AN ABSTRACT OF THE DISSERTATION OF

Alana Suzanne Pulay for the degree of Doctor of Philosophy in Design and Human Environment presented on May 21, 2015

Title: The Impact of the Correlated Color Temperature of Fluorescent Lighting and its Influence on Student On-Task Behavior in an Elementary School Classroom

Abstract approved:

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The aim of the study was to determine whether a higher correlated color temperature of the fluorescent lighting in an elementary school classroom influenced student on-task behavior as compared to fluorescent lighting with a lower correlated color temperature. A conceptual theoretical framework on interior lighting and human behavior was developed to investigate classroom on-task behavior. Using research based theory development and the theory synthesis process, a new conceptual theoretical framework was created incorporating past interior lighting framework concepts (Boyce, 2004; DeKort & Veitch, 2014; Kretchemer, Schmidt, & Griefahn, 2012).

The conceptual theoretical framework was tested in a pilot study that examined student on-task behavior under fluorescent lighting with a correlated color temperature (CCT) of 3000K as compared to fluorescent lighting with a 4100K correlated color temperature (CCT). Results indicated that students had more on-task behavior under the 4100K CCT of lighting and that the theoretical framework needed refinement and expansion. Modifications to the theoretical framework were

needed to uncover and explain relationships between the variables within a classroom that contributed to student on-task behavior. The processed-based theory development strategy was implemented to create a refined theoretical framework that included other variables within the school climate.

A case study tested the refined theoretical framework as well as investigated student on-task behavior under a 3000K CCT and a 4100K CCT of fluorescent lighting. Student on-task behavior scores were collected for five months by non-participant observation in a second grade elementary school classroom setting. Student on-task behavior scores were averaged and then used in combination with the movement mapping data to document student movement and behavior to give a holistic explanation of how the interior lighting influences student behavior.

The findings uncovered that the refined theoretical framework is a valid measure with which to research interior lighting and human behavior. Testing the refined framework showed associations among and between concepts. The strength of the relationship between human behavior and the interior lighting within a classroom environment was also uncovered while accounting for other variables within the school climate.

The results of the quantitative data collection method indicate that students displayed more on-task behavior scores under lighting with a CCT of 4100K than lighting with a CCT of 3000K. Further analysis resulted in correlations between student on-task behavior and the variables of time of day, scholastic subject, and type of work. Scholastic subject is independently significant at predicating on-task behaviors regardless of CCT levels.

Through implementing the refined theoretical framework, results of the case study uncovered that the interior lighting in a classroom environment is one of many variables that contribute to student on-task behavior. Additional research in this area will help designers create a better school climate that in turn will create higher levels of student academic success.

The Impact of the Correlated Color Temperature of Fluorescent Lighting and its Influence on Student On-Task Behavior in an Elementary School Classroom

by
Alana Suzanne Pulay

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Alana Suzanne Pulay, Author

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The Impact of the Correlated Color Temperature of Fluorescent Lighting and its Influence on Student On-Task Behavior in an Elementary School Classroom

Chapter 1

Introduction

Qualities of a built environment shape human behavior (Gieryn, 2000; Steidle & Werth, 2014). Studies suggest that individuals each respond and react differently to the cues around us. Humans unknowingly analyze environmental stimulants and sort out which are less important than others. Each individual processes stimuli differently, however, we are all more visual than auditory in assessing stimulations when forming opinions about the interior environment (Higgins & Tumure, 1984; Mahdjoubi & Akplotski, 2012). These stimuli therefore unconsciously influence human behavior (McAndrew, 1993) within interior environments.

Researchers have shown there is a connection between the physical environment and personal health, performance, actions, and behaviors (Knez & Kers, 2000; Steidle & Werth, 2014; Vischer, 2007) as well as, concentration, attention, and cognitive tasks (Fisher, Godwin, & Seltman, 2014; Kretchemer, Schmidt, & Griefahn, 2012). The interior environment is defined as “the interpersonal climate or organizational settings” (Moore, 1985, p. 26) such as schools and classrooms which are composed of multiple variables. These variables are the ambient conditions within the space that have nonvisual qualities (McAndrew, 1993).

Researchers suggest there is a correlation between child development and the interior variables in the physical environment (Evans, 2006). An interior environment with positive variables will enhance a child’s developmental processes whereas negative interior variables will have a negative influence on a child’s development (Duran-Narucki, 2008). Since children spend more time in a school facility than in home environments (Cartieaux, Rzepka, & Cuny, 2011;Ferreira, & Cardoso, 2014; Mahar et al., 2006) these variables are of concern in educational facilities.

Some interior environmental variables within a school facility include toxicology (Evans, 2006), noise (Evans, Hygge, & Bullinger,1995; Maxwell & Evans, 2000), size of building (Moore & Lackney, 1993), thermal comfort (Schneider, 2002; Theodosiou & Ordoumpozanis, 2008) indoor air quality (Ferreira & Cardoso, 2014; Ramachandran et al., 2005; Theodosiou & Ordoumpozanis, 2008), and furniture (Danko, Eshelman, & Hedge, 1990; Vischer, 2007). Another variable, which does have visual qualities, is interior lighting (DeKort & Veitch, 2014; Evans, 2006; Veitch & McColl, 2010). All of these variables contribute to the state of the classroom interior environment and contribute toward student academic success (Schneider, 2002; Uline, 2008).

Interior lighting influences cognitive performance, alertness, arousal, and visual clarity (Fleischer, Kruegar, & Schierz, 2001; Heerwagen, 2010; IES, 2014) subliminally through the human biological, psychological, and hormonal processes (Deguchi & Sato, 1992, Hathaway, 1995; Schlangen, 2010; Yasukouchi & Ishibashi, 2005). Past interior lighting studies have focused on the occupant's visual acuity (DeKort & Veitch, 2014) in the work place or laboratory setting. There are few empirically researched lighting studies in educational facilities, or performed on students (Hathaway, 1995), beyond some limited studies (Kuman, O'Malley, & Johnston, 2008).

Statement of the Problem

Researchers do not clearly understand the association between child development, cognition, and lighting in the interior environment (Mahdjoubi &Akplotski, 2012). Interior lighting research on the possible link between lighting and student academic success in the elementary school classroom is lacking in the empirical literature (Veitch & McColl, 2010). Since fluorescent lamps are the most common type of light fixtures installed in public school classrooms (Knez, 2014) and there is no recommended correlated color temperature (CCT) level for classroom lighting (IES, 2014), the objective of the study was to examine if a higher CCT level of lighting in a classroom influenced student on-task behavior. Children focus more on academic tasks when they are displaying on-task behavior. Therefore, students would be expected to have higher levels of cognitive development with more on-task behavior scores (Clare, Jenson, Kehle, & Bray, 2000; Fisher, Godwin, & Seltman, 2014; Kane & Engle, 2002).

The Conceptual Framework

Due to the lack of a comprehensive theoretical framework in which to study the relationship between human behavior and interior lighting (Evans, Yoo, & Sipple, 2010; Kretchemer et al., 2012) one needs to be developed (IES, 2011). This conceptual framework should focus less on visibility and more on the impact lighting has on the occupant's psychological processes such as mood and behavior (Boyce, 2004).

A new conceptual theoretical framework to study interior lighting and human behavior was developed using strategies from process-based theory development and the theory synthesis process. Since interior lighting is a component of the Physical Layer within the overall School System Layers (Gordon, Holland, Lahelma, & Tolonen, 2005), integrating all variables within the framework is necessary to show influential relationships. Interior lighting, either in combination with other variables or by itself, subliminally influences the human perceptual system that effects student behaviors in a learning environment. To test the framework, the hypothesis of; A higher CCT of fluorescent lighting that creates better light quality will produce more student on-task behavior in a learning environment was proposed through the theory development process. Each variable was measured in two empirical studies to predict the link between lighting and student behavior in a real world application (Handfield & Melnyk, 1998).

Manuscripts

This study includes two manuscripts. Since interior lighting in a classroom cannot be examined without a theoretical framework, it was necessary to develop one. Manuscript #1 documents the details and processes involved in the development of a conceptual framework to study interior lighting and human behavior. Manuscript #2 is a case study created to test the theoretical framework as well as document the influences of the CCT level of interior lighting and student on-task behavior. Together the manuscripts give a holistic explanation of student on-task behavior as influenced by the CCT of fluorescent lighting in a school classroom environment.

Manuscript #1. Using the theory synthesis process, concepts from the existing Boyce (2004), DeKort and Veitch (2014), and Kretchemer, Schmidt, and Griefahn (2012) theoretical frameworks were integrated into a new, more comprehensive conceptual framework within the overall School System Layers framework (Gordon et al., 2005). The new conceptual framework illustrates the relational links between the CCT of lighting through subliminal perception of the human psychological processes that result in acute behavioral effects while accounting for the other variables present within the classroom environment.

The process-based theory development strategy tested the conceptual framework (Handfield & Melnyk, 1998) in a pilot study. Based on the results, refinement was needed to include other variables present within the School System Layers. The process, details, and conceptual framework are discussed in Chapter 2: The Development of an Interior Lighting Framework to Examine Student On-Task Behavior in an Elementary School Classroom. Since the previous interior lighting theoretical framework models are not sufficient, the proposed model aims to fill that gap. The manuscript will be submitted to *Lighting Research & Technology*. The journal is published for academics, industry professionals, and designers. An area of focus in the journal is the human response to light that is congruent with the development of the theoretical framework.

Manuscript #2. A mixed methods case study was designed and conducted to examine the influence of the CCT of the fluorescent lighting in an elementary school classroom on student on-task behavior. Data were collected for student on-task behaviors and classroom student movements using quantitative and qualitative data collection methods in a second grade classroom under lighting with a CCT of 3000K compared to lighting with a CCT of 4100K. Results indicate that students had better on-task behavior scores under the 4100K CCT lighting situation. The movement mapping data concluded where and how students moved throughout the classroom.

The procedure and results of the study are discussed in Chapter 3: A Case Study on the Influence of the CCT of Fluorescent Lighting on Student On-Task Behavior in an Elementary School Classroom. This manuscript will be submitted to the peer-reviewed journal *Environment and Behavior*. The journal focuses on interdisciplinary and international studies on the relationship between the environment and human behavior. An area for focused research within this journal is the social and psychological processes that occur in special settings such as schools, workplaces, or extreme environments that aligns with the case study topic.

Definition of Terms

Ballast - a device that has the necessary circuit conditions that can start and operate an electric-discharge lamp such as fluorescent (IES, 2014).

Behavior Management System – a set of classroom rules, routines and expectations for student behavior that is proactive in preventing and redirecting misbehaviors (Buyse et al., 2008; Fabiano, Pelham, Karmazin, Kreher, Panahon, & Carson, 2008).

Child behavior - how a child expresses himself or herself through the “pattern of acting or doing in relation to adults, peers, and the classroom environment” (Lipton, 1971, p. 255).

Cognitive development – four categories that use age as a reference to explain cognitive development (Piaget, 1964).

Sensorimotor - from zero to two years of age where humans discover the environment by using the five senses. Language starts at the end of this phase (Piaget, 1964).

Preoperational - ages two through seven when language develops yet humans cannot grasp thoughts of others (Powell & Kalina, 2000). Children at this stage believe in what they can visually see and depend upon their five senses to interact with and understand the world (Cohen, Stern, & Balaban, 1997).

Concrete operational - from ages seven through eleven where inquiry or intuitive thought changes into logical reasoning (Powell & Kalina, 2000).

Formal operational - eleven years to adult in which there is a high level of thinking and processing (Powell & Kalina, 2000).

Child learning - occurs by hierarchy (Maxwell & Evans, 2000) through the process of adding information to existing knowledge (Piaget, 1964). Children in the pre-operational stage of development learn from organizing and then re-organizing information as they receive it (Powell & Kalina, 2000).

Common Core Standards - a set of shared K-12 learning expectations that 45 states in the United States follow for courses in English, language arts, and mathematics (DOE, 2014).

Correlated color temperature (CCT)- the color appearance of the light source in and of itself (IES, 2014) that appears warm (red), neutral (white), or cool (blue) (Mayr, Kopper, & Buchner, 2013) as compared to blackbody radiation (Mayr et al., 2013; Yu et al., 2012). At around 3000K (Kelvins) the light appears to have a warm color appearance (IES, 2014; Knez, 2001; Mayr et al., 2013). At 4000K the light emitted has a cool color appearance and at 5500K it produces a color temperature similar to daylight (Knez, 2001).

Color rendering index (CRI) – an index to measure the color appearance of an object under a light source (Veitch & McColl, 2010; Rea & Freyssinier-Nova, 2008; Yu et al., 2013). The higher the number, on a scale from zero to one hundred, the more "true, natural," or accurate the object's colors appear under that light source as compared to natural daylight (Karlene & Benya, 2004; Yu et al., 2013; Rea & Freyssinier-Nova, 2008, p. 132).

Efficacy - a measurement used to meet energy codes and describe how well the luminaire can translate energy to light and then deliver that light into the room (IES, 2014).

Flicker effect – The oscillation of circuitry in electric ballasts (Veitch, 2001) due to the delay of the phosphor compound output (Veitch, 2001; Veitch & McColl, 2010) that causes a flicker at twice the amount of power usage. A 50 Hz fluorescent lamp will flicker at 100 Hz which equals 90 times it turns off and on per second (Knez, 2014). The human eye cannot visually see this high frequency flicker rate yet can detect lower frequency rates (IES, 2014; Knez, 2014).

Fluorescent lamps – electric light sources made of a conductive low-pressure mercury electric-discharge that produces UV optical radiation. The balance of the mixture between the inorganic compounds and activators can be adjusted which controls the color of the light emitted from the lamp or CCT (IES, 2011).

Glare - produced by luminance in our visual field that is much higher than what the eyes are adapted to (IES, 2014).

Illuminance - the amount of light falling onto a surface at a distance from the light source measured in lux or footcandles (IES, 2014).

Lamp - a manufactured light source (IES, 2014).

Light - “the radiant energy that is capable of exciting the retina and producing visual sensation” (IES, 2014, p. 75).

Lighting design standards or codes - international measurements used to “communicate information about light and lighting in a consistent and meaningful way” (IES, 2014, p. 232). Codes and standards are based off lighting calculations that are “tools to analyze a lighting system and estimate the quantity of light delivered” (IES, 2014, p. 84).

Light quality – an interior environment designed with good visual comfort, good color, uniform light distribution, balanced brightness (IES, 2014), equal proportion of direct and indirect lighting, and no glare (Wu, 2003).

Luminaire - all the components used to distribute light into the space, position and protect the lamp, connect the lamp to the power source, as well as, the lamp and ballasts (IES, 2014).

Off-task behaviors - behavior not considered on-task behavior such as, “out of seat, play fighting, physical contact with force, throwing objects, and screaming” (McCurdy, Lannie, & Barnabas, 2009, p. 43), that cause disruption in student learning (Mahar et al., 2006).

On-task behaviors – when students are maintaining attention to the task at hand (Fisher et al., 2014) through actively listening, following instructions, being oriented towards the teacher or assignment, or seeking help by raising one's hand (Clare et al., 2000; Luke, Vail, & Ayres, 2014).

Semiotic distance – non-verbal cues used to communicate (Lim, O'Halloran, & Podlasov, 2012; Matthiessen, 2010) such as actions, body movements, and gestures (Martin & Stenglin, 2007).

Spatial Pedagogy - where the occupants move spatially within the room according to interactions and activities (Kendon, 2010).

Subliminal perception – a response to a stimulus that is not visually detected (Kihlstrom, 2004, p. 94).

Type of Work – the observed on-task behavior activity of the students classified as either independent deskwork, group work, active listening, or the transition time between those activities.

Independent deskwork – the task of writing or reading at one's desk

Group work – activity of performing the task given by the instructor with a peer or several peers

Active listening – actively engagement with the speaker by making eye contact, answer questions, or other body movements

Visual acuity - "measure of ability to distinguish fine details, measured with a set of optotypes (test types for determining visual acuity) of different sizes" (IES, 2014, p. 82).

The Development of an Interior Lighting Framework to Examine Student On-Task Behavior in an Elementary School Classroom

Chapter 2

Introduction

The first objective of this manuscript was to review past approaches and existing theoretical concepts used to study interior lighting and human behavior. The second objective was to develop a new conceptual theoretical framework to study interior lighting within a learning environment. This framework was created by implementing theory development strategies from multiple disciplines using evidence from past empirical lighting studies and environmental psychology principles.

The theory synthesis process, which involves organizing, combining, and linking concepts, was used to create a more comprehensive and parsimonious theoretical framework. The conceptual framework was tested in an empirical study using the process-based theory strategy to confirm relationships.

Background. Researchers in environmental psychology study all variables of the built environment because all elements contribute to an occupant's perception of a space (Evans, 2006; Kopec, 2012). One of the variables within the interior environment is the electrical lighting. Past empirical lighting studies have focused on the visual conditions within the space that focus on the technical aspect of the lighting systems. These include measurement and usage of illuminance, wavelength, color rendering, lighting layout, and energy usage. Human behavior has not been a focus of lighting research (Boyce, 2004; Caballero-Arce & Vigil-de Insausti, 2012) due to the lack of a comprehensive theoretical framework in lighting research (Kretchemer, Schmidt, & Griefahn, 2012).

Since the design discipline is interdisciplinary and integrative across multiple domains, a theoretical framework provides the link between known facts and the process of designing. It is therefore a model to describe the relationships between elements and explains how something works (Friedman, 2003). The framework is the focus, content, concepts, assumptions, and beliefs of the study (Neuman, 2011) and makes sense out of the “why”, “how”, and “what” of the research question (Friedman, 2003; Neuman, 2011). The development of a comprehensive theoretical framework is necessary for studying lighting in the built environment (IES, 2011) specifically in learning environments.

The physical environment of a school receives little attention as a contributing factor when researching student behavior (Kuman et al., 2008). Since multiple variables are present within an interior environment, it is difficult to find the influence of an individual variable towards occupant well-being (Danko et al., 1990; Moore, 2011). Therefore, to study the relationship between the interior lighting in a school environment and its influence on children’s academic success, a theoretical framework is needed (Evans et al., 2010) to give a basis for understanding and explaining behavior changes (Beach, Kincade, & Schofield-Tomschin, 2005; Nigg, Allegrane, & Ory, 2002) in response to a stimulus (IES, 2011).

Interior lighting theoretical frameworks. Examples of the current models to study interior lighting are depicted in Figure 2.1, Figure 2.2, and Figure 2.3. These models assume the correct lighting condition in a built environment enhances human cognitive performance; however, these models disregard the human perceptual system that contains mood and behavior that influence cognitive development through subliminal perception. Subliminal perception occurs as a behavior change in response to an unseen stimulus (Knez, 2014).

The previous interior lighting frameworks are lacking in relationships through the perceptual system. The Boyce (2004) framework, although comprehensive, disconnects lighting and the circadian process, which is the human sleep and wake cycle in response to light (IES, 2011). This is not consistent with the literature in that lighting influences the human hormonal processes that control the human circadian system (Rea, 2002). The Kretchemer, Schmidt, and Griefahn (2012) model (Figure 2.2), developed from the Boyce (2004) model (Figure 2.1), is limited for human behavior dimensions since it does not identify all concepts explaining the relationship between lighting and human behavior rendering it as not having parsimony (Friedman, 2003). The De Kort and Veitch (2014) model (Figure 2.3) includes more concepts and relationships than the Boyce (2004) model yet is not comprehensive for human behavior dimensions since it does not identify the biological or hormonal human processes influenced by lighting. Both models do not include the components of lighting (CCT, illuminance and CRI) therefore specific relationships that show correlations cannot be identified. Testing of the models to confirm relationships is difficult without the specificity of the components of light.

In order to investigate the multiple variables in a school setting, the school climate is divided into a system of layers as represented in Figure 2.4 (Gordon, et al., 2005). This framework includes the Formal Layer that encompasses the curriculum, lesson plans, textbooks, teaching materials and school rules. The Informal Layer consists of interactions in the school, application of school rules, and information hierarchy. Additionally, the Physical Layer is the physical space and the movement, sound, and time that occur in the school facility (Gordon et al., 2005). The layer of focus for this study is the Physical Layer.

Theory. The term theory has multiple definitions (Pedersen, 2007) used differently among social scientists, humanities, historians, those practicing in the field, academics (Walker & Avant, 2011), designers (Friedman, 2003) as well as the general public. Theories help guide research and practice, define phenomena, predict results, and guide practice (Walker & Avant, 2011), as well as, describe and explain the phenomena (Pedersen, 2007) or create inquiry and research (Rogers, 1959). A theory is a model that describes the relationship of how something works (Friedman, 2003). A definition of the term theory in regards to a design application is a "set of ideas, concepts, principles, or methods used to explain a wide set of observed facts." (Friedman, 2003, p. 515) within a set of boundary assumptions and constraints (Handfield & Melnyk, 1998).

Theory development is a complex and time-consuming endeavor in which there are multiple methods. These include theory analysis, synthesis, derivation (Walker & Avant, 2011) and process-based theory development (Handfield & Melnyk, 1998). Theory analysis is used to describe, explain or predict a phenomenon (Nigg et al., 2002). Theory synthesis is constructing a theory using interrelated ideas produced from evidence whereas theory derivation is using a theory from another field and changing it to fit the needs of the new or relevant field. (Walker & Avant, 2011). Finally, the process-based theory building strategy is when empirical research is used to develop a theory (Handfield & Melnyk, 1998), which is often the case in the practice of design after observing one's design work (Friedman, 2003).

Since theory derivation is time consuming and appropriate when no data are available this is not an option for theory development on lighting and human behavior research. The concepts of lighting and behavior have definitions and explanations with human actions, therefore, theory analysis would not be the best strategy for theory development. The process-based theory-building uses observations to describe problems, key issues, and relationships among the concepts (Handfield & Melnyk, 1998) and is an appropriate strategy to develop a theoretical framework on lighting and behavior, however, other lighting frameworks exist so the theory synthesis process would be appropriate as well (Walker & Avant, 2011).

The design process involves cognitive actions which change an existing situation to a preferred one (Friedman, 2003). It is, therefore, important for a design framework to explain the "how" "why" (Handfield & Melnyk, 1998) "what" and "who-where-when" (Friendman, 2003) relationship between the concepts. It is also necessary to test a design framework in a real world context. Thus, a combination of theory synthesis and process-based theory building were implemented in the development of a conceptual framework to study interior lighting and human behavior.

Conceptual Theoretical Framework Development

Concept definition. For theory in the design field (Dickson & Eckman, 2006), definitions can occur through observations (Handfield & Melnyk, 1998) or from existing literature (Walker & Avant, 2011). The concept of interior lighting is defined as being comprised of the components of illumination levels, color rendering index, and correlated color temperature. These components are designed for a space to create light quality that improves occupant performance and well-being. Interior lighting unconsciously influences humans on a biological, psychological, and hormonal level (Schlangen, 2010; Yasukouchi & Ishibashi, 2005). The concept of behavior is defined as how one acts in regards to the interior environment. Behavior can be physical movements or through subliminal perception (Knez, 2014).

Relational statement. The next step in theory development is creating relational statements about the concepts. Strong relational statements make the concepts clear and easily understood (Walker & Avant, 2011). The relational statement needs to be general and broad in its scope to explain or predict the phenomenon since this is a basis for the theory (Handfield & Melnyk, 1998; Walker & Avant, 2011) and theory construction (Friedman, 2003).

The first step in developing a relational statement is to generalize the “nature of the relationships between the key variables” (Handfield & Melnyk, 1998, p. 328) which address the “how” component in the theory. An explanation is developed about that relationship which is the “why” component. A relational statement must contain both components through observable and non-observable measures (Handfield & Melnyk, 1998).

There is a subliminal relationship between interior lighting and human behavior. The relationship is explained in previous lighting studies that describe how non-visual light travels through the eyes to the brain via the optic nerve. Light enters the part of the brain that unconsciously controls unwanted stimuli and transfers that into emotional behavior. Thus, indicating that some behavior takes place without conscious awareness (Knez, 2014). This explains the “how” and “why” of the relational statement. However, interior lighting is only one variable within the interior environment and other variables need to be accounted for since a change in one variable may influence and affect another (Zeisel, 2006).

Using evidence from past empirical research studies the following relational statement was developed. Interior lighting, one of the multiple interior environment variables, either in combination with other variables or by itself, influences the human perceptual system that unconsciously affects student behaviors in a learning environment.

The next step of the theory building process includes developing and testing the hypothesis. The hypothesis was developed from deduction methods utilizing the relational statement (Handfield & Melnyk, 1998). The deduction process concluded with the hypothesis that a higher CCT of fluorescent lighting that creates better light quality will produce more student on-task behavior in a learning environment. According to the process-based theory development strategy, the theory building process is complete when the “what”, “how” and “why” explaining the relationship between the concepts have been answered. The next step is testing the hypothesis (Handfield & Melnyk, 1998).

Framework. Using the theory synthesis process, concepts from the Boyce (2004), Kretchemer, Schmidt, and Griefahn, (2012), and DeKort and Veitch (2014) models were synthesized to graphically represent the new framework. The new framework suggests that the lighting of the interior space is composed of three elements of lighting that are correlated color temperature, illuminance and color rendering index. Each one of these components can influence human biological, psychological and hormonal processes through subliminal perception. These components could also combine to influence human biological, psychological, and hormonal processes, either visually or as a non-image forming pathway.

The psychological component of the conceptual model is based upon the De Kort and Veitch (2014) theoretical model. The new conceptual framework developed from the concept that lighting stimulates human vision that influences human psychological functioning through the non-image forming pathways that ends as subliminally influenced acute effects. For this theoretical framework, the acute effects occur as changes in student on-task behavior.

Behavior and cognition are considered both independent and as having a connected relationship in the conceptual theoretical framework. A behavior occurs when an occupant displays movement whereas cognition occurs when a students is on-task with focused attention. The more time students spend performing on-task behaviors the more time they spend on the scholarly material thus having improved cognition (Millman, Bieger, Klag, & Pine, 1983).

In order to test this hypothesis and framework, a pilot study was created to predict the relationship between lighting and student behavior in a real world application. The pilot study investigated the influence of correlated color temperature of the fluorescent lighting in an elementary school classroom on student on-task behavior. Testing occurred by measuring the variables in the theoretical hypothesis

(Handfield & Melnyk, 1998). Refer to Figure 2.5 for the proposed conceptual theoretical framework.

Method

Sample. Twenty-seven elementary students participated in the study. The age range of children was between six and seven years of age. Four children sat at one of six tables in the center of the room and three children sat at the remainder table (Figure 2.6). The number of and gender of the children were recorded at each table during data collection since children relocate periodically throughout the data collection time frame.

Classroom. The classroom has fifteen troffer light fixtures lamped with two T8 bulbs (Figure 2.7). No reflectors, de-lamping, or other changes were made other than replacing the existing with new lamps and ballasts to ensure that the lighting distribution did not change. The temperature, minimum and maximum noise levels, and relative humidity were recorded at intervals during the observation period. The illumination levels at each tables was also recorded twice during the observation period for each day with an average of 658.32 lux for Lamp A and 661.96 for Lamp B. To control for outside variables the window blinds were turned to horizontal each observation day and the back corner lights were turned off.

Procedure. The study used non-participant group observations of behavior. The researchers recorded on-task group behavior using a time-interval sampling method. Data were recorded every 10 seconds for 10 minute intervals throughout the duration of the observation period. The observation data were recorded using a laptop and a pre-developed observation data sheet. On-task behavior was reported as a “1” if three of the four students at that table were doing the class activity. Off-task behavior was reported as a “3” if three of the four students at the table were doing any activity not related to the task at hand given by the teacher. It was also reported as a “2” if two of the students were on-task and two students were off-task during the 10-second observation time period. Behavior was only recorded while students were at tables. The observation of tables was randomly selected using a random number generator each day. Observations were averaged at the end of five minutes for an average on-task behavior score for the whole class.

Three different researchers collected data over a 5-month period. Inter-rater reliability was established at 0.92. Data collection was from 9:00 a.m. to 10:00 a.m. then from 10:20 a.m. to 11:30 a.m. The teacher was present during 75% of observations during Lamp A and 89% during Lamp B. A total of 47.1 hours of observational data was collected: 25.25 hours for Lamp A and 21.85 hours for Lamp B.

The control lamp, which has a CCT of 3500K, 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 the CCT of 5000K. Another two-week adjustment period occurred and then data was collected for the following two weeks. The lamps were then changed back to the CCT of 3500K and this pattern continued from January 06, 2014 to May 13, 2014 (Figure 2.8).

To test the hypothesis, the variable of CCT was measured through the installation of two different CCT levels of fluorescent lamps. The variable of student productivity was measured by observing student on-task behaviors in a classroom setting. Light quality was tested by classroom illumination levels. Other interior variables present within the classroom were measured included noise levels, relative humidity, and air temperature.

Analysis. To calculate the percentage of on-task behavior, the average score for each 10-minute observational period was calculated and totaled for each day to give an average on-task score per day per lamp type (Table 2.1). Average on-task behavior scores were imported into the software package IBM SPSS Statistics to perform the statistical analysis.

Results. Hypothesis testing resulted in a significant effect for lamp correlated color temperature, $t(17) = 1.77$, $p < .1$, with more students demonstrating on-task behavior under Lamp B. The one-sample t-test on the difference in behavior scores between Lamp B and Lamp A was a mean of .074.

Discussion

This study investigated if the relationship between a higher CCT level of fluorescent lighting and student behavior existed. In the theory building process hypothesis testing concludes with directions of either 'end confirmation', 'modify', or 'over throw' the theory (Handfield & Melnyk, 1998, p. 332). This testing resulted in a 'modify' status due to several factors based on the results.

To validate the theoretical framework, the relationship between variables needs to be "based on the soundness of the logic used to measure the constructs" (Handfield & Melnyk, 1998, p. 334) and eliminate other explanations through the use of the appropriate measurement tools (Handfield & Melnyk, 1998). The tested hypothesis used valid measurement tools to record the relationships. CCT levels were measured with the installation of different lamps and other interior variables such as air temperature, relative humidity, and noise levels were recorded, however, variables within the School System Layers were not measured for their contributing relationship to student on-task behaviors (Figure 2.11). Thus, the theoretical framework is in need of refinement to include variables from the School System Layers. Including other variables will create parsimony or the correct number of variables to explain the relationship thoroughly (Friedman, 2003; Handfield & Melnyk, 1998) which indicates a significant theory.

Another refinement from the results, which is congruent with the DeKort and Veitch (2014) framework, is that non-image forming pathways of lighting have acute effects on the occupants and ultimately influence psychological human behaviors. Therefore, in the refined framework the non-image forming pathways need to have a direct relationship, as shown in Figure 2.12. In addition, behavior needs to be divided into two different categories of subliminal behavior and physical behavior. This should be categorized since the non-image forming pathways contribute to subliminal behavior in the form of student focused attention that differs from a physical behavior that includes body movement. These forms of behavior can be independent of one another or possibly have a contributing relationship. An example of a contributing relationship is when an occupant displays physical movement such as lowering the window blinds. The physical movement creates an appropriate illumination level that enhances visual acuity in reading the markerboard. Students have more focused attention because of enhanced visual acuity thus these behaviors are independent of each other yet connected.

Since interior lighting is a component of the school system layer framework and each layer has multiple components, the lighting variable is a small contribution toward the overall school climate. Testing concluded that the framework needs refinement and results indicate a new testing hypothesis as: A higher CCT of fluorescent lighting that creates better light quality, in addition to the School System Formal Layer, will produce more student on-task behavior in a learning environment.

Testing the framework by the measurable constructs gave the case study a systematic approach which uncovered the acute behavior changes that occurred unconsciously under two different CCT levels of the lighting. One can conclude that the framework is a theoretical basis but that a more comprehensive structure that includes direct relationships with other variables within the School System Layers would only enhance the framework and create an integrative platform for lighting research that can show correlations.

Summary/Conclusions

This manuscript outlined the processes involved in developing a research-based theory for the design discipline. Since the theory development process is continuous (Handfield & Melnyk, 1998) and results indicate that refinement is needed more testing should occur that includes other variables with contributing effects to student on-task behaviors. Refinement of this model will help uncover relationships between interior environment variables and the subliminal influence to human processes in a classroom environment. Uncovering correlations through frameworks, designers can organize observations of human behavior to infer the design concepts to other uses in other times and places (Friedman, 2003). Thus, theoretical frameworks create systematic knowledge, in the form of a simplified representation of reality, which creates an effective practice and professionalism within the design discipline (Friedman, 2003).

Figures

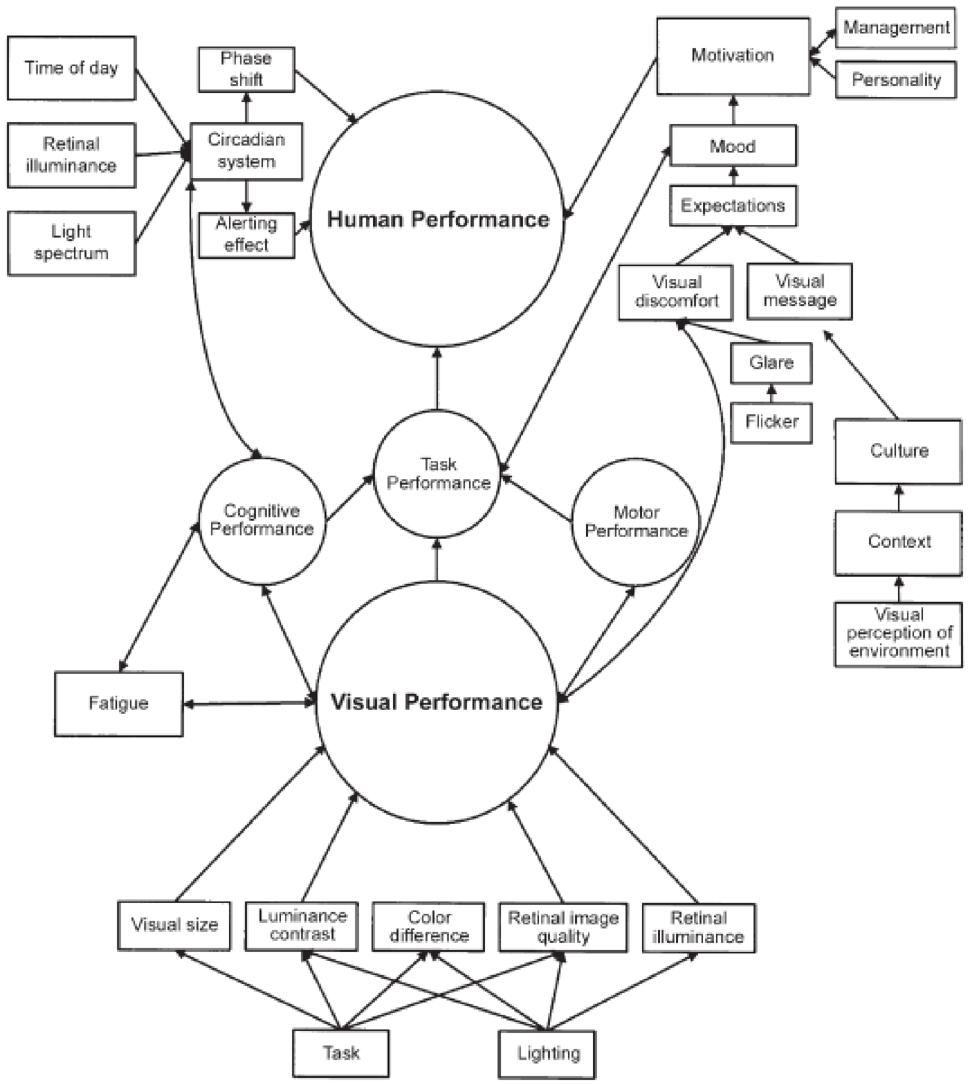

Figure 2.1: Interior Lighting Theoretical Model with Three Routes Whereby Lighting Influences Human Performance (Boyce, 2004, p. 285)

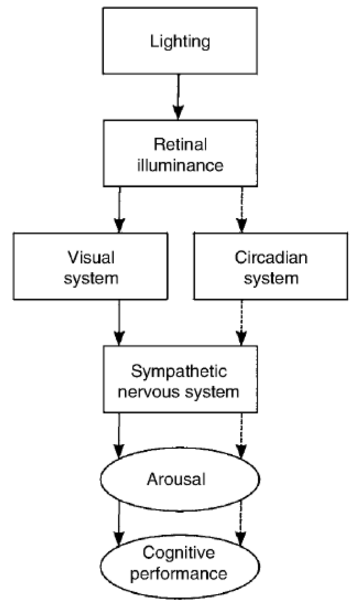

Figure 2.2: Simplified Theoretical Model Adapted from Boyce (2004) (Kretschmer et al., 2012, p. 44)

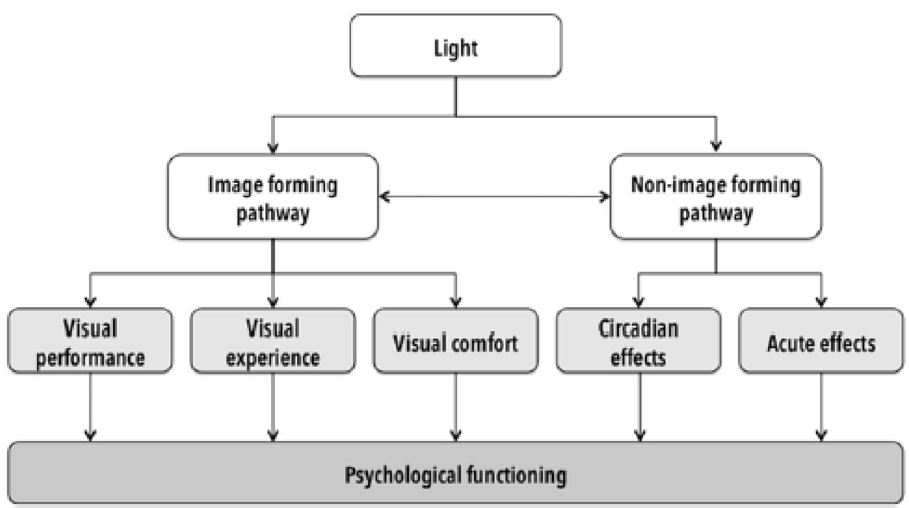

Figure 2.3: Framework of the Pathways of Light Relative to Psychological Functioning (De Kort & Veitch, 2014, p. 3)

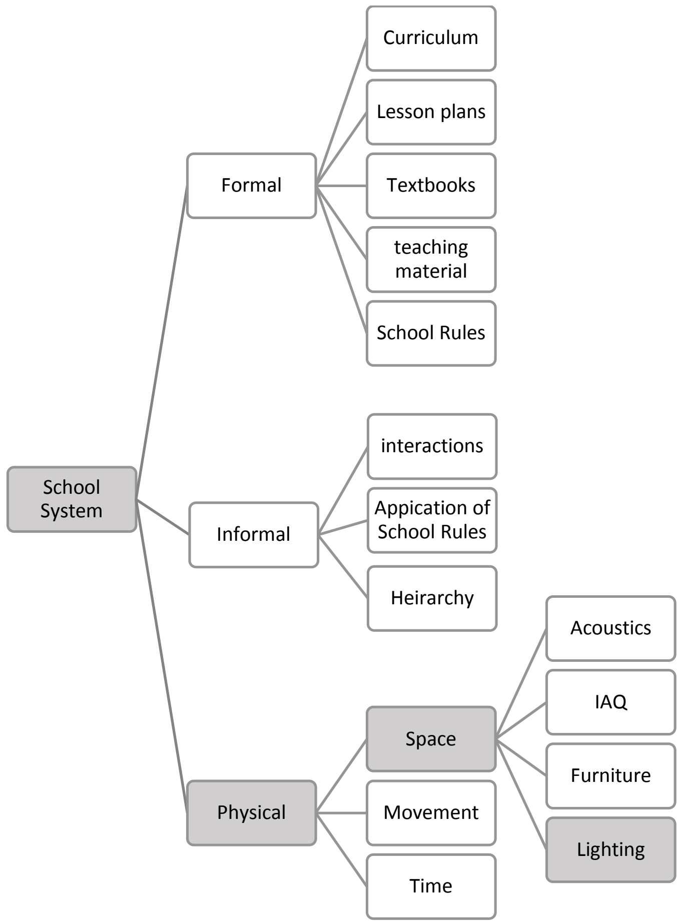

Figure 2.4: School System Layers with the Influence of Lighting in Grey (Gordon et al., 2005)

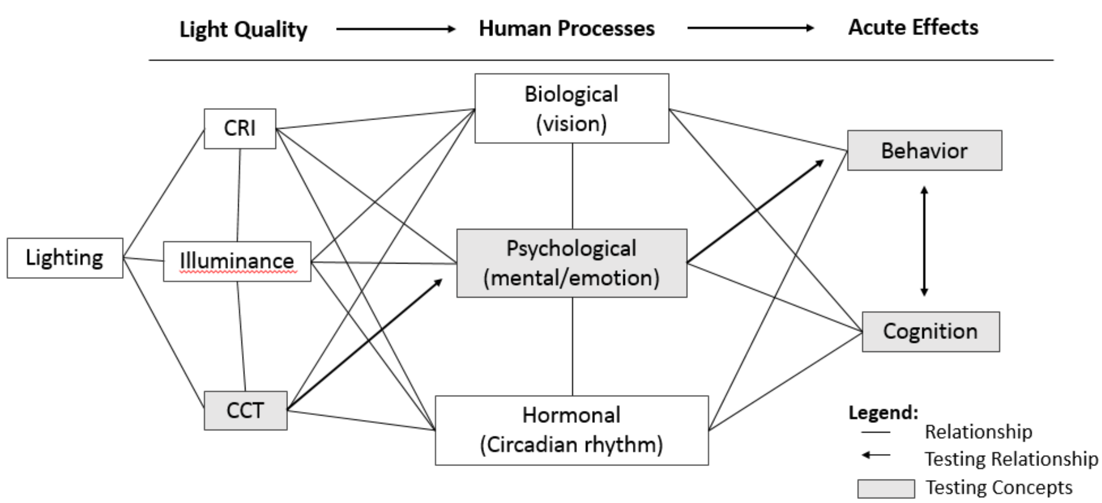

Figure 2.5: Proposed Conceptual Theoretical Framework

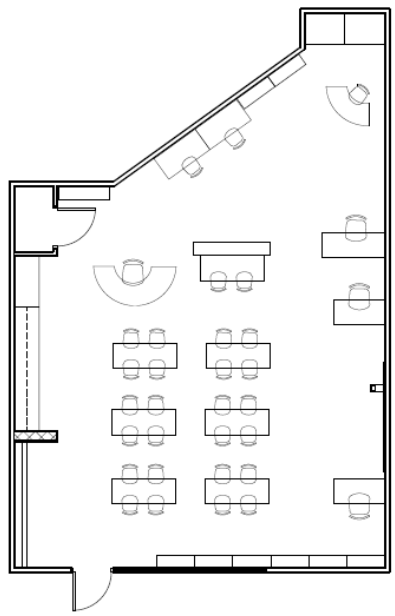

Figure 2.6: Floorplan

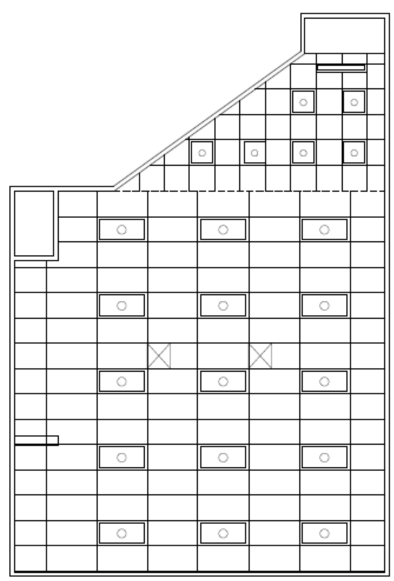

Figure 2.7: Reflected Ceiling Plan

	Fall/13										Winter/14										Spring/14									
	Week																													
Activity	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Students under Lamp "A"	X	X	X	X					X	X	X	X					X	X	X	X										
Students under Lamp "B"					X	X	X	X					X	X	X	X					X	X	X	X						
Observe Classroom			X	X			X	X			X	X			X	X			X	X			X	X						
Analyse and Evaluate																									X	X	X	X		
Summarize Findings																												X	X	X

Figure 2.8: Timeline


Figure 2.9: Photo of Classroom from Back (Lamp A on Left and Lamp B on Right)


Figure 2.10: Photos of Classroom from Front (Lamp A on Left and Lamp B on Right)

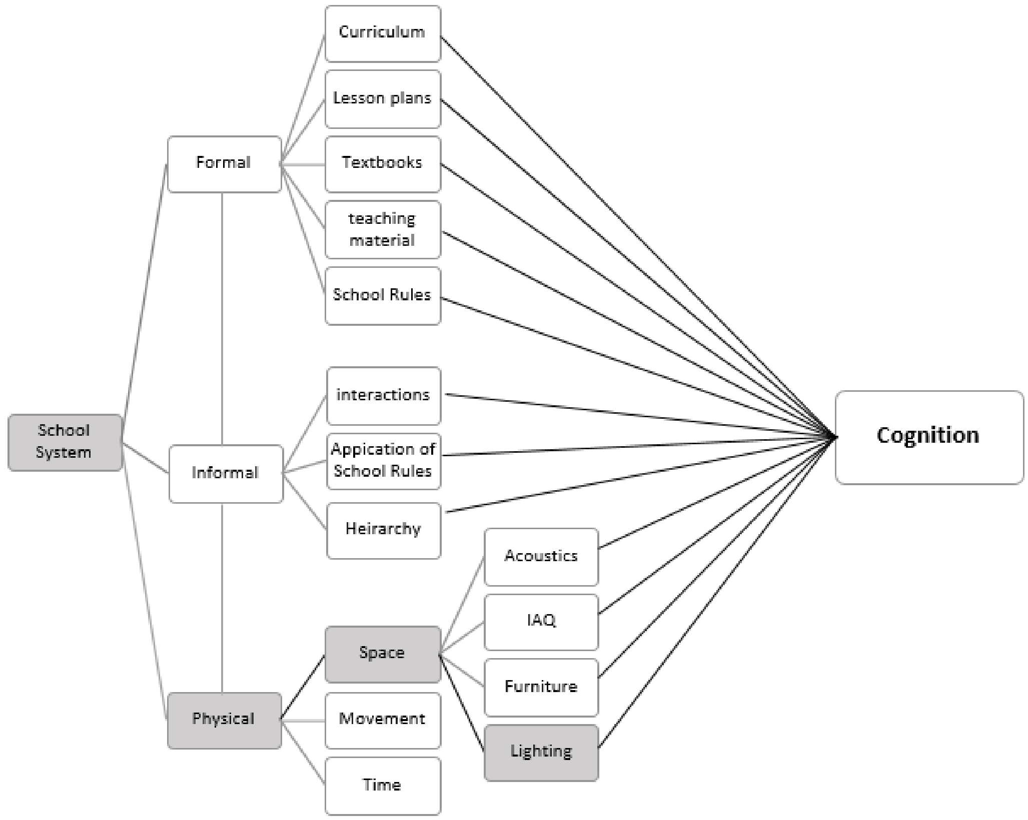

Figure 2.11: The Relationship of Interior Lighting in the Overall School System Layers Contributing towards Cognition

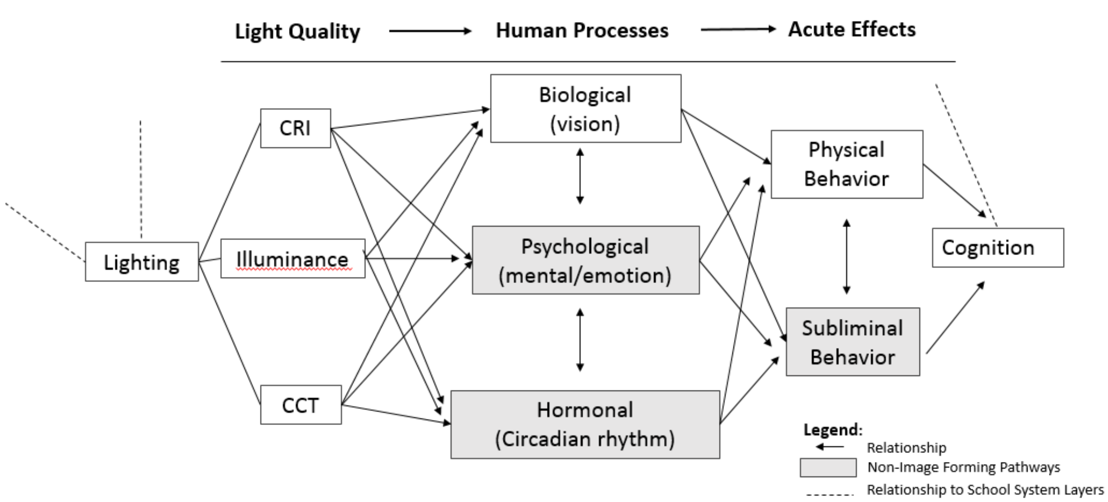

Figure 2.12: Refined Theoretical Framework within the Context of the School System Layers

Tables

Table 2.1

Average On-task Behavior Scores

Sequence	Average A	Average B	Lamp B- Lamp A
1	1.227	1.163	-0.064
2	1.350	1.152	-0.198
3	1.229	1.200	-0.030
4	1.289	1.391	0.102
5	1.241	1.102	0.140
6	1.265	1.194	-0.071
7	1.145	1.175	0.030
8	1.556	1.183	-0.373
9	1.116	1.146	0.031
10	1.168	1.169	0.001
11	1.184		
12	1.150	1.171	0.021
13	1.196	1.521	0.325
14	1.121	1.147	0.026
15	1.525	1.140	-0.385
16	1.286	1.185	-0.101
17	1.438	1.116	-0.322
18	1.083	1.119	0.036
19	1.349		
20	1.272	1.050	-0.221

Note: On-task behavior scored as 1.00 = on-task, 2.00 = half on-task & half off-task, and 3.00 = off-task behavior

A Case Study on the Influence of the CCT of Fluorescent Lighting on Student On-Task Behavior in an Elementary School Classroom

Chapter 3

Introduction

A school facility is an important environment for children since they spend six to ten hours a day there (Maxwell, 1999) which is over one thousand hours a year (Ghaziani, 2010). Children are actively looking for cues from their environment on how to behave, how to view themselves (Lim & Barton, 2010), or what they can accomplish (Duran-Narucki, 2008). It has been shown that “poor achievement early in children’s lives is known to affect their later achievement” (Nichols, 2003, p. 118). Therefore, the state of classrooms and educational facilities have a direct influence on student academic success and development (Duran-Narucki, 2008; Evans, 2006; Uline, 2008).

Throughout childhood and adulthood physical, biological, and neurological processes occur (Wuermli, 2012). Cognitive development consists of 4 stages (Piaget, 1964) that are used to structure the American public school system curriculum (Wachs, 1981). Young children learn through activities in and around their environment so a well-designed environment will positively influence children’s learning (Duran-Narucki, 2008:Uline, 2008). Fewer distractions lead to more time spent actively engaged in the scholarly material and result in a more academically successful student (Fisher et al., 2014; Buyse et al., 2008) since learning is composed of the time spent on the task (Millman et al., 1983).

A successful classroom environment is one that embodies a good relationship between the teacher and the students (Stone, 2005) resulting in positive social, emotional, behavioral and developmental outcomes (Sutherland et al., 2013). Teachers often establish a classroom behavior management system to assist students with on-task behaviors. Along with the behavior management system teaching style, spatial pedagogy, and semiotic distance influence child classroom behavior (Kendon, 2010; Lim et al., 2012; Matthiessen, 2010). In summary, there is a connection between the multiple variables within a classroom that contribute to student academic success, performance, and cognition (Maxwell & Chmielewski, 2008).

One of the physical interior variables within a classroom environment is the electrical lighting (DeKort & Veitch, 2014; Evans, 2006; Veitch & McColl, 2010). Fluorescent fixtures are the most common type of lighting installed in school classrooms because of energy efficiency, low price point, and good color quality (Knez, 2014). Lighting not only influences cognitive performance but also affects how humans view the ambience and impression of the environment, alertness, the atmosphere, and productivity (Fleischer, et al., 2001; Heerwagen, 2010; IES, 2014). These actions occur because non-visual light travels through the eyes to the brain via the optic nerve. Light enters the part of the brain that unconsciously controls unwanted stimuli and transfers that into emotional behavior. Thus, indicating that some behavior takes place without conscious awareness. This occurrence is referred to as subliminal perception (Knez, 2014).

Subliminal perception from interior lighting can influence occupants on a biological, hormonal, and psychological level. Psychologically, humans perceive a room as brighter and more pleasant with higher CCT levels of lighting (Boyce, 2003; Fleischer et al., 2001; Wei et al., 2014). The biological effects of CCT and illumination levels influence human health, well-being, alertness, and sleep quality (Schlangen, 2010). Higher CCT levels of lighting affect heart rate (Deguchi & Sato, 1992, Hathaway, 1995), autonomic nerve tone, hormonal secretion, motor function (Yasukouchi& Ishibashi, 2005), and body temperature (Mukae & Sato, 1992).

Past interior lighting studies have been performed on the occupant's visual acuity and productivity within a space (DeKort & Veitch, 2014) mostly in the work place or laboratory setting. There are few empirically researched lighting studies in educational facilities or performed on students (Hathaway, 1995) beyond some limited studies (Kuman et al., 2008). This is due to socio-economic status, school policies, and teacher behavior, that are hard to control for in a classroom setting (Veitch & McColl, 2010), resulting in little educational facility research in the field of interior lighting.

The objective of the present study was to examine if a CCT level in a classroom setting influenced student on-task behavior. Studies show that, with the correct ballast, children have better visual acuity under fluorescent lamps (Knez, 2001). With budget constraints and half of American school buildings over the age of forty years (Evans et al., 2010; Uline, 2008); replacing or changing the lighting fixtures with new technologies will most likely not occur. Since codes and standards do not specify CCT levels for classroom lighting (IES, 2014), a case study was performed to uncover the appropriate CCT level of fluorescent lamps and how this variable contributes to an effective learning environment.

Method

Theoretical approach. A new theoretical framework was developed to explain the relationship between interior lighting and student behavior in a learning environment (Figure 3.1). The conceptual lighting framework is one segment and one variable within the Physical Layer of the overall framework. Lighting is one variable within the School System Layer framework (Figure 3.2).

The new framework suggests that the lighting of the interior space is composed of correlated color temperature, illuminance and color rendering index. Each of these components can independently influence human behavior through subliminal perception of the human biological, psychological and hormonal processes. In order to test the theoretical framework the process-based theory development strategy was used to deduct the testing hypothesis that a higher CCT of fluorescent lighting, in association with or independent of other variables in a classroom environment, will unconsciously produce more student on-task behavior.

School. This study took place in a second grade classroom in a K-5th grade public school in Oregon that implements the Common Core State Standards. According to the 2013-2014 Report Card, this school is the second highest ranked public elementary school of the nine in the district and has an average of 94% rating 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).

Sample. Twenty-seven students, 16 males and 11 females, participated in the study. Ages were between seven and eight years old. 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” (Figure 3.3). The number of and gender of the children were recorded at each table since children relocate periodically.

No students in the class were visually overweight, unhealthy, or had any physical disablement. Throughout the course of the study two students, one male and one female, started to wear eyeglasses. No other students had any visual eye constraints.

Protocol. A Parent Notification letter was sent home with all students a week prior to the start of this study (Appendix A). No parents objected to the study. The control lamp, Lamp A (Philips F32T8/TL830/ALTO), which has a CCT of 3000K and a CRI of 85 was installed first. After a two week adjustment period, data collection followed for two weeks (Figure 3.4). At the end of the observation period the lamps were changed to Lamp B (Philips F32T8/TL841/ALTO) which has a CCT of 41000K and a CRI of 82. Another two week adjustment period occurred and then data was 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.

Classroom. The classroom had fifteen troffer light fixtures lamped with two T8 lamps (Figure 3.5). At the start of the study, new lamps and ballasts (Phillips Advance ICN2P32N351) were installed. The 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 the observation period. The illumination levels at each tables were recorded twice each day. To control for outside variables, the window blinds were turned to the horizontal position and the back corner lights were turned off. Refer to Figure 3.6 and Figure 3.7 for photos of the room.

Interior environment variables. Environmental variables must remain constant since a change in one variable may create a change in another (Zeisel, 2006). Temperature, noise levels, relative humidity, and illumination levels were documented (Table 3.1). Other variables were documented because they are part of the School System Layer framework. The variables of scholastic subject, time of day, day of week, and type of work were recorded for their contributing relationship, either independently or with CCT, towards on-task behavior.

Teaching style. The teacher has over seventeen years of teaching experience, mostly in upper elementary, but the past four years were in early elementary education. She went to a liberal arts college with the intent to continue her education at law school but after a term in law school changed to teaching. Her goal was to "help children not defend children" (A. Criscione, personal communication, February 11, 2015).

Her teaching style is eclectic and focuses on project-based learning. She describes this as hard to assess but allows for flexibility to adapt the assignment or project to each student so they are always challenged and therefore learning (A. Criscione, personal communication, March 12, 2015). She promotes individuality in student learning by adding or changing assignments for the students that are excelling in certain subjects (A. Criscione, personal communication, April 16, 2015).

She does not consider herself a traditional teacher that requires students to sit quietly in their chairs with feet on the floor and backside in the seat. She prefers not to follow the same schedule or repeat curricula in the same order. Her discipline style is individual and incorporates positive behavior management techniques (A. Criscione, personal communication, March 12, 2015).

Procedure. The study used non-participant group observations of behavior through recording both on-task behaviors and behavior mapping techniques. The researcher recorded on-task group behavior using a time-interval sampling method and behavior mapping using a pre-developed data collection sheet. During the two week observation periods, these two data collection recording methods alternated days. 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 follows the school's academic schedule (Appendix E).

Quantitative methods. Observations of 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 and a pre-developed observation data sheet (Appendix C). On-task behavior scored '1' if three of the four students at that table were doing the class activity. Off-task behavior scored a '3' if three of the four students at the table were doing 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 '2'. On-task behavior was classified into three categories, referred to as type of work. The categories are active listening, independent desk work, group work, or the transition between the tasks and scored '1' through '4' respectively. 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 of on-task behavior.

Behavior was only recorded while students were located at the tables. The observation order of tables was randomly selected using a random number generator. One researcher collected data over a five month period (Appendix B). 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.

Qualitative methods. The student's classroom movements were recorded every minute for 15 minutes on the floorplan (Appendix D). After the first student was observed, another student was observed in a similar manner. Six students were observed during each observation day. Illumination levels, minimum and maximum noise levels, temperature, and relative humidity were documented. Fifty-eight observations were performed under Lamp A. Thirty one were males, 25 were females and gender was not recorded for two observations due to researcher oversight. Fifty-nine observations were performed under Lamp B. Thirty-eight were male and 19 female while gender was not documented for two of the observations due to researcher oversight.

Teacher interview. Informal interviews with the teacher occurred on the Fridays of the two observation weeks throughout the study. The interview gathered data on her background experience, teaching philosophy, and teaching style. The interview found themes in the data and added another dimension to answer "why" or "how" the lighting influenced student behavior.

Analysis

Quantitative. Averages of on-task behavior scores and CCT, scholastic subject, type of work, day of the week, and time of day 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 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 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 (Neuman, 2011; Pardoe, 2012).

Qualitative. The movement mapping and teacher interview data analysis was done following the three types of qualitative data coding methods of open coding, axial coding, and selective coding (Neuman, 2011). Student and teacher 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. The female students were color-coded pink and male students blue. 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. This pattern was repeated for the teacher as well. There were 9 undocumented teacher locations for the 3000K CCT and 10 undocumented teacher locations for the 4100K CCT due to researcher oversight.

Results

Paired-samples t-test. A paired-samples t-test determined that students had more on-task behavior under the classroom lighting of 4100K CCT compared to the lighting of 3000K CCT (M = .033, 95% CI [.002, .065], $t(154) = 2.103$, $p < .05$).

Correlations. Analysis with all variables resulted in on-task behavior and scholastic subject and the interaction between on-task behavior and CCT is significantly correlated, as well as, type of work is significantly correlated with scholastic subject, CCT, and day of week. (Table 3.2). Correlations comparing the two different CCT lighting conditions on all variables indicated that under the 4100K CCT lighting, on-task behavior and types of work, scholarly subject and time of day were correlated (Table 3.3). Under the 3000K CCT lighting, correlations between on-task behavior and type of work and scholastic subject were significant (Table 3.4).

Boxplots. The boxplot of type of work and student on-task behavior revealed that transition between types of work had a large variation between the lighting conditions. The boxplot indicates that students were more off-task under the 4100K lighting situation during transitions, while they appear to be fairly close to on-task behavior (a score of 1.0) during transitions under the 3000K lighting (Figure 3.8). The boxplot on scholastic subjects and on-task behavior revealed that the transition between scholastic subjects had a large difference with more on-task behaviors under the 3000K CCT as compared to the 4100K CCT lighting situation (Figure 3.9).

Multiple Linear Regression. Multiple linear regression was used to test all relationships among on-task behavior, scholastic subject, CCT, day of the week, and type of work. Results indicate that on-task behavior, scholastic subject, CCT and type of work are statistically significant on predicting on-task behavior (*adj.* R^2 = .025, $F(3, 335) = 3.933$, $p < .01$) (Table 3.5).

Further investigation on the interacting relationships between the variables of scholastic subject and on-task behavior in regards to CCT uncovered scholastic subject independently is significant with CCT (*adj.* R^2 = .028, $F(3, 335) = 4.201$, $p < .01$), and without CCT (*adj.* R^2 = .027, $F(4, 334) = 3.305$, $p < .05$). According to Cohen's effect size (Lund & Lund, 2013), the adjusted R^2 are considered small and no further conclusions can be deducted. Refer to Table 3.6 for regression coefficients and standard of errors of the interacting effects.

Multiple linear regression was performed on all variables independently to compare the two lighting conditions. Results indicate that scholastic subject independently 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 3.7). Inspection into scholastic subject indicated that transition of subject is statistically significant at predicting on-task behavior under the 4100K CCT. ($F(1,132) = 4.382$, $p < .05$, adj. $R^2 = .025$) (Table 3.8). Further investigation of type of work independently resulted in group work and transition between work types as statistically significantly at predicting on-task behavior ($F(2, 131) = 6.224$, $p < .003$, adj. $R^2 = .073$) (Table 3.9).

Combinations of variables were compared under the two lighting conditions resulting in scholastic subject combined with type of work are statistically significant at predicting on-task behavior with CCT ($F(4, 334) =4.369$, $p < .05$, adj. $R^2 = .038$) and without CCT ($F(3,335) = 5.728$, $p < .001$, adj. $R^2 = .040$) (Table 3.10). The combination of time of day, scholastic subject, and type of work are statistically significant at predicting on-task behavior with CCT ($F(5, 333) = 3.460$, $p < .05$, adj. $R^2 = .035$) and without CCT ($F(4, 334) = 4.282$, $p < .05$, adj. $R^2 = .049$) (Table 3.11). Finally, the combination of time of day and scholastic subject are statistically significant at predicting on-task behavior with CCT ($F(4, 334) = 4.517$, $p < .001$, adj. $R^2 = .040$) and without CCT ($F(3,335) = 5.28$, $p < .0015$, adj. $R^2 = .042$) (Table 3.12).

A line graph of time of day (Figure 3.10) revealed that student on-task behavior starts at approximately the same in the morning hours but varies throughout the day between lighting situations. 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. 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.

Qualitative. Observation notes did not result in many differences between student activities under the 4100K CCT lighting compared to the 3000K CCT lighting. The following are the emerging themes and summary of student activities that occurred under both lighting conditions.

The term *fidgety* appeared in almost every observation. Students sat with their legs crossed underneath them or one leg bent underneath them instead of sitting traditionally, with both feet on the floor and backside in the chair. Students sat sideways in chairs to view the front of the room. Students stood and sat repeatedly while remaining at their desks. This behavior only occurred in the morning hours during language arts instruction and considered on-task behavior.

Student movement throughout the room had various forms. Students moved when asked by the teacher for assignments, during independent reading time, or during transitions between scholastic subjects or breaks. When students were out of their seat, they had off-task behaviors in the form of talking with peers. Off-task behaviors occurred during transitions between scholastic subjects and while leaving and entering the room for breaks. Transitions ranged from an average of 3 to 5 minutes for the 3000K CCT and between 10 to 20 seconds to 3 minutes in length for the 4100K CCT.

Students appear to be more on task during active listening assignments (even when the majority of them had to sit sideways in their chairs to see the board) over independent deskwork assignments unless the independent deskwork was in the morning hours.

When students sat on the carpet, off-task behaviors occurred. Students typically went to the carpet during independent reading time, group work, or asked by the teacher in order for the student to follow the lesson on the markerboard. This occurred more frequently with females and when two or more female students were sitting at the carpet. This did not occur when a male and a female or two males were sitting on the carpet. Most talking at the tables occurred between students of the same gender. A table with four male students appeared to have more off task behaviors in the form of talking and playing than a table with mixed gender.

The students are good at screening outside influences. The students, as a whole, did not stop to make eye contact with the teacher when she would make a class announcement in the middle of an independent deskwork assignment. However, the class, as a whole was distracted and many off-task behaviors occurred when older students were in the room whether it was a class of 5^{th} graders, a few high school student helpers, or the teacher's 13-year-old daughter. However, certain noises, such as the bell ringing out of time one day because of a power outage causing the system to be off, gained their attention. They did not acknowledge a phone ring or someone at the door until the teacher made a movement or acknowledgement of that noise or action.

Students looked around the room, out the window, and at their peers quite frequently. If the student finished the assignment early, they looked at their peers for guidance at what they should be doing next, however, some early finishers talked with their tablemates. Most of the time resulted in off-task behavior for both students. In fact, three different students on three different days put their head on the table for 10 to 20 seconds in what appeared to be a bored or tired action under the 4100K CCT.

Finally, student on-task behavior depended on where the teacher was located. When she was in the front of the room explaining the lesson, most students were on task as well as when she walked around the room from table to table. The table that she was visiting was on-task and those tables immediately around her but the tables not located directly by her were off-task. Most off-task behaviors occurred when she was at the jellybean table with a small group of students. However, this was not necessarily true every time. Twice, under the 4100K CCT, two male students, sitting at Tables 1 and 6, were on-task during the whole observation time while the teacher was at the jellybean table working with a group of students.

Qualitative comparing Lamp A and Lamp B. Figure 3.11 and Figure 3.12 shows the initial results of the student and teacher movement in the classroom. The floorplans indicate that students frequented the water fountain and cubbies equally under each lamp. Students appeared to 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. There also appeared to be more students gathering on the carpet and at the teacher's desk in the 4100K CCT than the 3000K CCT.

The gender frequencies (Figure 3.13) 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 3.14 shows the overall locations in the rooms that were most frequented by the student regardless of gender.

The results from the teacher frequency plan (Figure 3.15) indicate that the teacher was at her desk lecturing more during 4100K CCT than 3000K CCT. She was at the jellybean table more under 3000K CCT. More students went to the jellybean table in the 4100K CCT independently of the teacher as well as the teacher desk area. She stayed at her desk more during the 4100K CCT, yet students frequented her desk area more under the 3000K CCT.

Qualitative: Teacher interview. The teacher had various mixed feelings regarding if the students as a whole class were on-task or off-task. She said, during the 3000K CCT, “I don’t know if it’s the lights or the students maturing or perhaps it’s after the holiday rush but they seem to be better. Noticeably better recently” (A. Criscione, personal communication, January 27, 2015). She also mentioned that she was extremely tired one day of the 3000K CCT. Upon further conversation, another teacher suggested that the full moon may be the cause of the class behavior problem. (A. Criscione, personal communication, February 2, 2015). The researcher did not observe or document any unusual amount off-task behaviors that day.

Other informal interviews uncovered that she noticed the students were “more focused” on a Monday under the 3000K CCT. She further explained that it may be the fact that they had three days off for parent teacher conferences and perhaps that had something to do with their focused attention (A. Criscione, personal communication, April 14, 2015). This conflicted with the data collection results that indicated the students were off-task most of that day.

After observing a class discussion between the teacher and students in the 3000K CCT, the students felt they were more focused in the morning hours. That discussion also uncovered that the students' least favorite part of the day, because it felt the longest, is the time between 2:00 pm - 2:30 pm. The teacher revealed that she prefers the morning hours (A. Criscione, personal communication, April 15, 2015).

Discussion

The present study reports that the 4100K CCT lamp elicited a statistically significant increase in students on-task behavior compared to the 3000K lamp (M = .033, 95% CI [.002-.065], $t(154) = 2.103$, $p < .05$). Additional inquiry on the data through correlations and multiple linear regression found certain variables had significant association by themselves and in combinations towards on-task behavior under the two different lighting situations.

Scholastic subject and type of work showed statistical significance in regards to student on-task behavior. Transitions of scholarly subjects and types of work had negative correlations to student on-task behavior. This may be caused by the fact that transitions occurred during the time the researcher was not observing. Since the subjects of reading, writing, and spelling are similar, no transition is needed to change scholastic subjects.

The qualitative observations recorded that students were more on task depending upon where the teacher was located. More off-task behaviors occurred, under both lighting situations, when the teacher was at the jellybean table with a small group of students. Table 1 and Table 6 were more off-task when she was located at the jellybean table, thus one would assume that the student's behavior coincides with the teacher's physical distance. This is consistent with previous research on classroom special pedagogy.

The same off-task behaviors occurred under both lighting situations with distractions such as a phone call. The results of this study were consistent with previous studies that show the noise levels, primarily acute noise, in the classroom have an impact on student attention (Evans & Stecker, 2004). The results were consistent with the orienting reflex theory in that an unexpected noise, such as the bell ringing off schedule, caused a distraction whereas a constant familiar noise such as student talking, or someone opening the classroom door, did not (Sheldon et al., 2009).

Educational research suggests that time of day and student academic success are correlated as was confirmed in this study. Students are more on-task during their favorite time of day which, for this younger group of students, would be the morning hours (Holloway, 1999; Wile & Schoupe,2011) as observed in the class discussion.

When time of day is associated with scholastic subject, results indicate there is a positive relationship between math and time of day under the 4100K CCT. This is not necessarily consistent with the educational literature, however, the math lesson was usually taught in the form of group work. Even though studies suggest younger students are more focused in the morning hours (Holloway, 1999), having math in the afternoon combined with group work, which by itself contributes to on-task behaviors, still contributes to on-task behaviors.

The type of work is a variable that influenced student on-task behavior. The observations revealed that students were mostly off-task while doing individual deskwork yet on-task while active listening and performing group work regardless of lighting condition. When types of work were combined with scholastic subject, relationships among these variables were present regardless of CCT.

Furniture is another reoccurring variable that was present in the study. Observations uncovered how students sat in their chairs. This aligns with previous studies that the furniture layout and furniture fit are important variables within a classroom (Parcells, Stommel, & Hubbard, 1999). This study corresponds with Wingrat and Exnar (2005) study that illustrated furniture layout is important so that students do not have to move positions in their seats to see the front of the classroom where the markerboard is located.

Furniture fit also contributed to student movement regardless of lighting situation. This classroom contained one size chair with a seat height measured at 14" high. The table height measured 25" high. Both of these heights are appropriate for students in this grade level (Smith-Zuzovsky & Exner, 2004), however, the operational phase of development states that children grow at different rates (Wachs, 1980), and therefore need different sizes of furniture (Parcels et al., 1999; Smith-Zuzovsky & Exner, 2004). The results conclude that size and layout of the student furniture is a contributing factor towards student movement.

Observations conclude that the students respected the teacher. The teacher implemented good classroom management techniques within the classroom, under both lighting conditions, as made apparent by consistent and predictable behavior management practices (Stone, 2005). Studies show that teachers who give positive feedback for appropriate student behaviors had better overall classroom behavior than when teachers reacted to negative student behaviors in a irritable or coercive way (Leflot, Van Lier, Onghena, & Colpin,2010).

Limitations.

This study was performed in a classroom environment. It lacks representative reliability due to a small sample size, however the study can be replicated. A limiting factor studying an actual classroom environment is that changes in the classroom interior occur from educational activities. Although 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 often was not possible. Another limiting factor was that only one observer collected data which introduced bias, finally, outside factors such as diet, sleep, home life situations, illness, exercise and parental support affect student readiness to learn (Moore, 2011) and could not be recorded.

Conclusions

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 combination of variables are present that contribute towards student success.

The results concur with other lighting studies that indicate lighting as an unconscious stimulus (Knez, 2014). The lighting entered the brain through the eyes 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 of the lighting.

The higher CCT of the lamp makes the pupil constrict (Berman et al., 2006; Goodman, 2009). Due to this constriction of the pupil the light rays are directed towards the central part of the eye where vision quality is better (Berman et al., 2006). Thus, the smaller the pupil size the greater the depth of vision and better visual acuity (Veitch & McColl, 2010). Students may have had better visual acuity under the lamps with a higher CCT and therefore had more on-task behaviors instead of becoming distracted due to poor vision.

On-task behavior changes could be due to different frequency rates between the two lamps. Frequency rates influence visual acuity and performance. Low flicker rates that occur in low frequency lighting reduce visual performance. Even though frequency rates are not visible to the human eye, some special populations are still affected by them (Knez, 2014; Veitch & McColl, 2010). Occupants sensitive to flicker feel more stressed when under lower frequency lamps (Knez, 1014). Since lamps with a higher CCT have higher frequency (Veitch & McColl, 2010) it could be 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 and off-task behaviors while under the lamps with a lower CCT.

The fluorescent lighting with the 4100K CCT resulted in more on-task behavior because a higher CCT in lighting is perceived by the viewer as having a higher illumination level though it measured the same lux as the lighting with a lower CCT. Occupants view lighting with lower CCT as intimate and compensate behaviors by waiting longer to answer questions and decreasing in eye contact (Carr & Dabbs, 1974). A higher illumination level has been shown to increase alertness and arousal (Berman et al., 2006; Biner, Butler, Fischer, & Westergren, 1989; Smolders & De Kort, 2014; Wei et al., 2014). This increased alertness in the higher CCT may unconsciously influence students to be more on-task.

More students moved around the room, specifically male students, under the lighting of 4100K CCT than the 3000K CCT. Higher CCT of the lighting is more activating (Deguchi & Sato, 1992) because it increases human cortisol levels thus increased arousal (Kuller & Wetterberg, 1993). This 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). This is consistent with results by Knez and Kers (2000) in which different genders responded differently to the correlated color temperatures with shifts in their moods and higher activity levels in men under 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.

Students often looked around the room and to their peers to find out what they should be doing or how they should be behaving, regardless of lighting type. The time the student spent in this behavior was off-task. In a classroom environment, the presence of others in the room can promote or hinder student on-task behaviors (Barth et al., 2004) and is referred to as social facilitation (Biner et al., 1989). A concept within social facilitation is the co-action effect, which states that when individuals are placed within a group setting their working patterns matched those around them (Zajonc, 1965). The observation results indicated that social facilitation occurred in the classroom independent of lighting condition.

The teacher's behavior management skills are correlated to the student classroom behavior (Leflot, et al., 2010) regardless of the lighting situation within the classroom. It was evident that the teacher implemented positive behavior management techniques that led to positive classroom behaviors (Stone, 2005). Since this was a consistent practice throughout the course of the study under both lighting situations, this variable needs to be mentioned and should be accounted for in future studies but did not change or contribute towards the results of this study.

This study also supports the concepts behind semiotic distance and spatial pedagogy in regards to the teacher (Lim et al., 2012). Her location and actions throughout the classroom had an influence on student behavior regardless of the lighting type. Students were more on task when she was physically located closer to them in the Interaction space or had their attention teaching in the Authoritative space (Lim et al., 2012). The students themselves were more on task when located in their seats than at various other locations within the room.

In conclusion, this study, as well as information from the literature review confirm that multiple variables contribute to the interior classroom environment and student success. These environmental variables, some of which can be controlled for such as the amount of light, indoor air quality, noise levels, or furniture and those that cannot such as teacher behavior management techniques, student individuality, and school funding, all contribute to the overarching concept of school climate that includes all elements within the School System Layer framework. A high quality school climate is linked to high levels of student academic success (Uline, Wolsey, Tschannen-Moran, & Lin, 2010). It is therefore important that these variables, together and individually, be studied to verify their contribution to the school climate which influences student success.

Figures

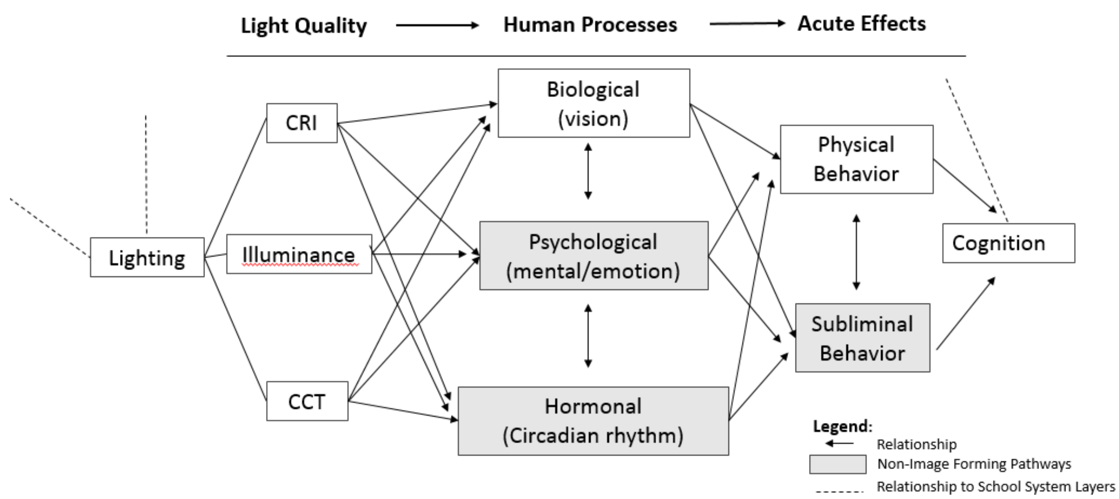

Figure 3.1: Proposed Theoretical Framework as Part of the School System Layers

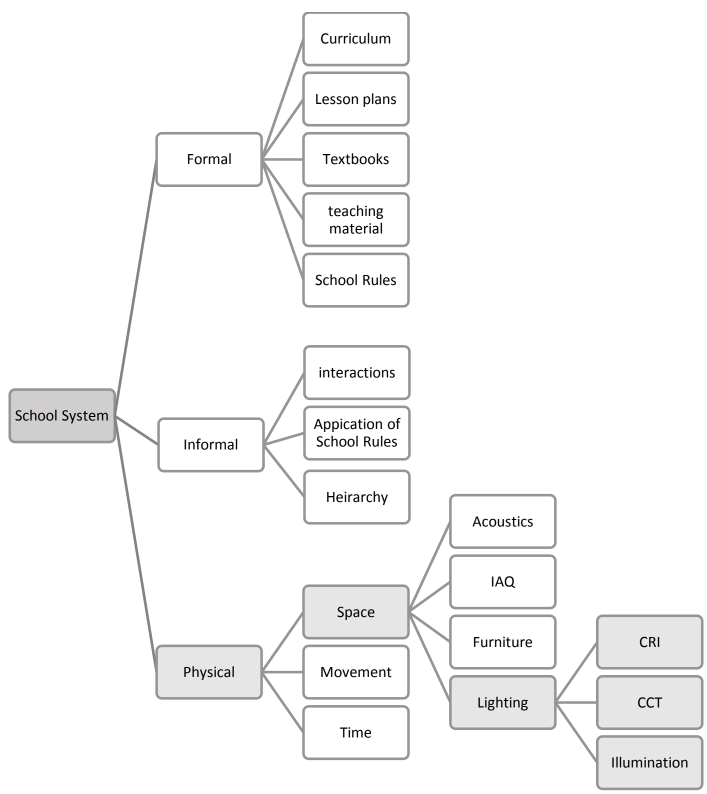

Figure 3.2: School System Layers with the Influence of Lighting Shown in Grey (Gordon et al., 2005)

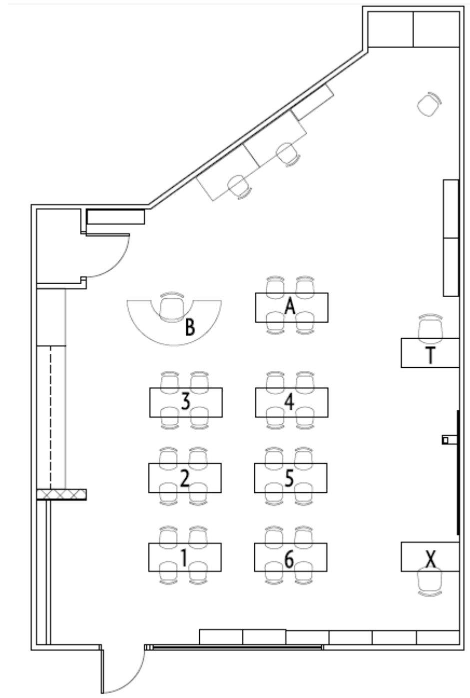

Figure 3.3: Hoover Elementary Room 1 Floorplan

	Fall/14										Winter/15										Spring/15									
	Week																													
Activity	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Students under Lamp "A"													X	X	X	X					X	X	X	X						
Students under Lamp "B"									X	X	X	X					X	X	X	X										
Observe Classroom (alternate days w/ on-task obserations and movement mapping)											X	X			X	X			X	X			X	X						
Analyse and Evaluate												X				X				X				X	X	X	X			
Summarize Findings																										X	X			

Figure 3.4: Weekly Time Frame

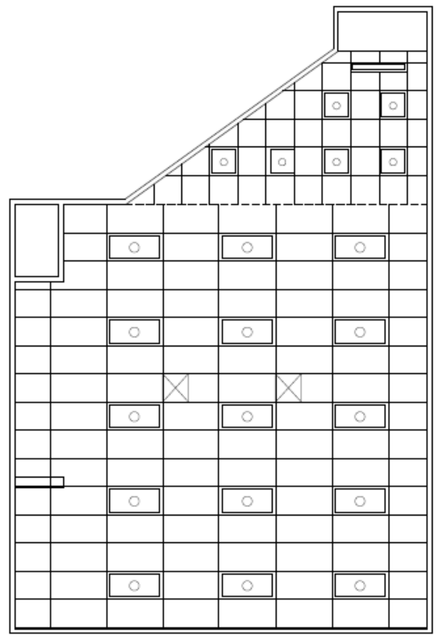

Figure 3.5: Hoover Elementary Room 1 Reflected Ceiling Plan

Figure 3.6: Photo from the Back of the Classroom – Lamp A on Left and Lamp B on Right

Figure 3.7: Photo from the Front Door – Lamp A on Left and Lamp B on Right

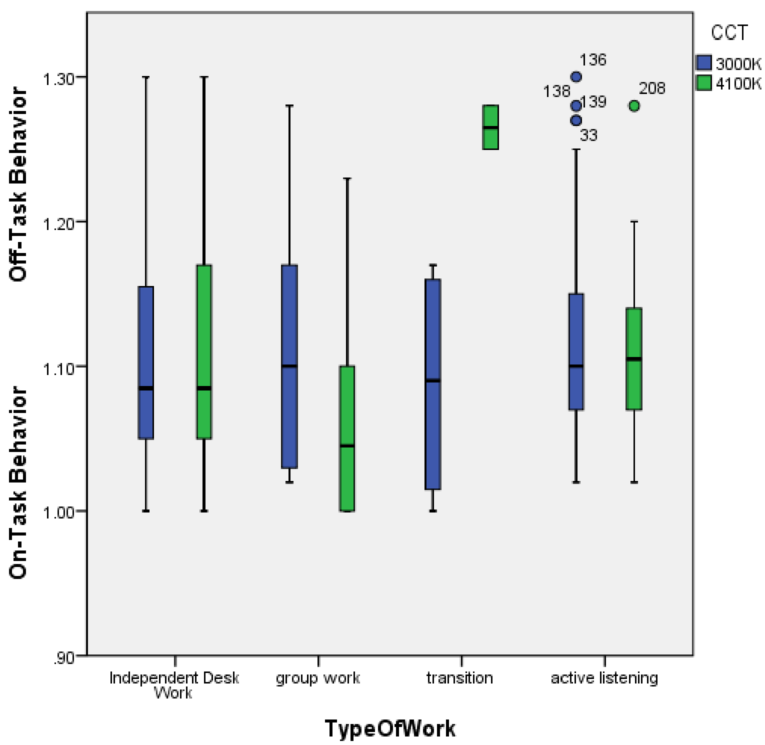

Figure 3.8: Boxplot of Type of Work and On-Task Behavior

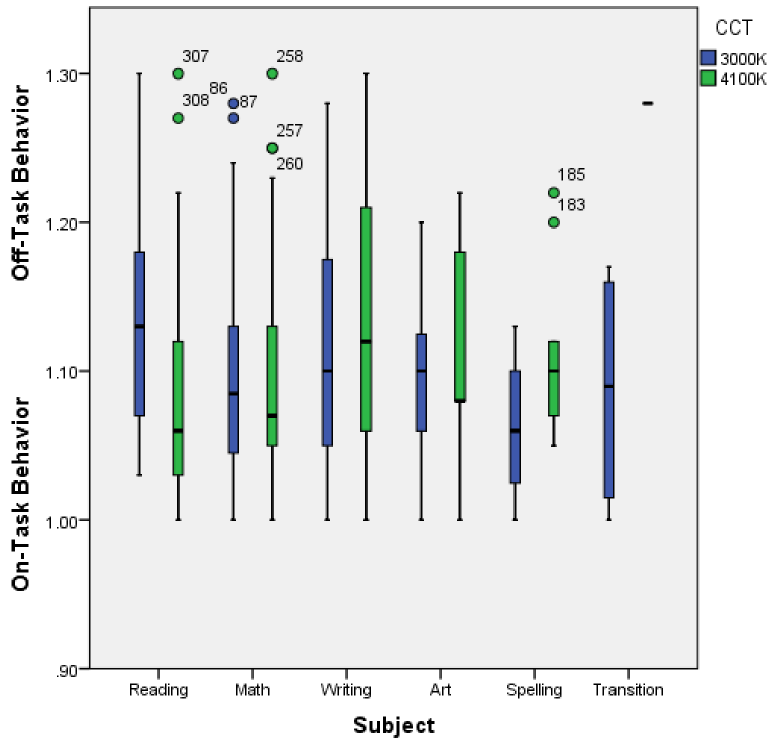

Figure 3.9: Boxplot of Scholastic Subject and On-Task Behavior

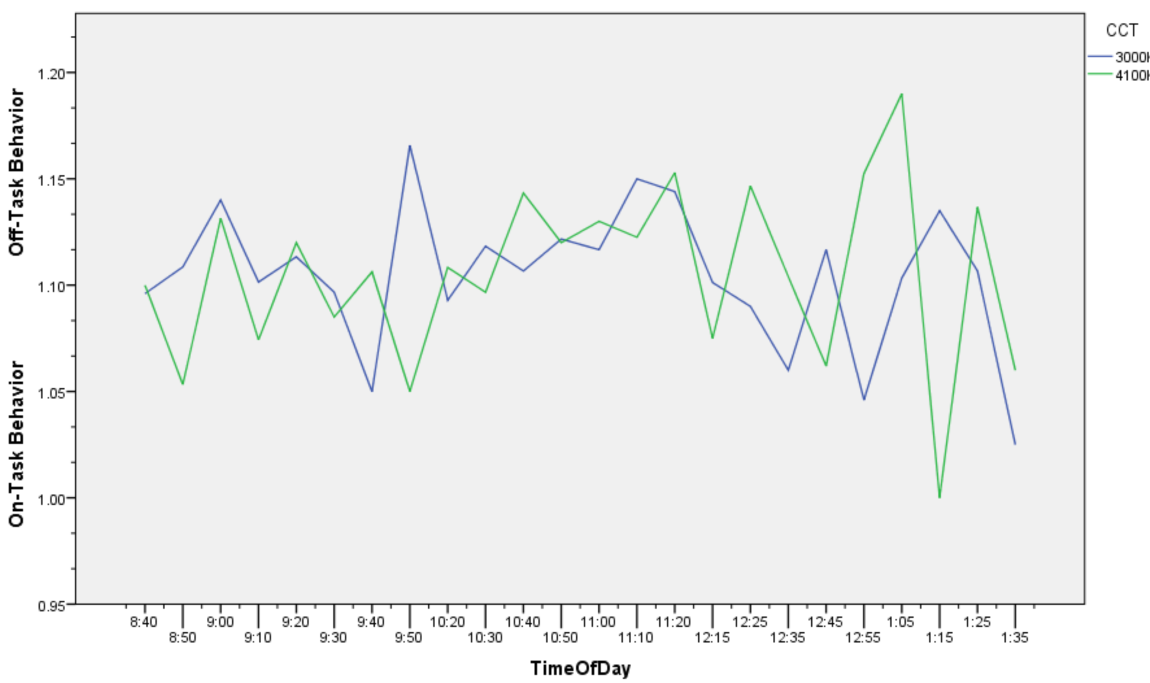

Figure 3.10: Line Graph of Time of Day and On-task Behavior

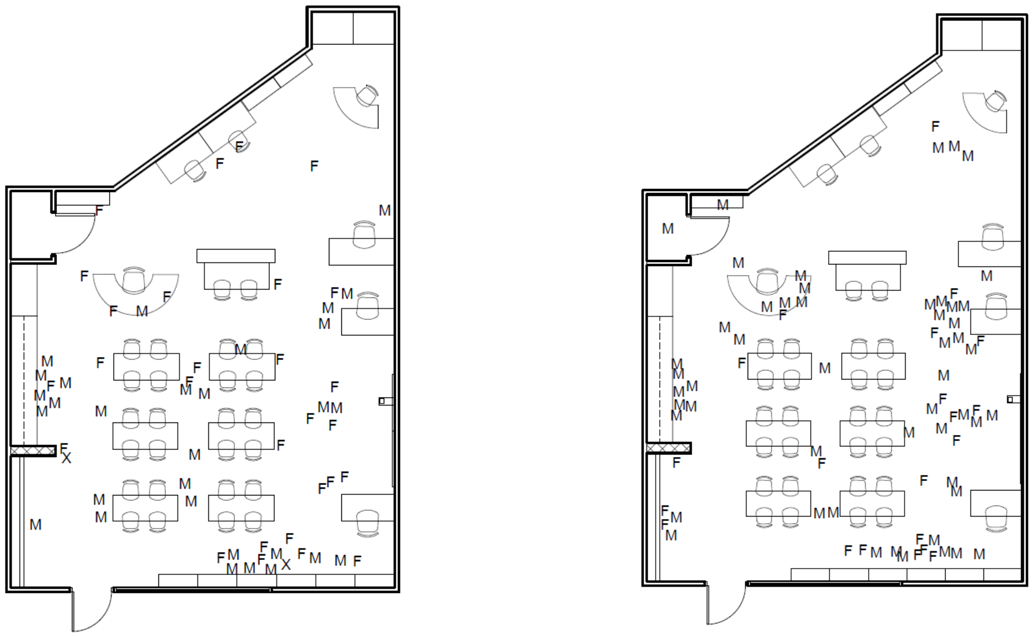

Figure 3.11: Initial Results of Student Movement Mapping – Lamp A on left and Lamp B on Right

Figure 3.12: Initial Results of Teacher Movement Mapping – Lamp A on left and Lamp B on Right

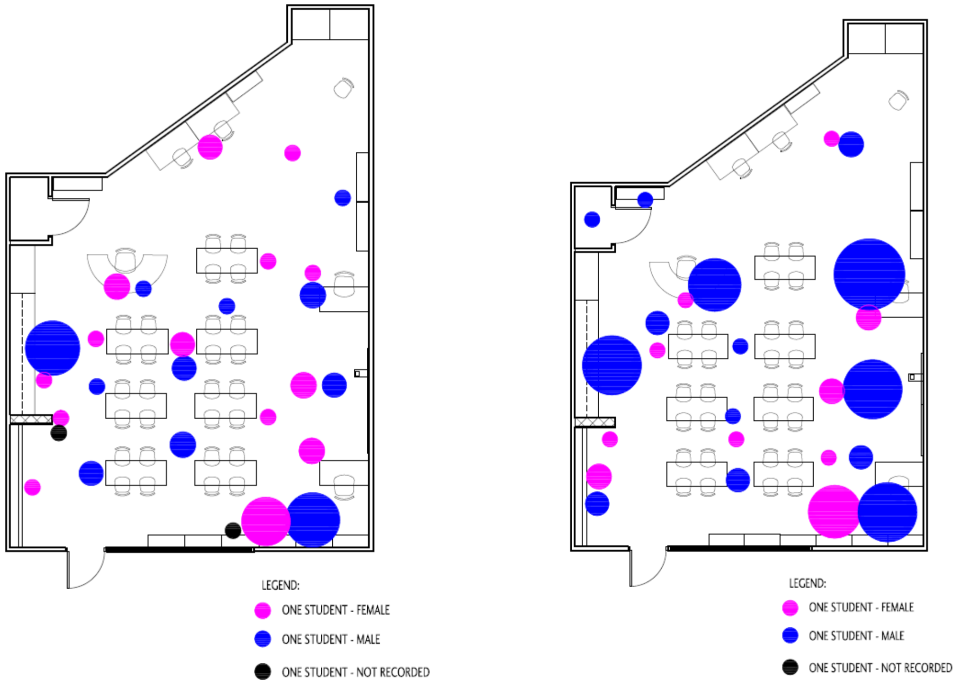

Figure 3.13: Frequency Results of Student Movement Mapping by Gender - Lamp A on Left and Lamp B on Right

Figure 3.14: Overall Results of Student Movement Mapping – Lamp A on left and Lamp B on Right

Figure 3.15: Results of Teacher Frequency Movement Mapping – Lamp A on Left and Lamp B on Right

Tables

Table 3.1

Averages of Classroom Minimum and Maximum Noise Levels, Illumination, Temperature, and Relative Humidity

Sequence	Noise: Min A	Noise: Min B	Noise: Max A	Noise: Max B	Temp A	Temp B	Avg Lux A	Avg Lux B	RH A	RH B
1	48	33	107	67	18	19	726	838	63	60
2	52	52	80	79	20	18	707	781	60	51
3	46	49	77	111	22	19	688	748	57	50
4	63	46	113	105	19	18	715	396	57	51
5	65	52	111	111	21	19	720	738	51	52
6	52	66	84	113	20	18	793	660	53	53
7	56	61	75	111	20	18	619	681	63	59
8	61	48	106	108	20	18	664	740	59	58
9	55	57	101	106	21	19	617	716	58	43
10	61	46	111	80	21	19	734	692	59	45
11	57	39	79	71	20	19	725	745	59	44
12	62	53	113	100	20	21	739	717	58	44
13	56	46	110	77	19	20	661	691	60	56
14	52	49	78	77	20	19	835	709	57	54
15	60	47	110	110	18	21	701	685	59	45
16	54	53	108	80	19		739	741	60	
17	48	48	79	79				820		
18		68		113				770		
19		49		111						
20		48		108						
21		59		113						
Average:	52	51	97	97	20	19	711	715	58	51

Note: Noise levels measured in decibels, temperature in Celsius, illumination in lux, and relative humidity in percent.

Table 3.2

Descriptive Statistics and Zero Order Correlation Matrix of All Variables

Variables	Mean (SD)	2	3	4	5	6	7
1. 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 3.3

4100K CCT Lighting Descriptive Statistics and Zero Order Correlation Matrix Including All Variables

Variables	Mean (SD)	2	3	4	5
1. Behavior	1.175(.18)	0.179*	0.306**	0.054	-0.052
2. Time of Day	12.25 (6.26)		-0.025	0.284**	-0.172*
3. Scholastic Subject	1.57 (1.24)			-0.015	0.151
4. Type of Work	.70 (1.15)				-0.292**
5. Day of Week	1.92 (1.37)				

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

Table 3.4

3000K CCT Lighting Descriptive Statistics and Zero Order Correlation Matrix Including All Variables

Variables	Mean (SD)	2	3	4	5
1. Behavior	1.162 (.14)	-0.107	0.021	0.005	-0.065
2. Time of Day	12.15(6.52)		-0.067	-0.112	0.054
3. Scholastic Subject	1.51 (1.244)			-0.230*	0.001
4. Type of Work	1.08 (1.33)				-0.025
5. Day of Week	1.85 (1.36)				

Note:*Significant at the p<.05 level

Table 3.5

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

Variable	Model 1			Model 2		
	B	*SE B*	β	*B*	*SE B*	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	
F for change in R^2		4.201			0.63	

Note: *Significant at the p<.01 level

Table 3.6

Summary of Regression Analysis for the Interaction of Scholastic Subject and CCT Predicting On-Task Behavior (N=339)

Variable	Model 1			Model 2		
	B	*SE B*	β	*B*	*SE B*	β
Intercept	1.168	0.009		1.168	0.009	
Scholastic Subject	0.023	0.007*	0.172	0.023	0.007*	0.173
CCT	0.011	0.017	0.035	0.011	0.007	0.017
Scholastic Subject x CCT				0.042	0.014*	0.160
R^2		0.031			0.057	
F for change in R^2		5.419			9.103	

Note: Scholastic subject and CCT were centered around their means. *Significant at the p<.01 level

Table 3.7

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)		
	B	*SE B*	β	*B*	*SE B*	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	

F for change in R^2	0.665	6.032

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

Table 3.8
Summary of Regression Analysis for Scholastic Subject on Predicting On-Task Behavior Under the Different CCT Levels (N=147)

Variable	Model 1 (3000K CCT)			Model 2 (4100K CCT)		
	B	*SE B*	β	*B*	*SE B*	β
Intercept	1.164	0.019		1.171	0.022	
Math	-0.034	0.027	-0.108	0.007	0.032	-0.018
Art	-0.068	0.041	-0.131	0.064	0.052	0.093
Spelling	0.076	0.057	0.103	-0.033	0.056	-0.044
Transition	0.094	0.061	0.119	0.459	0.076*	0.440
Reading	0.031	0.014	0.093	-0.053	0.036	-0.118
R^2		0.072			0.229	
F for change in R^2		2.646			9.242	

Note: *Significant at the p<.001 level

Table 3.9
Summary of Regression Analysis for Types of Work on Predicting On-Task Behavior Under the Different CCT Levels (N=147)

Variable	Model 1 (3000K CCT)			Model 2 (4100K CCT)		
	B	*SE B*	β	*B*	*SE B*	β
Intercept	1.104	0.008		1.111	0.008	
Active Listening	0.016	0.014	0.101	0.000	0.018	-0.001
Group Work	0.009	0.020	0.040	-0.049	0.023*	-0.182
Independent Desk Work	0.016	0.038	0.110	-0.154	0.058	-0.847
Transition	-0.016	0.038	-0.036	0.154	0.058*	0.225
R^2		0.012			0.087	
F for change in R^2		0.582			4.118	

Note: *Significant at the p<.05 level

Table 3.10

Summary of Regression Analysis for the Interacting Effect of Scholastic Subject and Type of Work on Predicting On-Task Behavior With and Without CCT (N=147)

Variable	Model 1			Model 2		
	B	*SE B*	β	*B*	*SE B*	β
Intercept	1.149	0.018		1.144	0.021	
Type of Work x Scholastic Subject	0.015	0.006*	0.217	0.014	0.006*	0.212
Subject	0.009	0.009	0.067	0.009	0.009	0.069
Type of Work	-0.013	0.011	-0.102	-0.012	0.011	-0.094
CCT				0.010	0.018	0.031
R^2		0.049			0.050	
F for change in R^2		5.728			4.369	

Note: *Significant at the p<.05 level

Table 3.11

Summary of Regression Analysis for the Interacting Effect of Scholastic Subject, Type of Work, and Time of Day on Predicting On-Task Behavior With and Without CCT (N=147)

Variable	Model 1			Model 2		
	B	*SE B*	β	*B*	*SE B*	β
Intercept	1.147	0.028		1.141	0.03	
Scholastic Subject	0.011	0.009	0.086	0.012	0.009	0.088
Type of Work	-0.010	0.010	-0.076	-0.009	0.010	-0.069
Time of Day	0.000	0.001	-0.005	0.000	0.001	-0.004
Type of Work x Scholastic Subject x Time of Day	0.001	.000*	0.195	0.001	.000*	0.189
CCT				0.008	0.018	0.461
R^2		0.049			0.049	
F for change in R^2		4.282			3.460	

Note: *Significant at the p<.05 level

Table 3.12

Summary of Regression Analysis for the Interacting Effect of Scholastic Subject and Time of Day on Predicting On-Task Behavior with and without CCT (N=147)

Variable	Model 1			Model 2		
	B	*SE B*	β	*B*	*SE B*	β
Intercept	1.17	0.031		1.166	0.031	
Scholastic Subject	-0.013	0.016	-0.1	-0.013	0.016	-0.099
Time of Day	-0.004	0.002	-0.14	-0.004	0.002	-0.139
Time of Day x Scholastic Subject	0.003	0.001*	0.354	0.003	0.001*	0.351
CCT				0.010	0.017	0.030
R^2		0.050			0.051	
F for change in R^2		5.928			4.517	

Note: *Significant at the $p<.05$ level

Conclusions, Discussions, and Suggestions for Future Research

Chapter 4

Summary

The school environment has multiple interior environment variables that contribute to student behavior and academic success. These variables are referred to as the school climate and are part of the School System Layer framework (Gordon et al., 2005) which consists of three main layers that are the Formal, Informal, and Physical Layers. Interior lighting is a variable within the Physical Layer of the School System Layers. The relationship between the interior lighting and the influence on student on-task behavior in a classroom environment is unknown due to a lack of a comprehensive theoretical framework to study interior lighting.

Theoretical frameworks are illustrations used to organize relationships among variables (Friedman, 2003), in interactions or individually, that explain a phenomenon (Pedersen, 2007). A framework is essential to empirically research classroom environments (Boyce, 2004; IES, 2014). The purpose of this research was to develop a comprehensive theoretical framework in order to examine the influence of the interior lighting on student on-task behavior in a classroom setting.

Using the process-based theory development strategy and the theory-synthesis strategy, a conceptual framework was created to systematically examine the classroom interior lighting. The framework was tested with a pilot study to determine if a higher correlated color temperature of the fluorescent lighting in an elementary classroom influenced student on-task behavior. Based upon the results of the pilot study, the conceptual theoretical framework was refined. Testing of the refined theoretical framework with a case study similar to the pilot study occurred. Results indicate that students had more on-task behaviors under the higher CCT of lighting and that the refined theoretical framework is a valid measure in which to study interior lighting and human behavior. Additional testing with the refined framework will expand the results and allow administrators and planners to specify the appropriate lighting for a classroom environment.

Theoretical framework. To create a framework to study interior lighting other variables must be considered because they are related to human behavior in the interior environment. Using the theory synthesis and process-based theory development strategies, a new conceptual framework was developed within the context of the School System Layer Framework.

After the concepts of lighting and behavior were defined this relational statement was created; interior lighting, one of the multiple interior environment variables, either in combination with other variables or by itself, influences the human perceptual system that in turn affects student behaviors in a learning environment. Using the deduction process, this hypothesis, that a higher CCT of fluorescent lighting that provides better light quality will unconsciously produce increased on-task behavior in a learning environment, was created. The hypothesis was tested in a pilot study to predict the relationship between the interior lighting and student behavior in a real world application (Handfield & Melnyk, 1998).

Pilot study. According to the conceptual framework, the higher CCT of interior lighting influences human psychological processes through subliminal perception that leads to a change in human behavior. Architectural codes and standards do not specify a CCT level for school classroom lighting. Research on the appropriate CCT levels of lighting is limited, thus this was investigated by examining student on-task and off-task behaviors in a first grade classroom through non-participant group observations. The lamp with a CCT of 3000K was first installed in the classroom. After an adjustment period of two weeks and data collection of two weeks, the lamps were changed to a CCT of 4100K. Another adjustment period and data collection occurred and then the lamps were changed back to the CCT of 3000K. This pattern continued for five months. Student group on-task behaviors were recorded using a time-interval sampling method. On-task behavior scores were averaged to give an overall on-task behavior score for the class. The data were imported into software package SPSS and analyzed for the difference of on-task behaviors between the two lighting conditions.

To test the theoretical hypothesis, the variable of CCT was measured through the installation of two different CCT levels of fluorescent lamps. The variable of student on-task behavior was measured by observing student on-task behaviors in the classroom setting. Light quality was tested by classroom illumination levels. Noise levels, relative humidity, and air temperature were measured since they are other physical interior environment variables present within a classroom.

The results indicate that students had more on-task behaviors under the higher CCT of lighting and that the conceptual theoretical framework needed refinement. Although the framework included the physical interior variables such as acoustics, interior air temperatures, and relative humidity it did not account for the additional variables in the School System Layers. These variables contribute towards student on-task behaviors and their relationships need documentation in the refined theoretical framework.

A refined theoretical framework was developed based on the results from the pilot study. The process-based theory development strategy was implemented to include relationships among the variables within the School System Layers. A case study was completed with similar research methods used for the pilot study to test the refined framework. The case study was also used to verify the results of student on-task behavior through a more thorough investigation using mixed methods data collection procedures to give a holistic explanation of the relationship between interior lighting and student on-task behaviors.

Case study. The refined conceptual theoretical framework was used to examine the CCT component of interior lighting that subliminally influenced student on-task behaviors in a classroom setting. A case study was completed in the same classroom, with the same students using a similar procedure as the pilot study to verify the results as well as test the refined theoretical framework.

The case study documented student on-task behavior under fluorescent lighting with a 3000K CCT compared to fluorescent lighting with a 4100K CCT. Using a pre-developed data collection sheet, student on-task behavior scores were collected by non-obtrusive observation at pre-determined times for five-minute observational rounds and averaged across conditions. This quantitative data collection method was used in combination with classroom movement mapping data collection techniques to document student movement and behavior throughout the room under two different lighting situations. Data were analyzed in the software package SPSS and results indicate that more on-task behavior was observed under the 4100K CCT lighting as well as more students, mostly males, moved throughout the classroom.

To test the hypothesis from the refined framework, the variable of CCT was measured through the installation of two different CCT levels of fluorescent lamps. The variable of student on-task behavior was measured by observing student on-task behaviors in a classroom setting. Light quality was tested by recording classroom illumination levels. Other physical interior variables present within the classroom were recorded which included noise levels, indoor air temperature, and relative humidity. Variables of time of day, scholastic subject, day of week, and type of work were documented as part of the School System Layers to verify if their relationships were contributing factors towards student behavior.

Based upon the refined theoretical framework, interacting effects of the variables within the school system layers and their influence on student behavior, either independently or with CCT, indicated contributing relationships. The variables of type of work, time of day, and scholastic subject were statistically significant at predicting on-task behaviors. Due to the small effect size of these contributing relationships, no conclusions can be deducted; however, since relationships were present these variables need to be included in further theoretical development to show the extent of their influence towards student on-task behavior.

Discussion and Conclusions

The pilot study and case study uncovered that students had more on-task behaviors in the classroom lit with a 4100K CCT lamp which is consistent with empirical lighting studies examining worker productivity in the workplace. The results indicate that the CCT of the lighting contributes towards student academic success, however, interior lighting is only one contributing variable within the overall school climate. Since other variables are present and contribute towards student academic success, the classroom lighting needs to be designed appropriately in conjunction with the other interior environment variables for student academic success for students in the pre-operational developmental stages.

Testing the design framework in a real world application found validity and uncovered defaults between relationships within the framework. The conceptual framework was tested in the pilot study and results indicated that the conceptual theoretical framework needed refinement to include other variables present in the school climate. Refinement of the conceptual framework occurred and testing followed on the refined framework in the case study that uncovered that scholastic subject, day of week, and type of work influenced student on-task behaviors. Since the refined framework used valid measurement tools, it can be concluded that the framework is a valid means to study interior lighting and human behavior within a school setting and further lighting studies should be based upon this framework.

Since previous comprehensive theoretical frameworks were lacking in the literature, theory synthesis and the process-based theory development strategies were implemented to create the refined framework. Following these theory development strategies gave a systematic way in which to document and test a design discipline framework. However, since the theory development process is continuous, more testing and refinement based on the results is recommended for further investigation.

Further testing with the refined theoretical framework that examines lighting in combination with other variables will infer correlations and the power of each contributing relationship on student academic success. Uncovering the variables that contribute to student on-task behavior will allow designers and administrators to create a better school climate resulting in higher levels of student academic success. Testing should occur in replication of the case study in a classroom environment since interior variables, class climate, and teacher and student individuality cannot be replicated in a laboratory setting. Additional testing will generalize the results to other applications and demographics and eventually lead to the appropriate interior lighting specifications for classroom settings.

Implications on Future Studies

This study addressed many current issues within a classroom environment in regards to interior electrical lighting, researching school facilities, student behavior and school climate variables that contribute to student learning. This study broadened current lighting research findings by focusing on an elementary school classroom environment. The classroom environment is composed of multiple variables that create the School System Layers. Each of these layers contributes to the school climate and student academic success. The pilot study and case study confirm that the interior lighting is one of many variables that influence student academic success. Results of the case study indicate that other interior variables within the School System Layers are present and had contributing relationships to student on-task behaviors. These variables need to be included in future interior lighting and human behavior studies.

The interior lighting conceptual framework should be the basis for more studies on interior lighting to confirm and expand the relationships among and between the concepts. Additional testing using the refined theoretical framework will explain the concepts and contribute towards the creation of a substantial theory in which all interior environmental variables are considered. More refinement of the framework will, most likely, uncover correlations and find the connection between human behavior and the interior environment.

Additional studies on interior lighting can be conducted in various ways by expanding the scope of the study. Future studies should include student and teacher individuality and interior environment preferences through interview data collection methods. Examining personal preferences would help give a more holistic view of the relationship between the learning environment, interior lighting, and human behavior. To generalize the results, more second grade classrooms as well as different age groups, schools, locations, and demographics could be studied. Students in different developmental phases or socio-economic classes may respond differently to the CCT of the lighting and without further studies that information is unknown.

Further studies that explore 4100K CCT levels along with new lighting technologies such as LED’s, would verify that the CCT level and not the lighting type influences student behavior. It would also be beneficial to investigate if different illumination levels during the morning hours and afternoon hours, which corresponded to students’ preferred time of day, influence student on-task behavior.

Future school facility interior lighting research needs to be studied in the classroom setting instead of a laboratory. Variables such as student and teacher relationships, teacher behavior management techniques, student interactions, and school climate cannot be replicated in a laboratory setting. As the results from the case study indicate, these variables or a combination of these variables, are influential in contributing towards student on-task behavior and ultimately student academic success. In order to appropriately study interior lighting in school settings these variables need to be accounted for to ensure accuracy in specifying the appropriate lighting for future applications.

In conclusion, this study was holistic in nature because it was based upon a theoretical framework and was performed in a classroom setting. Implementing the refined theoretical framework accounted for all variables within the School System Layers. Those variables are of importance towards creating the school climate that has been shown to influence student academic success. The results from this case study indicate that one variable within the School System Layers, the interior lighting, influences student on-task behavior. Since half of American public schools are over the age of 40 years old (Uline, 2008) and have budget constraints, a cost effective way to elicit more student on-task behaviors is to specify and install 4100K CCT fluorescent lamps. More student on-task behavior leads to better cognitive processes in students during the pre-operational phase of cognitive development. It is essential that school administrators and designers realize the combination of the correct variables within a classroom environment and design the facility to enhance student success and academic achievement.

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APPENDICES

Appendix A

Parent Notification Letter

PARENT NOTIFICATION LETTER
EXPLANATION OF RESEARCH

Project Title:	The Impact of Lighting on Children's On-Task Behavior in the Elementary Education Classroom
Principal Investigator:	Marilyn Read
Student Researcher:	Alana Pulay
Co-Investigator(s):	Elif Tural
Version Date:	September 25, 2014

Purpose: You are being notified that a research study is going to be going on in the classroom beginning October 2014. The purpose of this research study is to investigate the impact warm lighting and cool lighting have on children's on-task group behavior and movement. We will be using standard fluorescent lighting that is changed from a lower color index to a higher color index. Both types of lighting are within the parameters of lighting levels and color for educational settings. This study is for Alana Pulay's dissertation work at Oregon State University.

Time: Your child's participation in this study will be no different from standard classroom instruction. The only difference will be in the lighting variable of the classroom. The study will last for 6 months with the lighting varying for two weeks of exposure to warm lighting and two weeks exposure to two weeks exposure to cool lighting.

Activities: The study activities include the standard classroom instruction activities for the 2nd grade at Hoover Elementary School. One study researcher will sit at the back of the classroom observing on-task behavior of each group and child movements sitting at the tables. No identifiable information will be collected.

Risks: There are no foreseeable risks or discomforts associated with this research activity.

Benefit: This study is not designed to benefit your child directly. However, we believe researchers in lighting and human behavior may benefit from the conclusions of this study based on on-task behavior in the elementary education classroom.

Payment: Your child will not be paid for being in this research study.

Confidentiality:

Your child's participation in this study is anonymous. We will not collect any identifiable data.
Voluntary:

Participation in this study is voluntary. A table located under standard lighting, or the warm lighting condition, will be available for children whose parents do not want their child/children to participate in this study. Please notify Marilyn Read or *the teacher if you would prefer that your child sit at the table with standard lighting. Children will not be treated differently if they do not participate in the study.

Study contacts:

If you have any questions about this research project, please contact: Marilyn Read, Principal Investigator, at Marilyn.read@oregonstate.edu or (541) 737-0982. If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

Appendix B

Data Collection Schedule

Hoover Elementary Lighting Project in Room 1:

November 5
Remove existing lamps and switch to Lamp A (3000K)

December 9
Remove existing lamps and install Lamp B (4100K)

January 12
Remove existing lamps and install lamp A (3000K)

February 12
Remove existing lamps and install Lamp B (4100K)

March 16
Remove existing laps and install Lamp A (3000K)

April 16
Remove existing lamps and install Lamp B (4100K)

Appendix C

Data Collection Sheet in Excel

Date:

Daily items:
Lights off in back roo
blinds down
set timer
record weather
overall class climate

Number of Gender		
Tables	Boy	Girls
1		
2		
3		
4		
5		
6		

Code:	Description
1	On task behavior
2	neutral (half table)
3	off task behavior

If student approches you say,
"Studying the classroom."
*65 mins per sheet

Notes:

9:00-9:05

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
6		4		4		5		2	
1		3		2		1		4	
3		2		1		4		1	
2		5		3		2		3	
5		6		5		6		6	
4		1		6		3		5	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
3		2		4		5		4	
1		1		1		6		6	
2		3		3		1		1	
5		5		5		3		3	
6		6		2		4		5	
4		4		6		2		2	

total	

9:05

Noise level for 1 minute	
Min dB	Max dB

9:06

Temperature	Relative Humidity

9:10 - 9:15

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
1		6		3		4		4	
4		4		4		3		5	
3		1		2		2		3	
5		3		1		6		1	
2		5		5		5		2	
6		2		6		1		6	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
6		6		2		4		2	
5		4		5		2		3	
2		2		1		6		6	
3		3		6		5		5	
1		1		4		3		1	
4		5		3		1		4	

total	1

9:20 - 9:25

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
3		5		2		1		4	
6		2		6		2		2	
1		6		4		6		6	
5		3		1		5		1	
4		1		3		3		5	
2		4		5		4		3	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
2		2		3		4		2	
1		3		2		6		3	
6		4		5		2		6	
4		5		4		5		1	
5		6		6		3		4	
3		1		1		1		5	

total	1

9:2500 AM

Noise level for 1 minute	
Min dB	Max dB

9:26

Temperature	Relative Humidity

9:30 - 9:35

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
3		4		3		4		6	
1		3		1		1		2	
4		1		4		5		5	
6		6		2		2		3	
5		5		5		3		1	
2		2		6		6		4	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
2		5		6		6		2	
6		3		3		5		1	
4		4		5		1		3	
5		1		2		3		5	
1		2		1		4		4	
3		6		4		2		6	

total	1

9:40- 9:45

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
3		5		2		1		3	
5		3		6		5		6	
6		1		5		4		5	
1		2		3		6		2	
2		4		4		2		4	
4		6		1		3		1	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
2		5		6		1		2	
6		6		3		2		1	
4		3		5		4		3	
5		2		2		3		5	
1		4		1		6		4	
3		1		4		5		6	

total	1

9:50- 9:55

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
6		5		5		5		6	
3		3		3		1		2	
1		1		1		2		5	
4		2		4		3		3	
5		4		6		4		1	
2		6		2		6		4	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
2		6		5		4		4	
6		2		4		5		2	
4		1		3		3		3	
5		4		6		2		1	
1		5		2		1		5	
3		3		1		6		6	

total	1

10:00

Light Level	Light Level	Light Level	Light Level	Light Level	Light Level
Table 1	Table 2	Table 3	Table 4	Table 5	Table 6

total	#DIV/0!

10:20-10:25

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
5		1		6		1		5	
2		4		3		4		4	
3		6		4		6		6	
4		5		5		5		1	
6		2		1		3		2	
1		3		2		2		3	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
3		5		3		4		2	
5		4		2		1		3	
1		2		1		6		6	
4		6		5		3		5	
2		3		4		2		4	
6		1		6		5		1	

total	1

10:30-10:35

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
4		3		2		1		6	
6		6		3		6		3	
5		5		6		5		4	
1		4		5		2		5	
3		1		4		4		2	
2		2		1		3		1	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
6		3		1		3		2	
5		1		5		4		6	
2		5		3		6		5	
4		4		6		2		3	
1		6		2		1		4	
3		2		4		5		1	

total	1

10:36

Noise level for 1 minute	
Min dB	Max dB

10:37

Temperature	Relative Humidity

10:40-10:45

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
4		3		6		5		3	
3		1		3		2		1	
6		4		4		3		2	
1		6		1		1		4	
5		5		5		6		5	
2		2		2		4		6	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
5		5		5		3		3	
3		3		4		1		2	
2		4		2		2		6	
6		2		6		5		5	
1		1		1		4		1	
4		6		3		6		4	

total	1

10:50-10:55

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
3		5		6		4		1	
2		6		2		2		2	
6		4		3		3		6	
1		2		5		5		3	
5		1		4		6		4	
4		3		1		1		5	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
4		1		4		5		6	
2		6		3		3		4	
5		4		5		1		3	
6		2		6		4		5	
1		3		1		2		2	
3		5		2		6		1	

total	1

11:00 - 11:05

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
5		5		2		4		1	
2		6		6		2		2	
6		4		1		3		6	
1		2		3		5		3	
3		1		5		6		4	
4		3		4		1		5	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
4		2		4		5		1	
2		6		3		3		2	
5		1		5		1		5	
6		3		6		4		3	
1		4		1		2		4	
3		5		2		6		6	

total	1

11:10-11:15

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
5		5		5		4		1	
2		6		4		2		2	
6		4		2		3		4	
1		2		6		5		3	
3		1		3		6		6	
4		3		1		1		5	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
3		1		5		5		3	
6		6		6		3		6	
5		4		3		1		1	
2		2		2		4		5	
4		3		4		2		4	
1		5		1		6		2	

total	1

11:16

Noise level for 1 minute	
Min dB	Max dB

11:17

Temperature	Relative Humidity

11:20-11:25

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	code:	Tables	Code:	Tables	Code:	Tables	Code:	Tables	Code:
6		4		1		5		2	
3		2		5		4		4	
1		5		3		3		3	
4		1		4		6		6	
5		6		6		2		1	
2		3		2		1		5	

30 seconds		30 seconds		30 seconds		30 seconds		30 seconds	
Tables	Code	Tables	code	Tables	code	Tables	code	Tables	code
4		2		5		1		4	
6		6		3		6		2	
5		1		1		3		3	
2		4		4		2		1	
1		5		6		4		5	
3		3		2		5		6	

total	1

11:30AM

Light Level	Light Level	Light Level	Light Level	Light Level	Light Level
Table 1	Table 2	Table 3	Table 4	Table 5	Table 6

total	#DIV/0!

Daily Averages

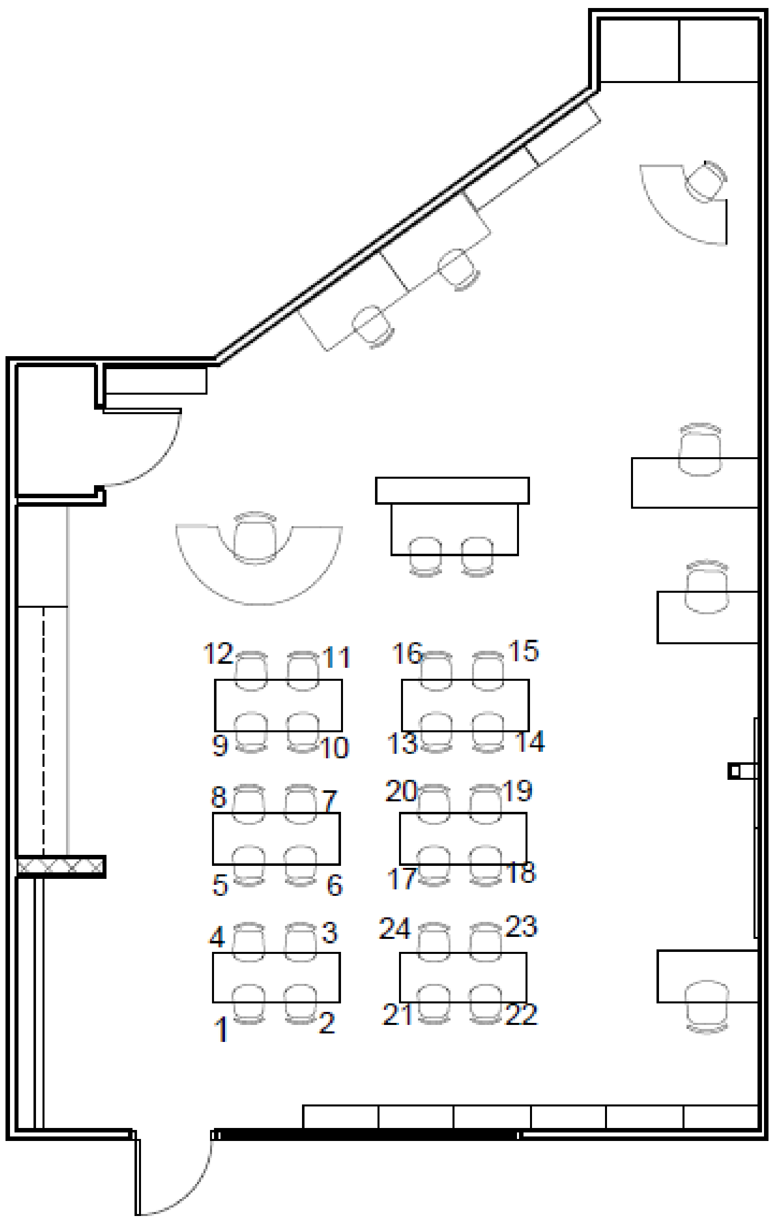
on task AVG	lighting AVG	Temperature AVG	Relative Humidity	Min noise AVG	max noise AVG
1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Total minutes of data collected today?

Appendix D

Movement Mapping Data Collection Sheet

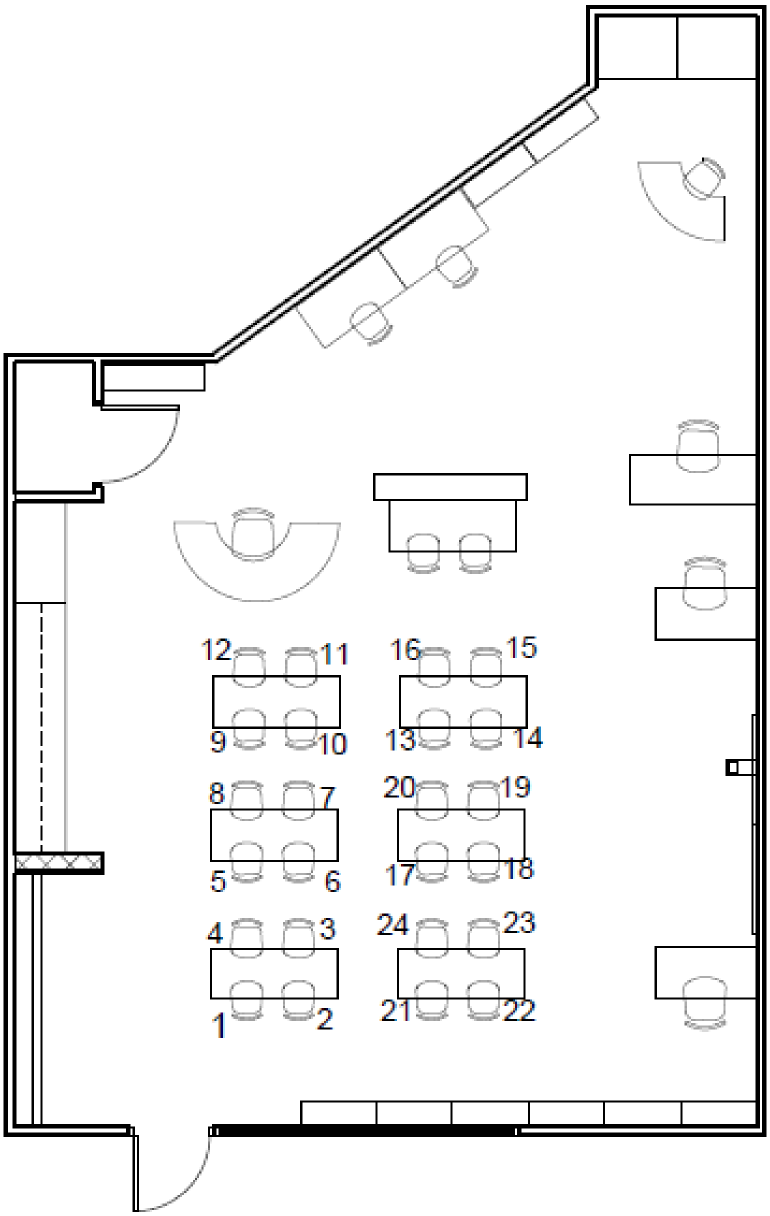
Movement Mapping – lamp type A
Student A – **Seat # 21**
Time: 9:00-9:15 *(*at each minute mark the number 1-15 of where the student is throughout the room)*
Class climate:



Notes:

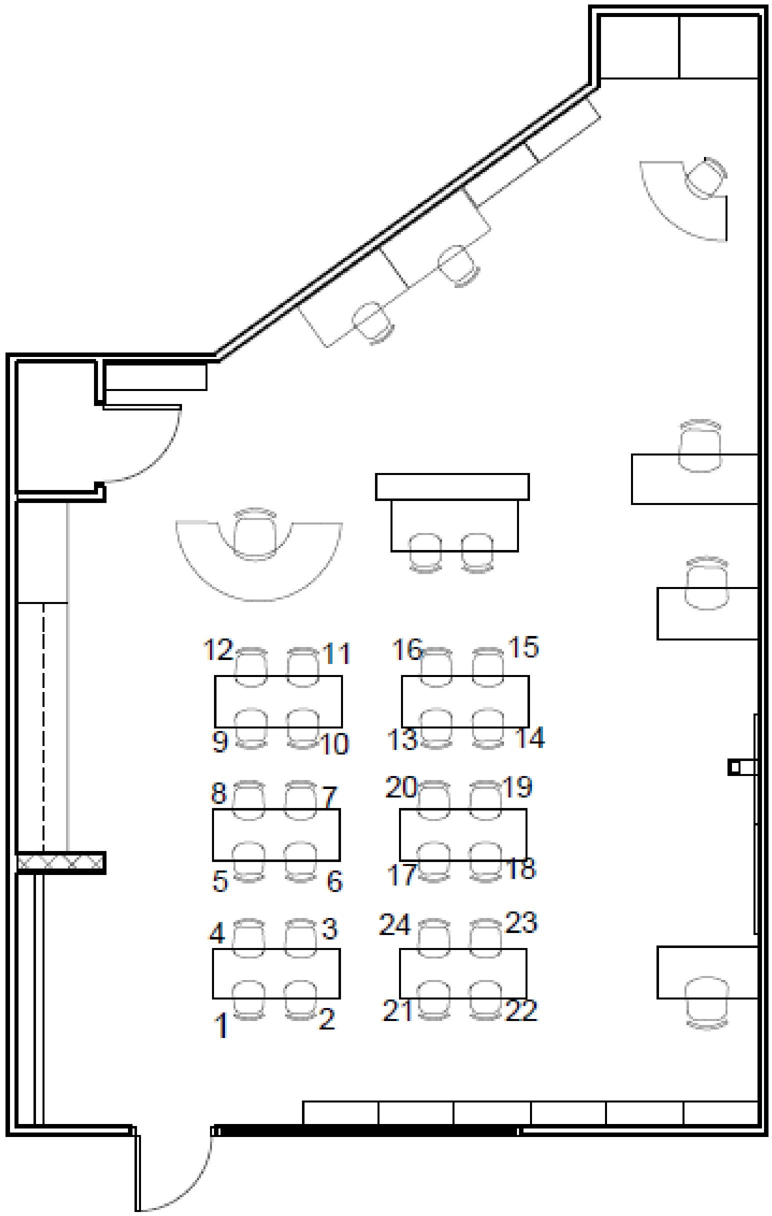
Movement Mapping – lamp type A

Student B – **Seat # 11**
Time: 9:20-9:35*
Class climate:



Notes:

Movement Mapping – lamp type A
Student C – **seat # 24**
Time: 9:40-9:55*
Class climate:

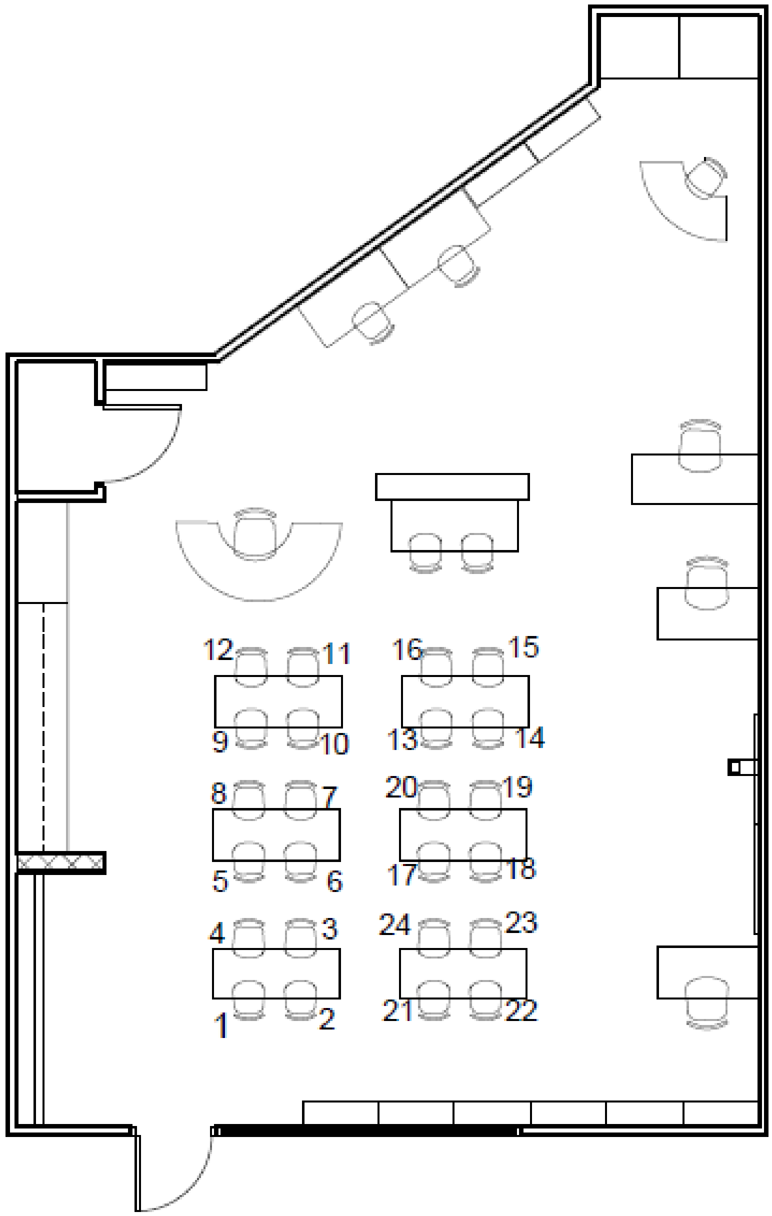


Notes:

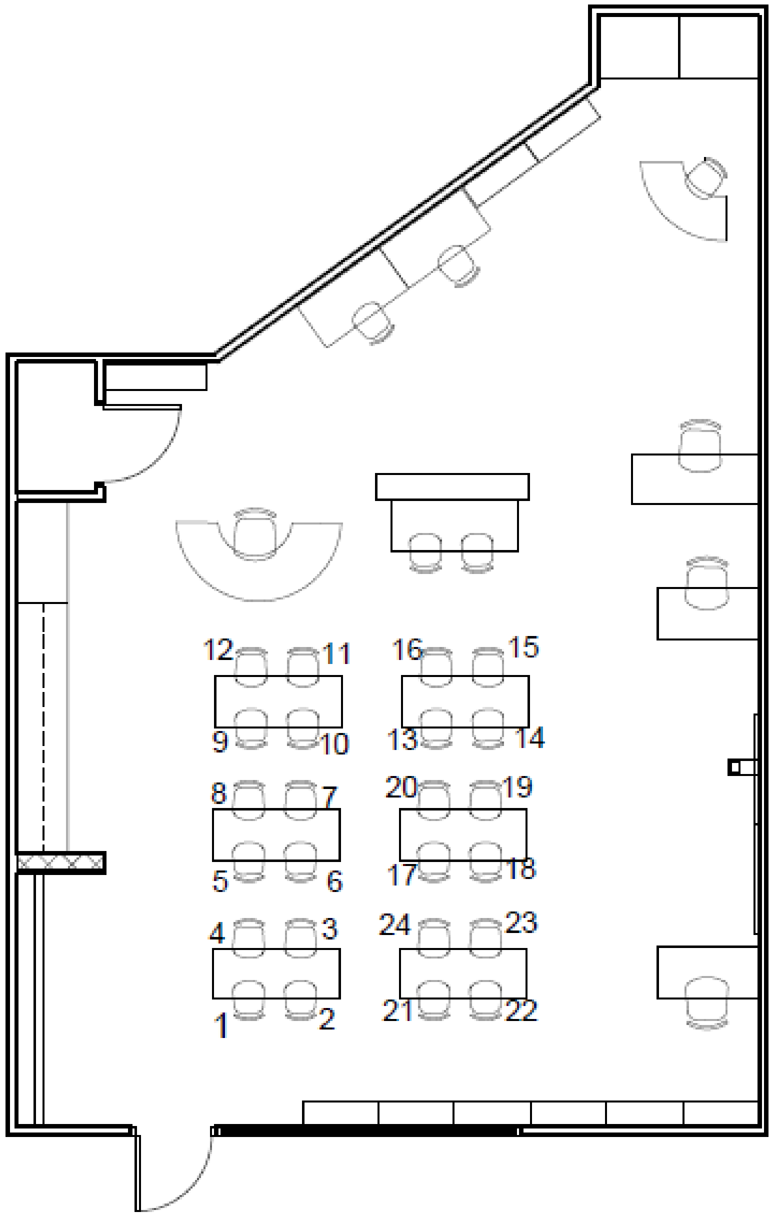
Illumination levels (10:00):

Table 1	Table 2	Table 3	Table 4	Table 5	Table 6

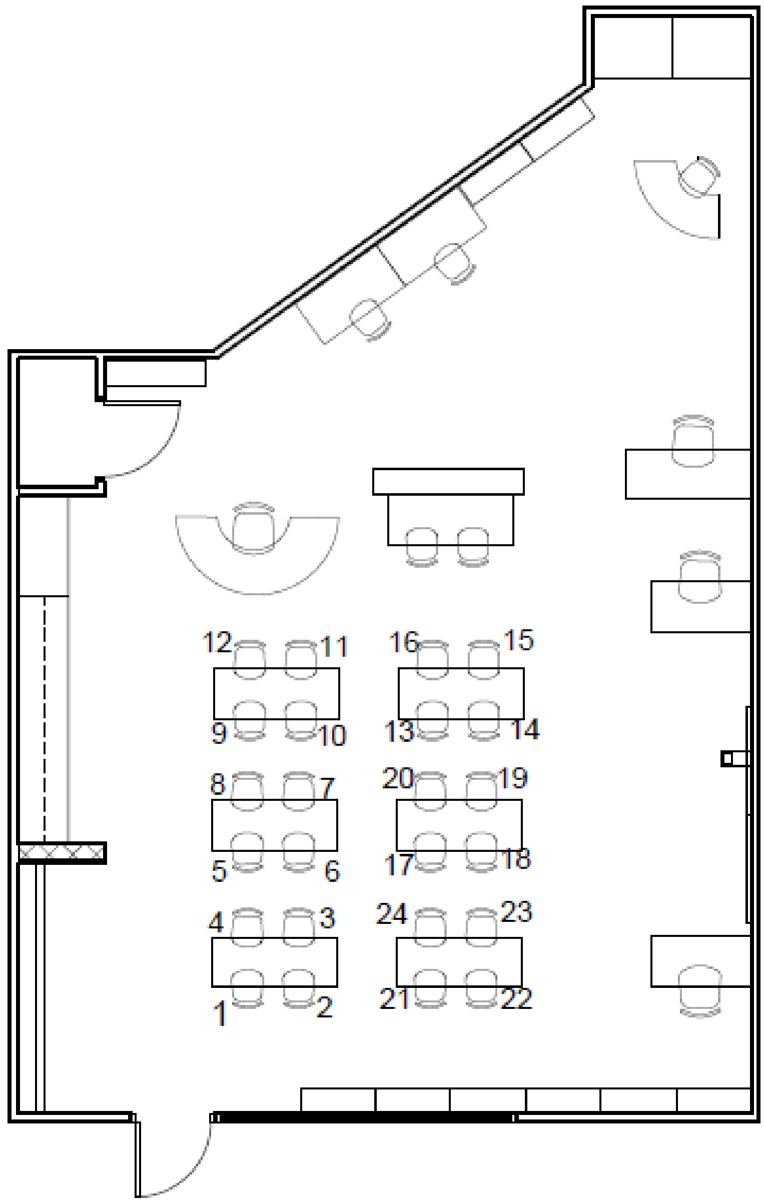
Movement Mapping – lamp type A
Student D – **Seat # 12**
Time: 10:20-10:35*
Class climate:



Movement Mapping – lamp type A
Student E – **Seat # 6**
Time: 10:40-10:55*
Class climate/activity:



Movement Mapping – lamp type A
Student F – **Seat # 5**
Time: 11:00-11:15*
Class climate:



Illumination levels (11:30):
Table 1 Table 2 Table 3 Table 4 Table 5 Table 6

Appendix E

Classroom Daily Schedule

Tent. Schedule 2014 - 2015	8:15 -9:15	9:15- 10:00	10:15 – 10:45	10:45 – 11:15	12:15 – 1:00	1:05 – 1:35	1:30 – 2:30
Monday	Poetry/ Reading	Reading Stations- Teresa Barden	Music	Independent Reading Projects/ Research/RTI (Get ready for lunch 11:15)	Math	Math Games 1:00- 1:15 Activity Break 1:15 – 1:30	Science/Social Studies Dismissal is at 2:40
Tuesday	Poetry/ Reading	Reading Stations	Writing Independent Reading Projects when time allows		Math	PE	Library (1:45 – 2:15) Choice Reading (2:15 – 2:35
Wednesday	5th Grade Buddies/ Poetry/ Reading	Reading Stations- Amy Welter and Cori Bland	Music	Independent Reading Projects/ Research/RTI (Get ready for lunch 11:15)	Math	Math Games 1:00- 1:15 Activity Break 1:15 – 1:30	Science/Social Studies Dismissal is at 2:40
Thursday	Poetry/ Reading	Art	Writing- Mrs. Read 10:15 – 11:15 Independent Reading Projects when time allows		Math	PE	Computer Lab (1:45 - 2:30)
Friday	Spelling/ Reading/Mr. Prechel	READ Dogs 9:30 – 10:00	Math Games 10:15 – 10:30 Number Club 10:30 – 11:15 (Get ready for lunch 11:15)		Math	**Dismissal is at 1:40 on Friday**	Teachers in PLC Meetings