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Effects of Light Intensity on Spatial Visualization Ability

By Petros J. Katsioloudis and Mildred Jones

ABSTRACT

A plethora of technological advances have happened since artificial illumination was developed by Thomas Edison. Like technology has had an effect in many areas in the modern civilization it also made a difference in the classroom. Nowadays, students can have instruction in classrooms with no external windows, even during gloomy winter or rainy days, and virtually during any hour of the day. Several lightning devices are being used, ranging from energy efficient LEDs to fluorescent lighting. Some forms of lighting methods have been found to be inappropriate for prolonged exposure to the human eye such as various gas-discharge lamps that create poorer color rendering due to the yellow light. A large number of research studies have focused on topics such as the effect of light on intensity to oral reading proficiency, its effect on stress levels, and the effect it may have on autistic children. However, a small number of studies was found related to the optimal levels of light intensity related to successful student learning regarding spatial visualization ability. The purpose of the current study is to identify whether light intensity can increase or decrease spatial ability performance for engineering technology students.

Keywords: Light intensity, spatial visualization, engineering technology, technology education

INTRODUCTION AND BACKGROUND

Spatial abilities are essential to success in a variety of fields, including science, technology, engineering, and mathematics (Bogue & Marra 2003; Contero, Company, Saorin, & Naya, 2006; Miller & Halpern, 2013; Mohler, 1997; Sorby, 2009; Sorby, Casey, Veurink, & Dulaney, 2013). Spatial skills are not only fundamental in freshmen engineering coursework, but also they are critical to the success and retention of students in engineering and technology programs. Research suggests that there are positive correlations between spatial ability and retention and completion of engineering and technology degree requirements (Brus, Zhoa, & Jessop, 2004; Mayer, Mautone, & Prothero, 2002; Mayer & Sims, 1994; Sorby, 2009).

Hegarty and Waller (2004) described spatial ability as a collection of cognitive skills which permit the learner to adapt within their environment. Developed through spatial cognition, spatial ability can be explained as the ability to form and retain mental representations of a stimulus mental model, which is used to determine if mental manipulation is possible (Carroll, 1993; Höffler, 2010). This type of ability is also considered an individual ability independent of general intelligence. Literature review supports that individuals with higher spatial abilities have a wider range of strategies to solve spatial tasks and platforms (Gages, 1994; Lajoie, 2003; Orde, 1996; Pak, 2001).

Spatial visualization is often used interchangeably with "spatial ability" and "visualization" (Braukmann, 1991) and involves the mental modification of an object through a series of adjustments, and it is considered a key factor in the success of engineering students (Ferguson, Ball, McDaniel, & Anderson, 2008). According to McGee (1979), spatial visualization is defined as "the ability to mentally manipulate, rotate, twist or invert a pictorially presented stimulus object" (p. 893). In addition, Strong and Smith (2001) suggested a definition 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). Engineering and technology education researchers, industry representatives, and the U.S. Department of Labor have initiated a need for the enhancement in spatial visualization ability specifically in engineering and technology students (Ferguson, et al., 2008). An enhanced sense of urgency on spatial visualization as a fundamental focus in engineering and technology education has been reported in conference proceedings as well as journal articles over the past two decades (Marunic & Glazar, 2013; Miller & Bertoline, 1991).

Spatial thinking performance in higher education is considered to be the "gatekeeper" to entry and achievement in STEM (Science, Technology, Engineering, Mathematics) studies (Kell, Lubinski, Benbow & Steiger, 2013;

Uttal, Meadow, Tipton, Hand, Alden, Warren & Newcombe, 2013; Newcombe, 2010). Research has suggested that environmental factors may have an impact on spatial ability (Belz & Gear;1984; Harris, 1978; Mann, Sasanuma, Sakuma, & Masaki, 1990; Mohler, 1997; Tracy, 1990).

Light Intensity

Light intensity has always been important for human existence since it greatly influences sleep, alertness, melatonin and cortisol levels, blood pressure, pulse, respiration rates, brain activity and biorhythm (Wurtman, 1975). It is suggested that lighting enhances the overall performance in the workplace (assembly) as well as learning environments (Akbari, Dehghan, Azmoon, & Forouharmajd, 2013). Classroom lightning has been found to be related to student learning in various ways (Winterbottom & Wilkins, 2009). Light intensity is found to be very important for classroom settings for children with autism because their neural system responds in an unusual way to different light intensities and different light sources; especially bothersome is the fluorescent lighting (Menzinger & Jackson, 2009). Student discomfort in the classroom, such as headaches and impaired visual performance have been reported in classrooms with 100 Hz fluorescent lightning in studies that included a sample of 90 schools in United Kingdom (Winterbottom & Wilkins, 2009). In contrast, different negative effects, such as increased stress hormone level in children have been reported in situations where levels of lighting were lower than usual, as during winter months and in classrooms with no windows (Küller & Lindsten, 1992). Light influences melatonin production, and influences student learning (Boyce & Kennaway, 1987).

Teachers have reported that daylight is their preferred lighting setup and they prefer to have control over lights in the classroom (Schreiber, 1996). Although the optimal level of luminescence can be defined, it is hard for the teacher to always enable the optimal lighting condition throughout the day since he or she is focused on teaching and multiple activities, and the position of the sun and weather changes constantly throughout the day (Ho, Chiang, Chou, Chang, & Lee, 2008). For that purpose, building automation systems have developed to enable more efficient and environmentally friendly use of lighting systems in classrooms (Luansheng, Chunxia, Xiumei, & Chongxiao, 2012). Samani and Samani (2012) published a study to determine how learning settings in schools, universities, and colleges can be designed to provide an environment where lighting quality and students' learning performance can be enhanced through lighting intensity (Samani, 2012). According to Hygge and Knez (2001) and Knez (1995), light output and color temperature have an important effect on a person's visual perception, cognition, and mood state (Hygge & Knez, 2001). All of these areas fundamentally influence a person's visual strengths, especially spatial ability. LED lighting in particular offers color temperature flexibility and control over output, as well as a reduction in energy usage (Li, Lu, Wu, & Wang, 2015).

Light Intensity and Visuo-spatial ability

Several neuroimaging studies support the hypothesis of non-visual effects of light on performance by showing that different wavelengths and intensity of light exposure can modify the neural activity in cortical areas as well as in subcortical structures during cognitive tasks (Vandewalle, Maquet, & Dijk, (2009). Neuroimaging studies have also shown light-induced activity in both the prefrontal cortices and parietal lobes (Vandewalle et al., 2009), recognized to be involved in visuo-spatial abilities.

Technological lighting development over the last decade has created the need for more accurate and stringent analyses of their effects on human performance and health (Ferlazzo, Piccardi, Burattini, Barbalace, Giannini, & Bisegna, 2014). Work by (Hawes, Brunyé, Mahoney, Sullivan, & Aall, 2012) compared visual perceptual, affective and cognitive implications of four different luminous scenarios: one fluorescent lighting (3345 K) and three LED lighting (4175 K, 4448 K, 6029 K). Results showed a better performance of 24 volunteers on cognitive tasks with LED sources because reaction times resulted faster with the increase of CCT, and significant improvements were recorded with 4175 K in respect to 3345 K (Ferlazzo, et al., 2014).

Definition of light intensity

For the specific study light intensity is defined as the quantity of visible light that is emitted in unit time per unit solid angle on a specific drafting model. The unit of Lux was used for the study that represents illumination equal to the direct illumination on a surface that is everywhere one meter from a uniform point source of one candle intensity or equal to one lumen per square meter (Lux, 2017). The researcher is assuming that increase of light intensity will remote an increase of visual detail related the drafting model that it will then increase the amount of information transfer to the observer. Higher amount of visual information should allow the learner to better mentally visualize a sectional view of the drafting model.

RESEARCH QUESTION AND HYPOTHESIS

To enhance the body of knowledge related to light intensity for spatial visualization ability, the following study was conducted.

The following was the primary research question:

> *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 analyzed in an attempt to find a solution to the research question:

> H_0: *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 750-1000 Lux.*

> H_A: *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 750-1000 Lux.*

METHODOLOGY

A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability and lighting during the fall of 2016. Using a convenience sampling process the authors decided that a quasi-experimental method was appropriate for conducting the experiment. The research protocol was generated and submitted for approval to the College's Human Subjects Review Committee where it received exempt status. Using a convenience sample, there was a near equal distribution of participants among the three groups.

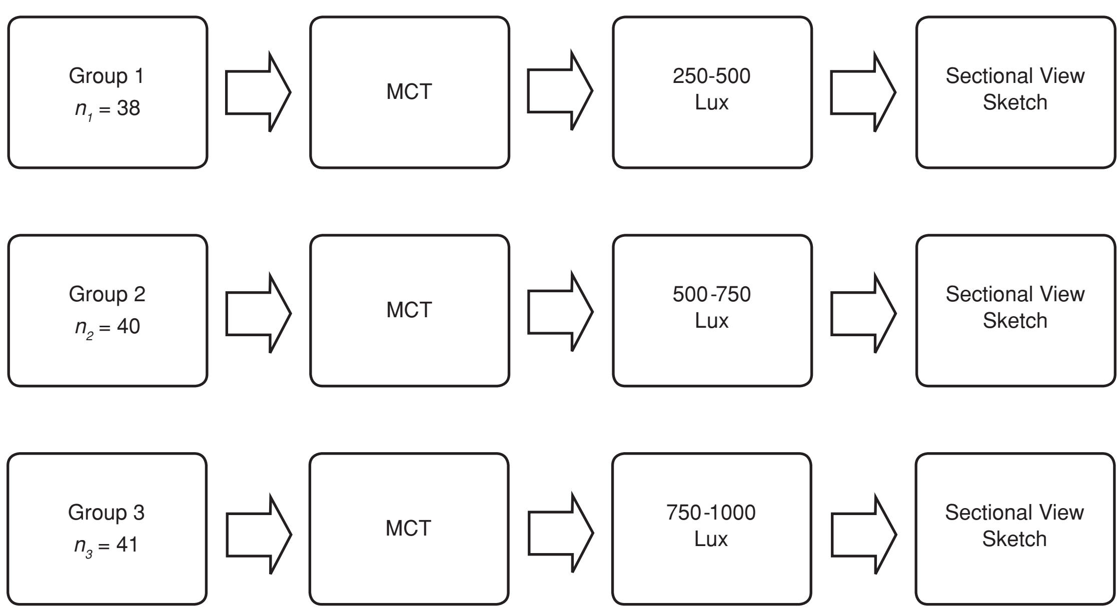

Figure 1: Research Design Methodology

The study was conducted in a 200-level Engineering Graphics course offered as part of the Engineering Technology program. The participants from the study are shown in Figure 1.

The engineering graphics course emphasized hands-on practice using 3-D Autodesk & AutoCAD software in a 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.

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 representation of an object (visualization). All three groups (n_1, n_2, n_3) received a 3-D printed pentadecagon (see Figure 2) model, and were asked to create a sectional view sketch (see Figure 3) while the model was exposed into three different light intensities for each group, (250-500 lux, 500-750 lux and 750-1000 lux), respectively (see Figure 4). 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 250-1000 lux), and they were asked to report whether they could see clearly or not. No students were identified as having difficulty seeing within the spectrum of the lighting conditions used in this experiment.

To establish a baseline and identify spatial visualization ability level, all groups were asked to complete the Mental Cutting Test (MCT) (College Entrance Examination Board [CEEB], 1939) instrument, two days prior to the completion of the sectional view. 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 and Hoffman (2006), the MCT (CEEB, 1939) has been widely used in all age groups, making it a good choice for a well-rounded visual ability test. Compared to other spatial tests measuring spatial visualization ability, the MCT problems are solved by looking at a visually presented stimuli and subjects have to mentally produce solutions (Quaiser-Pohl, 2003). In addition, the fact that there is no visually presented stimuli, the problems also cannot be solved by just reasoning, which it makes MCT an appropriate instrument to be used for this study.

The Standard MCT consists of 25 problems. The Mental Cutting Test is a subset 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.

According to Quasier-Pohl (2003), for the MCT test, subjects have to mentally cut three-dimensional geometrical figures (e.g., pyramids, cones) that are hollow. Examples include a sphere that after the cut it results into a circular

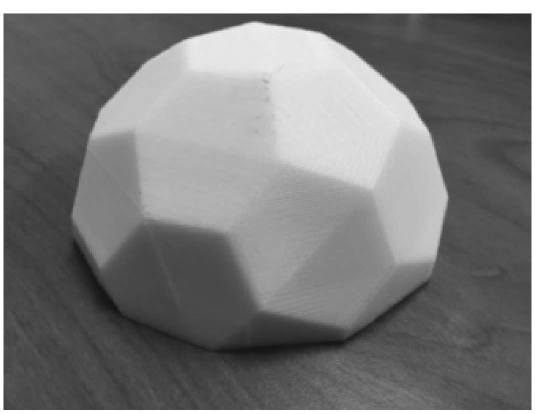

Figure 2: The model for all groups was a 3D printed pentadecagon

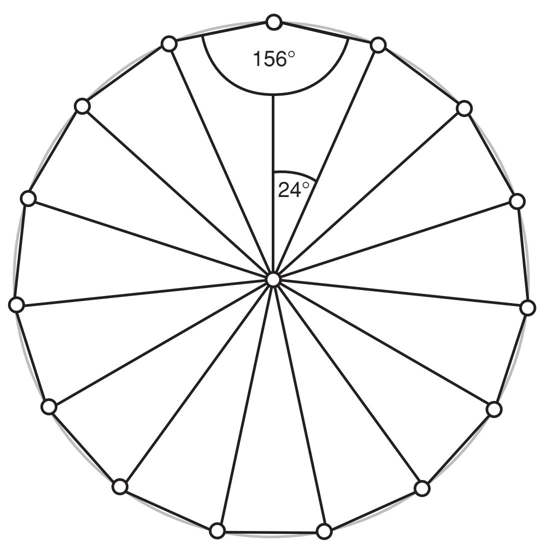

Figure 3: Sectional views of the pentadecagon 3D printed model (Németh, 2013)

Figure 4: Photometer used to measure ambient light for the three treatments

shape. More complex forms could also be used that result from cutting more complex geometrical shapes such as the pentadecagon used in this study (Quaiser-Pohl, 2003). For the specific study, the researcher considered student experiences as they related to academic background (engineering technology students that have completed the first 100-level engineering graphics course and were enrolled in the 200 level). Additional external student abilities or experiences were not considered for the specific study because the author believed this could be addressed at a different study in the future.

Subjects were then asked to choose one correct cross section from among five 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 problem*s, 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).

Upon completion of the MCT, the instructor of the course placed identical models of the dynamic 3-D pentadecagon for groups n_1, n_2 and n_3 in a central location in three different classrooms. The three groups were asked to create a sectional view of the pentadecagon (see Figure 3). 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 of 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: (a) use of section view labels, (b) use of correct hatching style for cut materials, (c) accurate indication of cutting plane (d) appropriate use of cutting plane lines, and € 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 it from a close range.

DATA AND ANALYSIS

Analysis of MCT Scores

The first method of data collection involved the completion of the MCT instrument prior to the treatment to determine equality of spatial ability between the three different groups. The researchers scored 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 the group scores were very close with no significant difference.

Due to the abnormality of the population (convenience sample), 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 $X^2 = 1.012$, $p < 0.230$. Data were tested for equality of variances using Levene's test. Levene's test indicated equal variances ($F = 2.28$, $p = .234$); therefore, degrees of freedom did not have to be adjusted.

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 worked in 500-750 Lux lighting conditions ($n = 40$), had a mean observation score of 3.944. The groups that were exposed to 250-500 Lux ($n = 38$) and 750-1000 Lux ($n = 41$) had lower scores of 3.924 and 3.032, 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 significant: $X^2 = 1.432$, $p < 0.0036$. Data were 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 550 vs. 750 Lux ($p < 0.057$, $d = 0.203$, $Z = 2.8234$) and the 750 vs. 1000 Lux ($p = 0.002$, $d = 0.394$, $Z = 2.4242$).

TABLE 1: MCT Descriptive Results

Light Intensity [Lux]	*N*	*Mean pre-test*	*Mean post-test*	*SD pre-post*	*SE pre-post*	*95% Confidence Interval for Mean Lower Bound pre-post*	*95% Confidence Interval for Mean Upper Bound pre-post*
250-500	38	23.839	24.845	3.374	.893	22.849	23.945
500-750	40	22.947	23.983	3.938	.683	23.209	23.034
750-100	41	22.833	24.093	4.839	1.892	22.908	23.039
Total	119	23.206	24.307	4.050	1.156	22.988	23.339

TABLE 2: MCT pre and post-test Kruskal-Wallis H test Analysis

Light Intensity [Lux]	*N*	*DF*	*Mean Rank*	*X^2*	*p-value*
250-500	38	2	22.529	1.012	0.230
500-750	40		23.932		
750-100	41		24.031		
Total	119				

TABLE 3: Sectional View Drawing Descriptive Results

Light Intensity [Lux]	N	Mean	SD	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound
250-500	38	3.924	0.692	0.1203	3.928	4.028
500-750	40	3.944	0.502	0.1424	4.392	4.422
750-100	41	3.032	0.532	0.1392	3.782	3.028
Total	119	3.633	0.575	0.1399	3.824	3.826

TABLE 4: Sectional View Kruskal-Wallis H test Analysis

Light Intensity [Lux]	N	DF	Mean Rank	X^2	p-value
250-500	38	2	22.92	1.432	0.0036*
500-750	40		23.78		
750-100	41		23.998		
Total	119				

* 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	550 vs. 750 Lux	0.203	0.1673	2.8324	0.057*
2 vs 3	750 vs. 1000 Lux	0.394	0.1725	2.4242	0.002*
3 vs 1	1000 vs. 250 Lux	0.183	0.1783	1.3247	0.310

DISCUSSION

This study was done to determine whether the different levels of light intensity, 250-500 lux, 500-750 lux and 750-1000 lux, 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 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 750-100 Lux, was accepted.

The fact that two of the groups gained a statistically significant advantage when exposing the drafting model in different levels of light intensity could suggest that important details on the drafting model can be hidden during lower light conditions. Previous 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). In addition, a review of literature supports that color and light intensity have positive effect on cognitive performance, and the level varies across different groups such as female or male students (Knez, 1995).

The results of this pilot quasi-experimental study suggest that lighting conditions affect learning in different ways. It is suggested that if a specific spectrum of light (250 Lux up to 1000 Lux) could aid learning, the following question arises: Since specific lighting conditions seem to promote and enhance learning abilities, why are these not offered at all schools? Löfberg (1970) states that adequate lighting level might be hard to obtain since many schools and universities are focusing on cost savings and more environmentally friendly use of electrical energy. Some schools in different countries are limiting time that the artificial light is used in the classroom due to the energy cost (Ho et al., 2008). Moreover, the problem of adequate lighting setup is also related to many variables, such as classroom location, classroom shape, direction of light at different points, distribution of luminance in the student's field of vision, and so on (Löfberg, 1970). The cost of energy is especially important in warmer climates and it affects the choice of lighting schemes along with sun shades, both of which are found to be optimal for the classroom (Ho et al., 2008).

Limitations and Future Plans

In order to have a more thorough understanding of the effects on spatial visualization ability and light intensity for engineering technology students, it is important 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.

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