, *n1* had a mean of 22.622, *n2* had a mean of 23.839, and *n3* had a mean of 23.983. As far as the post-test *n1* had a mean of 23.489, *n2* had a mean of 23.993, and *n3* had a mean of 24.180.

Due to the relatively low numbers of the participants and the fact that we did not have random samples, a non-parametric Kruskal-Wallis test was run to compare the mean scores for significant differences, as it relates to spatial skills among the three groups. The result of the Kruskal-Wallis test, as shown in Table 2, was not significant $X^2 = 1.102$, $p < 0.576$.

Table 1
MCT Descriptive Results

Light Reflection	*N*	*Mean pre-test*	*Mean post-test*	*SD pre-post*	*SE pre-post*	*95% Confidence Interval for Lower Bound pre-post*	*Mean Upper Bound pre-post*
Mirror	39	22.622	23.489	3.532	.693	22.428	23.497
Specular	35	23.839	23.993	3.142	.592	23.124	23.692
Diffuse	38	23.983	24.180	3.391	1.252	22.941	24.639
Total	112	23.814	23.887	4.050	2.537	22.831	23.942

Analysis of Drawing

The second method of data collection involved the creation of a sectional view sketch drawing. As shown in Table 3, the group that used the specular model (*n* = 35), had a mean observation score of 3.632. The groups that used the mirror model (*n* = 38) and the diffuse model (*n* = 39) had lower scores of 3.249 and 3.532, respectively (see Table. 3). A Kruskal-Wallis test was run to compare the mean scores for significant differences among the three groups. The result of the Kruskal-Wallis test, as shown in Table 4, was

Table 2
MCT pre and post-test Kruskal-Wallis H test Analysis

Light Reflection	*N*	*DF*	*Mean Rank*	*X^2*	*p-value*
Mirror	39	2	23.482	1.102	.576
Specular	35		23.289		
Diffuse	38		23.029		
Total	112				

significant: X^2= 1.502, p < 0.0029. The data was dissected further through the use of a post hoc *Steel-Dwass* test. As it can be seen in Table 5, the post hoc analysis shows a statistically significant difference between the mirror vs. specular model (p < 0.053, d = 0.190, Z=2.532) and the specular vs. diffuse model (p = 0.004, *d* = 0.381, Z=2.421).

Table 3
Sectional View Drawing Descriptive Results

Light Reflection	N	Mean	SD	Std. Error	95% Confidence Interval for Lower Bound	Upper Bound
Mirror	39	3.532	.395	.132	3.532	4.064
Specular	35	3.632	.405	.125	4.522	4.523
Diffuse	38	3.249	.459	.142	3.294	3.028
Total	112	3.633	.551	.218	3.782	3.871

Table 4
Sectional View Kruskal-Wallis H test Analysis

Light Reflection	N	DF	Mean Rank	X^2	p-value
Mirror	39	2	23.841	1.502	.0029*
Specular	35		23.342		
Diffuse	38		23.642		
Total	112				

* Denotes statistical significance

Table 5
Sectional View Drawing Steel-Dwass test Results

	Light Intensity (1 vs. 2 vs. 3)	Score Mean Diff.	Std. Error	Z	p-value
2 vs 1	Mirror vs. Specular	0.190	0.192	2.532	0.053*
2 vs 3	Specular vs. Diffuse	0.381	0.164	2.421	0.004*
3 vs 1	Diffuse vs. Mirror	0.301	0.184	1.422	0.510

* Denotes statistical significance

Discussion

This study was conducted to determine whether the different types of light reflection; mirror, specular and diffuse, significantly change the level of spatial visualization ability;

as measured by the MCT and sectional drawings, for engineering technology students. It was found that the different types of light reflection 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 reflection; mirror, specular and diffuse was accepted.

The fact that two of the groups gained statistically significant advantage when exposing the drafting model in different types of light reflection could suggest that important details on the drafting model can be hidden during light reflection conditions. Previous studies suggested a positive correlation between light reflection and intensity and oral reading fluency performance among middle schools students and learning in general (Mott, et al., 2012). The literature also supports that color and light intensity could positively effect on cognitive performance, and the level varies across different groups such as female or male students (Knez, 1995).

The effects of direct and indirect lighting as well as its reaction to an object (absorption, reflection, or refraction) have an impact on how one mentally processes the appearance of an object. Xiao & Brainard (2008) offered the hypothesis that an observer integrates luminance and chromaticity across an object as they synthesize the spatial average of light. However, data did not support this simple hypothesis rather the observer's visual scheme offsets for the physical effect of light (or gloss) so that the appearance of the object is supported in relation to what would be predicted. Furthermore, an object's composition (the material it is made up of) creates a wide range of optical properties (Fleming, Dror, & Adelson, 2003). Different materials will "reflect, transmit, refract, disperse, and polarize light to different extents and in different ways" (Fleming, et al., 2003, p. 347). This results in the reflectance properties of an object's surface becoming its most critical optical properties (Fleming, et al., 2003).

The results of this quasi experimental study suggest that light reflection conditions could affect learning in a positive way. More specific, a particular light reflection type (mirror) could enhance learning; however, this conclusion it is based only on the results of a small pilot study, therefore, additional studies need to be conducted in order to strengthen this conclusion.

Limitations and Future Plans

In order to have a more thorough understanding of the effects on spatial visualization ability and the effects of light reflection for models used by engineering technology students, it is imperative to consider further research. Future plans include, but are not limited to:

- Repeating the study using a larger population to verify the results

- Repeating the study using a different population such as mathematics education, science education, or technology education students
- Repeating the study by comparing male versus female students
- The short timeframe of treatment was not long enough to influence on spatial visualization or student's ability to create the rotational view

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