

EXAMINING STUDENT BEHAVIOR UNDER TWO CORRELATED COLOR TEMPERATURE LEVELS OF LIGHTING IN AN ELEMENTARY SCHOOL CLASSROOM

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ABSTRACT

Numerous studies suggest a correlation between a school's physical environment and children's academic success. A variable within the classroom environment that has received little attention in the literature is the interior lighting. It is known that higher levels of correlated color temperature (CCT) lighting influence worker productivity in a workplace or laboratory setting. The CCT is the color of light emitted from a light source ranging from low (red) to high (blue). It is therefore necessary to uncover if a higher CCT level of lighting compared to the typically specified lower CCT level of lighting would influence student productivity and academic success in a classroom environment. This is a mixed method within-subjects case study designed to observe student behaviors as a way to gauge student productivity and academic success. Two different CCT levels of fluorescent lighting, which is the standard lighting fixture in most American public school classrooms, were installed in an existing second grade classroom using an ABAB study design. The study utilized both behavior mapping techniques to record student physical locations in the room and a time sampling non-participate observation technique to record on-task behaviors of the students for a duration of 5 months. The findings on the relation between the CCT of the lighting fixtures and student on-task behavior in an elementary classroom concluded that the higher CCT of the lighting the more student on-task behaviors were ($p = .038$) even while more male students physically moved around the classroom. This study has practical implications to facility managers and school officials interested in bettering classroom physical environments to advance student academic success.

INTRODUCTION

The physical variables within a classroom environment have a direct influence on student academic success and development (Duran-Narucki, 2008; Evans, 2006; Uline, 2008). Studies have examined various classroom variables including room size and color (Moore & Lackney, 1993), indoor air quality (Ferreira & Cardoso, 2014), noise levels (Maxwell & Evans, 2000), and room temperature (Theodosiou & Ordoumpozanis, 2008). Possible links between the classroom's electrical lighting and student behavior have received little attention in the empirical literature, specifically with younger students (Sleegers, Moolenaar, Galetzka, Pruyn, Sarroukh, & Zande, 2012).

Past interior lighting studies have focused on the occupant's visual acuity and productivity within a workplace or laboratory setting (DeKort & Veitch, 2014). The association between child development, cognition, and lighting in the interior environment is unclear (Mahdjoubi & Akplotski, 2012). This is of concern for children since they process and respond to stimuli differently than do adults because of their smaller physical size (Evans, 2006). Since it is known that interior lighting influences worker productivity in the workplace it is hypothesized that the interior lighting would influence student productivity in a school classroom environment. Productivity is displayed as on-task behaviors in young children. Children ages 2-7 are in the preoperational developmental stage and have yet to develop appropriate cognitive abilities to

complete a standardized academic test (Piaget, 1964). A way to gauge productivity and learning for this developmental stage is to observe students engaged with the academic material which is displayed through on-task behaviors leading to more academically successful students (Fisher, Godwin, & Seltman, 2014)

Previous interior lighting studies show that lighting quality contribute toward cognition and worker productivity in the workplace (Knez, 2014; Kretschmer, Schmidt, & Griefahn, 2012). Good light quality is achieved with the correct illumination level, correlated color temperature, and color rendering index (Barkmann, Wessolowski, & Schulte-Markwort, 2012). Illuminance is used to specify lighting levels for commercial facilities depending on facility use (IES, 2011). The correlated color temperature is the color of light emitted from the lamp and the color rendering index is the color appearance of an object under a light source relative to natural light (Veitch & McColl, 2010).

These qualities of light influence cognitive performance. They also affect how humans perceive the ambience and impression of the environment, their alertness, the quality of the atmosphere, and their productivity (Heerwagen, 2010; IES, 2014). These human actions are in response to a stimulus. In this situation, the interior light travels through the eyes to the brain via the optic nerve. Light enters the part of the brain that controls stimuli and transfers that into human behavior. Some behavior takes place without conscious awareness resulting in subliminal perception influenced by the interior lighting (Knez, 2014).

Previous studies with adults suggest that subliminal perception from interior lighting can influence subjects on biological, hormonal, and psychological levels. On a psychological level, humans perceive a room as brighter and more pleasant with higher CCT levels of lighting (Boyce, 2004; Wei et al., 2014). Higher levels of CCT lighting in a room also subliminally influence human heart rate (Schlangen, 2010), autonomic nerve tone, hormonal secretion and motor function (Yasukouchi & Ishibashi, 2005). These actions occur from an increase in brain activity as a response to non-visual short wavelengths present in lighting with high CCT levels (Keis et al., 2014). Thus, it is important that classroom lighting has the appropriate CCT level to promote student well-being and behavior in order to promote academic success, however, architectural codes and standards currently do not specify a CCT level for classroom lighting (IES, 2014). Most public school classrooms across the United States have fluorescent lighting fixtures installed with a low CCT level around 3000K. Fluorescent fixtures are specified because of their low price point and energy efficiency yet good color rendering abilities (Knez, 2014). With budget constraints and half of American school buildings over the age of forty years (Evans, Yoo, & Sipple, 2010; Uline, 2008), replacing or changing the fluorescent lighting fixtures with new technologies will most likely not occur. Thus, it is necessary to uncover if the typically installed low CCT level of fluorescent lighting compared to a higher CCT of fluorescent lighting influences student on-task behavior in a classroom setting.

PURPOSE OF THE STUDY

We reasoned that students would display more on-task behaviors in a classroom lit with a high CCT level of lighting that resembles natural daylighting based upon the literature review. Due to findings indicating that CCT levels above 4100K and below 3000K are not typically specified in commercial built environments (IES, 2011) and to keep the illumination levels similar between the two lighting conditions, these two standard CCT levels of fluorescent lamps were included. An ABAB within subject research design was employed as a field investigation in an existing elementary classroom environment. The purpose of this case study was to examine if a high CCT level as compared to low CCT level of fluorescent lighting in an existing elementary school classroom setting influenced student on-task behavior.

METHODOLOGY

Research Participants

A total of 27 students, 16 males and 11 females, participated in the study. Ages were between 7 and 8 years old. No student in the class was visually overweight, unhealthy, or had any visually recognizable physical disability. Throughout the course of the study two students, one male and one female, started to wear eyeglasses. No other student had any visual eye constraints.

Setting

This study took place in a second grade classroom in a K-5th grade public school in the Pacific Northwest that implements the Common Core State Standards. According to the 2013-2014 Report Card, the student academic abilities scored a 94% rating at this school compared to public elementary schools in the nation. Fifteen percent of the school population is economically disadvantaged and 8% of the school population have disabilities (ODOE, 2014).

The classroom had 15 troffer light fixtures lamped with two T8 lamps (Figure 1) installed in an 2'-0 x 4'-0" acoustical tile ceiling system. The overall classroom size was approximately 990 square feet and the ceiling height was 8'-0". The classroom had a 12'-0" wide x 3'-0" high window and standard metal door located on the north wall. The light reflectance values, or how much light is reflected by a surface, of the walls were 70% according to matching a Sherwin Williams paint sample to the wall color. The estimated light reflectance value of the flooring was around 60%.

The classroom furniture layout is shown in Figure 1. Four children sat at one of six tables in the center of the room, labeled 1-6. Three children sat at the remainder table labeled "A". The researcher sat at the table labeled "X". The teacher's desk is labeled "T" and the table shaped like a jellybean is labeled "B". The number of and gender of the children were recorded at each table since children relocate periodically.

Procedure

The study used non-participant group observations of student behavior through recording both on-task behaviors and behavior mapping techniques. The researcher recorded on-task table group behavior using a time-interval sampling method and behavior mapping. These two data collection recording methods were used on alternate days during data collection. Data collection was from 8:40 am to 10:00 am then from 10:20 am to 11:20 am and 12:15 pm to 1:30 pm, which followed the school's daily academic schedule.

On-task behavior method

Non-participant observations of student on-task behavior recorded data every 5 seconds for 5 minute intervals for a total of approximately 90 minutes per day. The observation data were recorded using a laptop onto the pre-developed observation data sheet. On-task behavior scored '1' if three of the four students at that table were actively engaged in the class activity. Off-task behavior was scored as a '3' if three of the four students at the table were engaged in any activity not related to the task at hand given by the teacher. If two of the students were on-task and two students were off-task, the on-task behavior score was scored as '2'. At the end of the 5-minute observational round, all of the on-task behavior scores were averaged together to result in a single score to reflect the average score of the whole class. A total of 355 scores were collected.

Behavior was only recorded while students were located at the tables. Observation order of tables was randomly selected using a random number generator. Data collection occurred over a five-month period. On-task behavior was recorded for 14.58 hours for Lamp A and 14.33 hours for Lamp B for a total of 28.91 hours.

Behavior mapping method

The student and teacher classroom location in the room were recorded every minute for 15 minutes with location markers on the floorplan. After the first student was observed, another

student was observed in the same manner. A total of fifty-eight observations were completed under Lamp A of which 31 were male students and 25 female students. Gender was not recorded for two observations due to researcher oversight. A total of fifty-nine observations were completed under Lamp B of which thirty-eight were male students and 19 were female students while gender was not documented for two of the observations due to researcher oversight.

Protocol

Upon university IRB approval, a Parent Notification letter was sent home with all students a week prior to the start of this study. No parents objected to the study. The control lamp, Lamp A (Philips F32T8/TL830/ALTO), which has a CCT of 3000K was installed first. After a two-week adjustment period, data collection followed for two weeks. At the end of the observation period the lamps were changed to Lamp B (Philips F32T8/TL841/ALTO) which has a CCT of 4100K. Another two-week adjustment period occurred and then data were collected for the following two weeks. The lamps were changed back to the CCT of 3000K and this pattern continue for the duration of the study.

At the start of the study, new lamps and ballasts (Phillips Advance ICN2P32N351) were installed. The illumination level, temperature, minimum and maximum noise level, and relative humidity were recorded with an Extech Industries 5 in 1 Environmental Meter Model EN300 at pre-determined intervals during all observation periods. The illumination levels at each table were recorded twice each day. Average illumination at desk height for Lamp A was 711 lux and Lamp B was 715 lux. To control for outside variables, the window blinds were turned horizontal and the back corner lights were turned off.

The variables of type of work, scholastic subject, time of day, and day of week were recorded for their contributing relationship, either independently or with CCT, towards on-task behavior. Type of work was the academic activity and categorized as active listening, independent desk work, group work, or the transition between the task. Active listening was scored when the student was engaged with the speaker by either looking at the speaker, reading along, or answering questions. Independent desk work included when the student was engaged in an activity individually while seated at their table. Group work was defined as two or more students engaged with the academic activity while transition included the change between academic activities. Scholastic subject includes the academic subject area such as math, reading, writing, art, or spelling. Time of day refers to the hour and day of week was either Monday, Tuesday, Wednesday, Thursday, or Friday.

Analysis

On-task behavior

All data were imported into IBM statistical package SPSS and analyzed. Hypothesis testing was carried out using a paired-samples t-test to determine whether there was a statistically significant mean difference between student on-task behavior scores under the classroom lit with 3000K CCT compared to the same classroom lit with 4100K CCT lighting. Graphs and boxplots were created to visually analyze the data based upon the multiple variables. Correlations between CCT, on-task behavior average scores, type of work, time of day, scholastic subject, and day of week found independent or interacting relationships. Multiple linear regression on the variables with correlations found power of relationships.

Behavior mapping

Student movement throughout the classroom was documented on separate floorplans. Each documented floorplan was overlaid over the original floorplan to compare where student and teacher movement occurred. The frequency floorplans were created from the results of the initial floorplan. Each student in each location was given a 1-foot diameter circle and coded by gender. If multiple students were located within the same area, the size of the circle increased to include their 1-foot diameter circle in order to graphically show the gender and number of students in each

location. The overall frequency plans combined all students regardless of gender into frequency circles based upon each student having a 1-foot diameter circle representation. Only areas with 3 or more students were recorded to find the most populated areas within the room.

RESULTS

On-task Behavior

The result of a paired-samples t-test indicated that students had more on-task behavior under the classroom lighting of 4100K CCT as compared to the lighting of 3000K CCT ($M = .033$, 95% CI [.002, .065], $t(154) = 2.103$, $p < .05$). Descriptive data on all of the variables are included in Table 1. The interacting effect of the CCT and on-task behavior is included in the matrix to see the zero-order intercorrelations among all of the data. As can be seen in Table 1, significant correlations occur between on-task behavior and scholastic subject as well as between scholastic subject and type of work. To control for effect, on-task behavior x CCT interaction was used.

To test correlations, we used multiple linear regression on all relationships with and without CCT to all on-task behavior scores, scholastic subject, day of the week, and type of work. On-task behavior, scholastic subject, and type of work are statistically significant on predicting on-task behavior with and without CCT ($adj. R^2 = .025$, $F(3, 335) = 3.933$, $p < .01$). See Table 2.

To further examine effect of CCT on the interior variables, multiple linear regression was performed on all variables independently to compare the two lighting conditions. Table 3 indicates that scholastic subject is statistically significant at predicting on-task behavior in the 4100K CCT ($F(5, 156) = 9.242$, $p < .001$, $adj. R^2 = .204$) as well as the 3000K CCT ($F(5, 171) = 2.645$, $p < .05$, $adj. R^2 = .045$). Table 4 also shows that time of day and type of work are statically significant to on-task behavior under the 4100K CCT lighting condition ($F(2, 131) = 6.224$, $p < .003$, $adj. R^2 = .073$).

Further investigation into time of day reveals that student on-task behavior starts at approximately the same in the morning hours but varies throughout the day between lighting situations as depicted in the line graph of time of day (Figure 2). Two peaks in off-task behavior occur at 9:50 am and 11:20 am under the CCT of 3000K, which is immediately before both breaks. A spike in on-task behavior occurs at 12:15 pm under the 4100K, when the students return from lunch break yet this did not happen when they came back from their morning break at 10:20 am. More variation between on-task behaviors are present under the 4100K CCT with the most on-task behaviors occurring at 1:15 pm, directly after the most off-task behaviors. Larger variations occur at the end of the day in the CCT of 4100K opposed to the CCT of 3000K.

Behavior Mapping

The floorplans indicate that students frequented the water fountain and cubbies equally under each CCT lamp. Students gather around the teacher's desk more under the 4100K CCT as well as the jellybean table, whereas students moved in between tables while under the 3000K CCT. More students gathering on the carpet and at the teacher's desk in the 4100K CCT than the 3000K CCT. The gender frequencies (Figure 3) reveal that more male students moved around the room under the 4100K CCT, and were at the jellybean table as well as the teacher's desk more than the 3000K CCT. More students, mostly female, stopped around and between the tables under 3000K CCT than 4100K CCT. Figure 4 shows the overall locations in the rooms that were most frequented by the student regardless of gender.

DISCUSSION

This study makes a valuable contribution to the empirical literature on the classroom physical environment and student on-task behavior. The findings on the relation between the correlated color temperature of the lighting fixtures and student on-task behavior in an elementary classroom conclude that the higher CCT of the lighting does influence more student on-task behaviors ($p = .038$). However, multiple variables and combinations of variables are present that contribute towards student behavior as shown in Tables 1 and Table 2.

The results of this study concur with other lighting studies that indicate lighting as an

unconscious stimulus (Knez, 2014). The lighting enters the brain through the eyes and is then transferred into a change in the occupant's behavior due to unconsciously perceived stimuli (Merikle, Smilek, & Eastwood, 2001). Results indicate that students' behavior changed under the different CCT levels the lighting. One factor that may contribute to this behavior change is the different frequency rates between the two lamp types. Even though frequency rates are not visible to the human eye, some special populations still feel the effects (Knez, 2014; Veitch & McColl, 2010). Occupants sensitive to flicker from fluorescent lighting feel more stressed when under lower frequency lamps (Knez, 2014) thus influencing performance. Since lamps with a higher CCT have higher frequency (Veitch & McColl, 2010) it is assumed that lamps with a lower CCT have lower frequency and those students who were more sensitive to this, had more stressful behavior or distractions resulting in off-task behaviors while under the lamps with a lower CCT.

We reasoned that another factor which could contribute to more on-task behaviors might be that a higher CCT in lighting is perceived by the occupant as having a higher illumination level though it measured the same lux as the lighting with a lower CCT. Occupants view lighting with a lower CCT level as intimate and compensate behaviors by waiting longer to answer questions and display a decrease in eye contact (Carr & Dabbs, 1974). Whereas, a higher illumination level has been shown to increase alertness, arousal, and productivity (Smolders & De Kort, 2014; Wei et al., 2014). The increased alertness that is associated with higher illumination levels may have unconsciously influenced students who displayed more on-task behaviors since the higher CCT level lamp was perceived as having a higher illumination level.

Physical movement around the room could be due to the fact that arousal levels in the students may have been influenced by the shorter wavelengths that occur in blue light exposure (Keis, Helbig, Streb, & Hille, 2014). The results indicate that more students physically moved around the room, specifically male students, under the lighting of 4100K CCT than the 3000K CCT. This could be attributed to the fact that higher CCT levels of lighting are more activating because it increases human cortisol levels thus increased arousal (Keis et al., 2014). This occurrence is referred to as ascending reticular activation system. Cortisol levels measured higher in men under higher CCT lighting as compared to lower CCT levels (Yasukochi & Ishibashi, 2005). Knez and Kers (2000) concluded that male and female genders responded differently to CCT levels with mood changes. Higher activity levels in men were found when subjects were exposed to blue light (Lehrl et al., 2007). Males also tend to respond positively to higher CCT levels (Knez & Kers, 2000) which was perhaps why they were more active than their female peers while under the lamp with 4100K CCT.

Although there were limitations to the study design, it was completed in an existing classroom environment, which acknowledges that changes in the classroom interior variables occur from normal educational activities. The window blinds were to remain in the horizontal position and the lighting in the back turned off to block out the influence of natural light and other light sources. This was not always possible due to teacher instruction and activities which is typical in any classroom environment. Other outside factors such as diet, sleep, home life situations, illness, exercise and parental support which affect student readiness to learn (Moore, 2011) were not included in this study. However, the study design and study duration were created to acknowledge these limitations and verify that a higher CCT level could be utilized in an existing classroom setting. Although there is a need for a larger sample size, controlling for subject activity, and a longitudinal study which would provide stronger correlational evidence for the conclusions that CCT of the interior lighting influences student on-task behavior, this study demonstrates that this topic is worthy of further investigation.

In conclusion, this study extended prior work on the CCT level of interior lighting by hypothesizing that students would display more on-task behaviors under the higher CCT of fluorescent lighting. The CCT level of interior lighting influenced student on-task behavior in an elementary classroom environment, however, other variables contributed towards student on-task behavior. Further interior lighting research focusing on CCT levels would clarify this information.

FUTURE RESEARCH DIRECTIONS

Findings from this study provide opportunities for additional investigations into student on-task behavior in regards to the CCT of the interior lighting in classrooms. Because this study was performed on one classroom with a small number of subjects, it is unknown if this would be true for other socio-economic status's or geographical locations. Future investigations should include a larger sample size with multiple age levels and school locations in a longitudinal study design to provide further evidence that the higher CCT level of lighting is correlated to student on-task behaviors. Studies that include higher CCT levels, such as 5000K that more closely resemble natural daylighting, may have different results and should be included in future studies. Since school operating budgets are of extreme importance examining energy savings and life cycle costs of standardizing the lamps and ballasts to the correct system to promote academic success may prove useful and provide economic benefit to school systems.

A variable that was not measured in this study that is of value in future studies is to investigate different CCT levels of lighting on developmentally disabled students compared to normally developing students. Since developmentally disabled students are included in public school systems, investigating a CCT level to enhance their success would be beneficial to the overall classroom environment. Studying this topic could yield more clues towards creating a classroom environment to promote student academic success.

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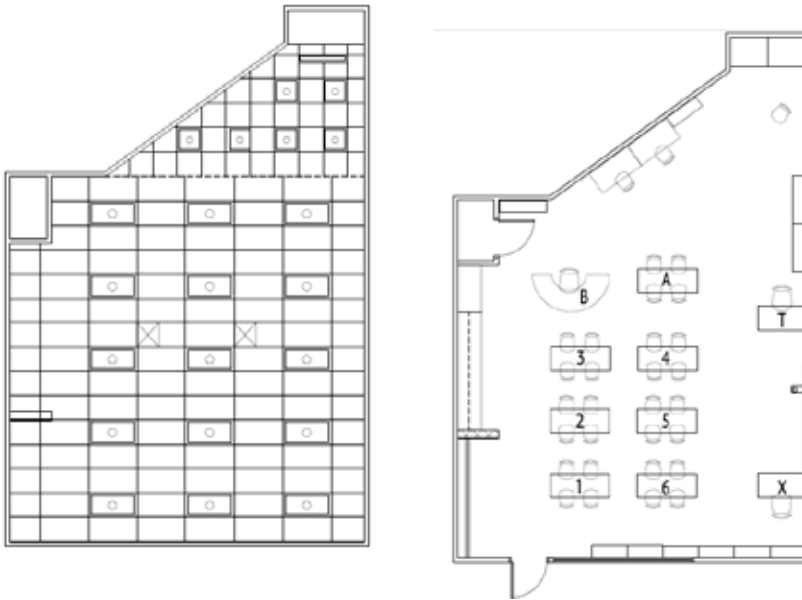


Figure 1: Classroom Reflected Ceiling Plan on Left and Classroom Furniture Plan on Right

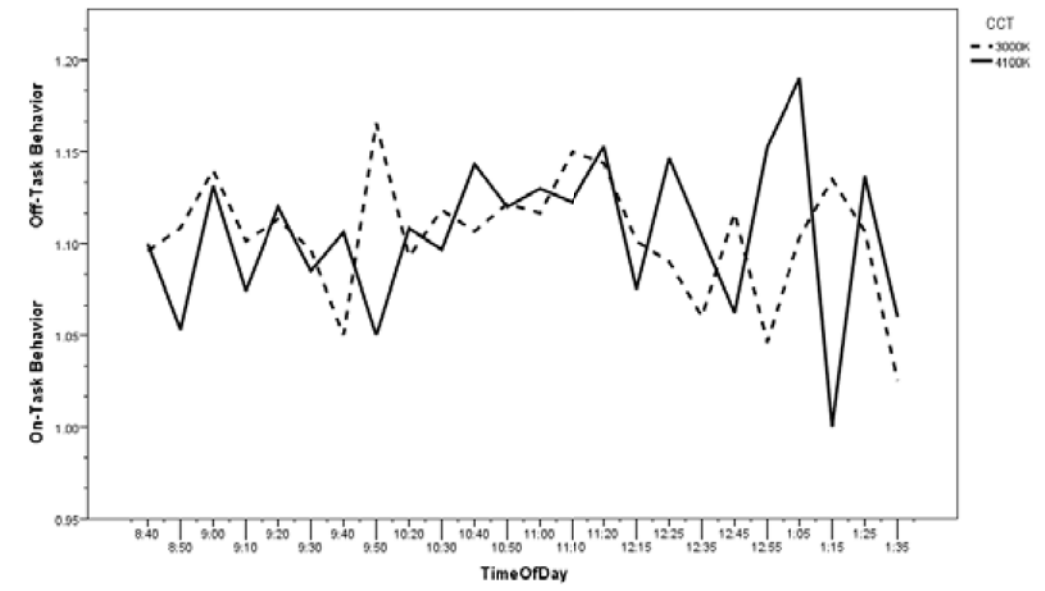


Figure 2: Line Graph of Time of Day and On-task Behavior

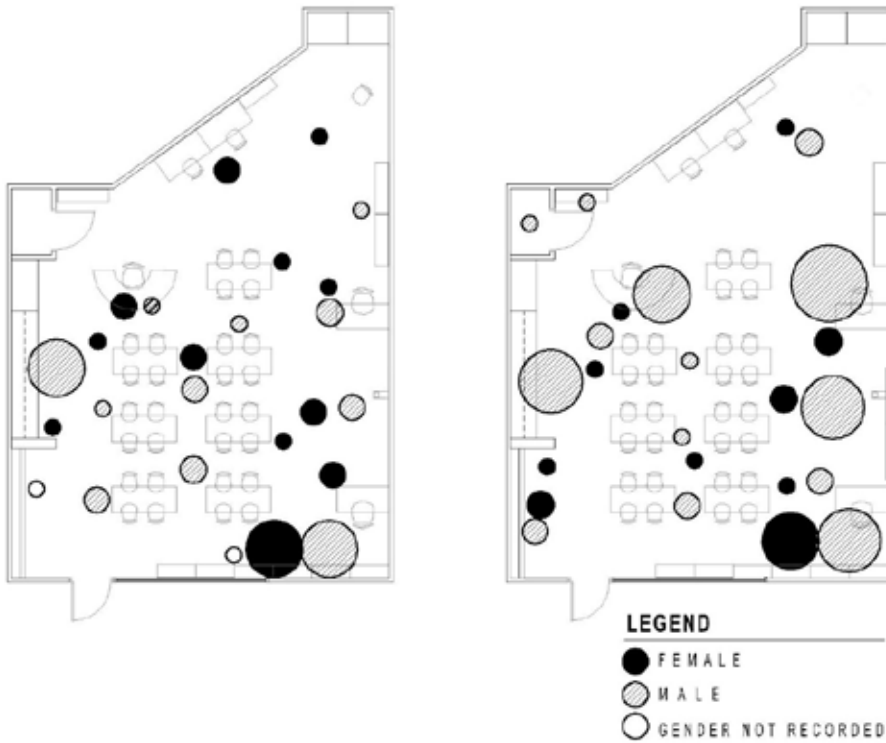


Figure 3: Frequency Results of Student Movement Mapping by Gender - Lamp A on Left and Lamp B on Right

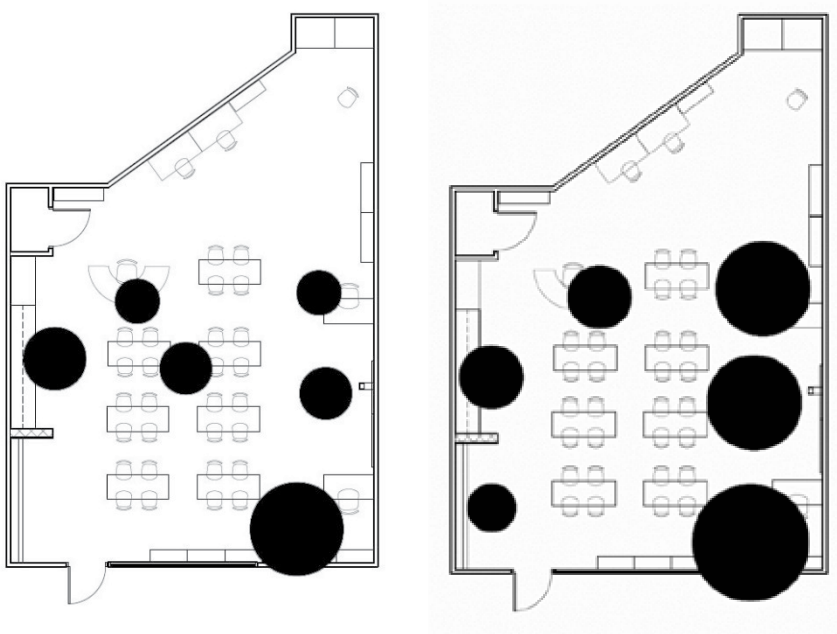


Figure 4: Overall Results of Student Movement Mapping – Lamp A on left and Lamp B on Right

Table 1

Descriptive Statistics and Zero Order Correlation Matrix of All Variables

Variable	Mean (SD)	2	3	4	5	6	7
1. On-task Behavior	1.16(.16)	0.042	0.173*	0.023	0.400	-0.056	.198**
2. Time of Day	12.19(6.39)		-0.047	-0.047	0.008	-0.052	0.033
3. Scholastic Subject	1.54 (1.24)			0.137**	0.026	0.073	0.07
4. Type of Work	0.90 (1.25)				-0.148	-0.145	-0.138
5. CCT	0.48 (.50)					0.024	.979**
6. Day of Week	1.88 (1.27)						0.016
7. CCT x On-task Behavior	0.56(.60)						

Note. * Significant at the $p < .01$ level; **Significant at the $p < .05$ level.

Table 2

Summary of Regression Analysis for all Variables With and Without CCT Predicting On-task Behavior (N=339)

Variable	Model 1			Model 2		
	<i>B</i>	<i>SE B</i>	β	<i>B</i>	<i>SE B</i>	β
Intercept	1.141	.020		1.134	0.022	
Time of Day	.001	.001	.046	.001	.001	.045
Scholastic Subject	0.024*	0.007	0.183	0.024*	0.007	0.183
Type of Work	0.005*	0.007	0.039	0.006*	0.007	0.045
Day of Week	-0.008	0.006	-0.064	0.008	0.006	-0.064
CCT				0.014*	0.018	0.043
R^2		0.036			0.038	
<i>F</i> for change in R^2		4.201			0.63	

Note. *Significant at the $p < .01$ level.

Table 3

Summary of Regression Analysis for All Variables on Predicting On-task Behavior Under the Different CCT Levels (N=147)

Variable	Model 1 (3000K CCT)			Model 2 (4100K CCT)		
	<i>B</i>	<i>SE B</i>	β	<i>B</i>	<i>SE B</i>	β
Intercept	1.200	0.034		1.058	0.041	
Time of Day	-0.002	0.002	-0.104	0.005**	0.002	0.178
Scholastic Subject	0.002**	0.009	0.013	0.047*	0.011	0.032
Type of Work	0.000	0.008	-0.005	0.002**	0.013	-0.014
Day of Week	-0.006	0.008	-0.059	-0.010	0.010	-0.074
R^2		0.015			0.133	
<i>F</i> for change in R^2		0.665			6.032	

Note. *Significant at the $p < .01$ level, **Significant at the $p < .05$ level.