

Illuminating the Effects of Dynamic Lighting on Student Learning

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## **Abstract**

Light is universally understood as essential to the human condition. Yet light quality varies substantially both in nature and in controlled environments leading to questions of which artificial light characteristics facilitate maximum learning. Recent research has examined lighting variables of color temperature, and illuminance for impacting sleep, mood, focus, motivation, concentration and work and school performance. This has resulted in artificial light systems intended to support human beings in their actualization through dynamic lighting technology allowing for different lighting conditions per task. Eighty-four third graders were exposed to either focus (6000K-100fc average maintained) or normal lighting. Focus lighting led to a higher percentage increase in oral reading fluency performance (36%) than did control lighting (17%). No lighting effects were found for motivation or concentration, possibly attributable to the younger age level of respondents as compared to European studies. These findings illuminate the need for further research on artificial light and learning.

## **The Effects of Lighting on Humans in General**

The human evolution is shaped by light. In the course of evolution, human beings have adapted and developed an internal clock that under natural light conditions is synchronized to the earth's 24-hour light-dark rotational cycle (Czeisler et al., 1999). Research reveals the mechanism for how light is essential for human functioning (Boyce, Hunter, & Howlett, 2003). Light is a strong enabler for visual performance (Grangaard, 1995), regulates a large variety of bodily processes such as sleep and alertness (Dijk et al., 1997; Wright et al., 2006; Takasu et al., 2006; Viola et al., 2008), is essential for

cognition and mood (Veitch & McColl, 2001; Goven et al., 2011; Taras, 2005), enables production of important hormones such as melatonin and cortisol (Berson, 2002; dijk et al., 1997; Leproult et al., 2001), and is essential for a healthy rest-activity pattern (Wurtman, 1975).

Lights of different wavelengths also affect blood pressure, pulse, respiration rates, brain activity, and biorhythms. The role of lighting in our daily lives is essential in order to operate ideally in every environment. Thus, lighting directly influences every dimension of human existence. Tanner reiterated: “Light is the most important environmental input, after food and water, in controlling bodily functions (as cited in Wurtman, 1975).

Since the industrial revolution, people spend more and more time indoors while artificial lighting has shown the power to at least partially compensate for the processes that stabilize the body, mind, and emotions (Knez, 1995; Tanner, 2008, van Someren et al., 2005; Takasu et al., 2006; Mishima et al., 2001; Viola et al., 2008). In the following we elaborate a bit more on the proven effects artificial light has on human functioning.

### *Circadian rhythm*

Sleep is one of the most basic physical requirements for human functioning. Amount and quality of lighting invariably affects the degree and quality of sleep in humans and regulates our biological clocks. In 2002, Berson et al. (2002) identified a new non-image forming photo-pigment residing within a cell type in the retina of the eye. It is referred to as melanopsin and regulates the biological effects of light. When ocular light (light perceived by the eyes) reaches these cells, a complex chemical reaction occurs, producing electrical impulses that are sent via separate nerve pathways to our

biological clock, the suprachiasmatic nuclei (SCN). The SCN in turn regulates the circadian (daily) and circannual (seasonal) rhythms of a large variety of bodily processes, such as sleep, and some important hormones, such as melatonin and cortisol, essential for a healthy rest-activity pattern. The system that generates the circadian rhythmicity of biological processes is denoted as the circadian system. The melanopsin pigment is most sensitive to blue light with a peak sensitivity at 480 nm (Brainard et al., 2001; Thapan et al., 2001; Hankins et al., 2008).

Sleep consolidation is optimal when sleep timing coincides with the period of melatonin secretion (Dijk et al., 1997). People that sleep during their melatonin peak (as in normal, i.e., well-synchronized, people), are reported to have a longer total sleep time and less wakefulness after sleep onset as compared with people that schedule their wakefulness during the melatonin peak (non-synchronized people) (Wright et al., 2006). Moreover, the same study indicates that cognitive performance (i.e., learning) was better in a synchronized group of people, whereas learning was impaired in a non-synchronized group of people. This indicates that proper alignment between sleep-wakefulness and biological (internal circadian) time is crucial, not only for sleep quality, but also for enhancement of cognitive performance.

### *Vision*

The most obvious effect of light on humans is to enable vision and performance of visual tasks through the eyes. The eye contains “photoreceptor cells” called rods and cones. These photoreceptor cells regulate the visual effects. When light reaches these cells, a complex chemical reaction occurs. The chemical that is formed creates electrical impulses in the nerve that connects the photoreceptor cells to the visual cortex at the back

of the brain. In the visual cortex the electrical impulses are interpreted as “vision”. Rod cells “operate in low-level light situations and do not permit color vision.” Cone cells on the other hand, operate best in “normal daytime lighting conditions,” and are “responsible for sharpness, detail, and color vision.” Studies show that the nature of the task – as well as the amount, spectrum, and distribution of the light – determines the level of performance that is achieved.

### *Mood and Cognition*

Lighting plays an important role in evoking emotions. Lighting can be used to make an architectural space more aesthetically pleasing or it can create an atmosphere in that space; both affect people’s emotions. In addition, the user’s well-being can be directly influenced by light. Brightness, color, direction, contrast and time are parameters used to create lighting conditions that address this.

Nevertheless, concerning the relationship between lighting and mood/cognition, research has not shown consistent results. In a study by Knez (1995), two experiments were performed in order to analyze the effects of color temperature and illuminance levels on mood and cognitive performance tasks including long-term recall, free recall, and performance appraisal between males and females. After each experiment, a test to measure each subject’s mood was administered. The results showed that females performed better in warm white lighting environments, whereas males performed better on cognitive tasks in cool white lighting. Both males and females perceived and responded differently in evaluating the illuminance levels and color index of the lighting and therefore each gender’s mood was affected differently. Positive mood measures showed no increase in mood in both genders; however, the cooler lighting had a more

negative effect on females' moods. Thus, females' performance on cognitive tasks decreased under cooler lighting.

Because physiological changes occur when humans are exposed to light, mood and cognition can be affected indirectly and variably. According to Veitch and McColl (2001), lighting's cognitive and mood-related effects on people have noteworthy implications: 1) better performance on cognitive related tasks in the workplace or academic environment and 2) overall improved quality of life and well-being. Both visual perception strength and adequate sleep could have a considerable impact on cognitive abilities such as concentration and memory. Mood may also determine the sharpness of these cognitive abilities. Mood can be influenced by the quality and amount of lighting (Partonen et al., 2002; Veitch & McColl, 2001; inter alia Beauchemin & Hays, 1996; Benedetti et al., 2001; Goven, 2011). For instance, light therapy has proven a successful treatment for those with Seasonal Affective Disorder (SAD) and other non-seasonal mood related disorders such as depression and eating disorders (Spiegel et al., 2004; Van Cauter et al., 2000; McColl & Veitch, 2001).

### **Effects for Lighting and Learning**

Because lighting profoundly impacts numerous levels of human functioning such as vision, circadian rhythms, mood, and cognition, its implicit effects on learning and classroom achievement cannot be dismissed. Several studies have addressed how the quality and color of lighting can either impair or enhance students' visual skills and thus, academic performance. Visual impairments alone can induce behavioral problems in students as well as level of concentration and motivation in the classroom. Cheatum and Hammond (2000) estimated that around 20% of children that enter the school encounter

visual problems (e.g., problems with focusing, eye tracking, strabismus, lazy eye, and trabismus). Among elementary school children, 41% have experienced trouble with tracking, 6% have refractive errors and 4% have strabismus (Koslowe, 1995, as cited in Cheatum & Hammond, 2000). The same study suggests that “the inability of visual tracking is also thought to be the cause of behavioral problems and being illiterate.”

Winterbottom (2009) suggested that certain features of lighting can cause discomfort and impair visual and cognitive performance. These features include “imperceptible 100 Hz flicker from fluorescent lighting and glare induced by 1) daylight and fluorescent lighting, 2) interactive whiteboards (IWBs) and dry-erase whiteboards (DWBs)” (2009). The purpose of his study was to determine the degree and magnitude to which students are subjected to the above stated lighting inefficiencies in the classroom. The 100 Hz flicker from fluorescent lighting was displayed in 80% of the 90 UK classrooms used for the study. Other general lighting issues were that many of the classrooms had “an unnecessarily inefficient form of fluorescent lighting that has been shown to cause headaches and impair visual performance,” some were “over-lit with excessive fluorescent lighting and excessive daylighting,” and finally, that “glare from IWBs and DWBs is common. Pattern glare from Venetian blinds is a possibility” (Winterbottom, 2009).

A study by Ott (1976) revealed that cool white fluorescent lighting in classrooms can drastically improve the behavior of students who are hyperactive or have learning disadvantages. Four “windowless” classrooms containing first graders in Sarasota, Florida were observed. Two of the classrooms had standard fluorescent lighting and the other two had the new full-spectrum fluorescent lighting installed. Cameras were set up

in each room to take snapshots of the students throughout the day. Results proved that the students in the full-spectrum lit classrooms were able to pay attention better which led to improved performance. Ott concluded that “hyperactivity is partly due to a radiation stress condition,” and that when the exposure to the radiation from the lighting was minimized, behavior and performance improved.

Another study (Grangaard, 1995) measured how “color and light” had an effect on eleven six-year old students’ on-task and off-task behaviors and their blood pressure measurements. The children went through three phases of testing in which each lasted for ten days. During this time, the students were videotaped for fifteen-minute intervals at the same times each day and their blood pressure was also measured each day. The results showed that a decrease appeared in the children’s blood pressure during the second phase in the experimental classroom with blue walls and full-spectrum lighting, and a gradual one percent increase occurred upon returning to the original classroom setup with cluttered white walls and plain white fluorescent lighting in the third phase. The results also revealed that the six-year olds exhibited a dramatic decline in off-task behaviors in the second phase as compared with the first. In the first phase, a total of 390 off-task behaviors were measured as opposed to a total of 310 in the second phase, a twenty-two percent decrease. The author concludes that “the enhancement of human performance requires the optimum environment” and that “educators must recognize the fact that surroundings are never neutral”.

A study by Tanner (2008) reiterates the idea that the physical design of schools can effect student achievement. One of the areas of design discussed was lighting. The author relates evidence from other studies that have shown that lighting affects human



physiological functions, health, development, and performance. Regression models were used to help determine the relationships between school design elements and student performance. The overall outcome expressed variances in achievement when compared to controlled and non-controlled design elements in schools including lighting.

Heschong et al. (2002) examined second through fifth grade students' math and reading test results to determine whether the effects of daylighting in the schools had an impact on student performance. Three different schools districts across the nation were chosen to participate in this study. Each school districts' lighting conditions were categorized into several sets of data. A "multivariate regression analysis" was used to differentiate the highly variable data for each school district. The statistical evidence revealed that school buildings with the greatest capacity for daylight, such as those "with increased window and skylight areas," had a noteworthy effect on students' performance and behavior. Within the different school districts, the findings were consistent.

Different types of lighting can play different roles in enhancing classroom performance such as improving vision (and perhaps affecting concentration and motivation), behavior, and academic achievement. For example, cool white fluorescent lighting is recommended to aid in reading speed and accuracy and attentiveness or focus. On the other hand, warm white lighting can assist in helping adults to work together and to minimize conflict (Baron, 1992). A study by Galetzka et al. (2011, in preparation) showed that lighting can improve children's cooperative learning. Children were 20% faster in solving a puzzle together in the relaxed light setting compared to the standard setting. In the energy setting, children talked 95% more than compared to the standard light setting. These results are in line with results of Schulte-Markworth, Barkmann, and Wessolowski (2010,

personal communication) who found a non significant small trend towards cooperation under warm light conditions.

Additionally, recent research addressing artificial light in school environments has investigated light effects for student achievement (Wolhfarth, 1986), motivation, concentration and cognition (Schulte-Markwort et al., 2011; Slegers et al., 2012). The current study further examined effects of lighting on motivation and concentration revealed by Slegers et al. (2012), and extended to include a measure of reading accuracy and rate.

### **Defining Oral Reading Fluency**

In the most recent edition of the *Handbook of Reading Research* (2011), Rasinski, Reutzel, Chard, and Linan-Thompson provide the following definition of fluency— “a characteristic of reading that occurs when readers’ cognitive and linguistic systems are developed to the extent that they can read with sufficient accuracy and rate to allow for understanding the texts and reflecting its prosodic features” (p. 287). Many researchers (Rasinski, 2011; Rasinski et al.; Kuhn & Rasinski, 2011) describe the main components of fluency as automaticity in word recognition (which includes accuracy) and prosody. According to Rasinski and Samuels (2011), automaticity is the “ability of readers to decode words not just accurately but effortlessly or automatically” (p. 95). When readers can read with automaticity, they can devote more cognitive energy to comprehending the text and less to decoding individual words. The other component of fluency is prosody. Kuhn and Rasinski (2011) define prosody as the “melodic elements of language that, when taken together, constitute expressive reading” (p. 278). That is, the reader is able to automatically recognize words while providing the appropriate expression implied by the

text (e.g., intonation, stress, and timing) so that the “oral reading of written text takes on the quality of fluent speech” (Kuhn & Rasinski, 2011, p. 278).

For many years, oral reading fluency (ORF) has typically been assessed through the use of informal reading inventories (IRIs). IRIs are designed to determine the percentage of words a reader can read correctly in a passage within one minute. However, IRIs only provide information about the reader’s ability to decode accurately, not automatically. Measuring word accuracy provides information to classify a text as being on a reader’s independent, instructional, or frustration reading level. Research (Rasinski, et al., 2011) does support that comprehension of text declines as the number of words decoded accurately declines. Another method of measuring ORF is to determine the reading rate. Reading rate assessment tools actually measure automaticity with the assumption that readers decoding text rapidly coincides with automatic recognition of words. Curriculum-Based Measurement (CBM) is a more recent attempt to measure ORF. These measures define ORF by the number of words read accurately in grade level text in one minute (Rasinski et al., 2011). CBM tools have been found to correlate with other measures of reading achievement, such as reading comprehension (Deno, Mirkin, & Chiang, 1982; Fuchs, Fuchs, Hosp, & Jenkins, 2001; Good, Simmons, & Kame’enui, 2001; Marston, 1989; Rasinski, Padak, McKeon, Krug-Wilfon, Friedauer, & Heim, 2005; Riedel, 2007; as cited in Rasinski, et al., 2011). Measuring prosody is more difficult to measure because it is not as easily quantified. Rubrics have been developed and can be used to measure prosody. However, these are typically more appropriate for classroom teacher use in order to inform classroom instruction (Rasinski et al., 2011).

## **ORF: A Bridge to Reading Comprehension**

Pikulski and Chard (2005) describe fluency as the bridge between phonics and comprehension. That is, fluency links to phonics via the automatic recognition of words with little cognitive energy expended by the reader. Also, fluency links to comprehension via prosodic reading where text is read with expression. For decades, educational research concerning literacy skills has focused on how ORF correlates with overall reading ability including reading comprehension. LaBerge and Samuels (1974) introduced the theory of automatic information processing in reading where they argued that surface-level processing of words should occur automatically with little cognitive effort so that readers could concentrate on comprehension. In fact, they described the notion that poor comprehension could be traced to a reader's lack automaticity. Stanovich (1980) extended this theory in stating that good and poor readers could be characterized by how automatically they recognized words. In addition to the automaticity issue, prosody also correlates to good comprehension (Rasinski, 2004, 2010; Wright, Sherman, & Jones, 2004). These researchers provide evidence of how fluency bridges the gap between phonics and comprehension.

Because fluency is an important part of reading instruction and is a major factor in developing reading comprehension, it is important to note the relationship between oral and silent reading fluency. Although fluency is typically thought of as occurring orally, fluency also extends to silent reading. Fluency should manifest itself in silent reading parallel to ORF because one would infer that the manner in which an individual reads orally would translate into how the same individual reads silently. Research does support that ORF and silent reading comprehension correlate on silent reading assessments

(Deno, 1985; Deno, Mirkin, Chiang, 1982; Rasinski, 1985 as cited in Rasinski & Samuels, 2011).

ORF is important to developing overall reading as without a sufficient level of competence in lower level reading skills such as “word recognition,” one’s capability to perform higher level skills required to comprehend text will be hampered. This theory is based on the premise that *constructing meaning* is the primary goal of reading. Thus, efficient ORF skills are necessary for a solid foundation for comprehension and overall reading ability (Fuchs et al., 2001).

In addition to concentration and motivation, the current study examines ORF in an effort to determine artificial lighting effects on learning as measured via a reliable and valid highly prevalent norm-referenced assessment utilized in the authentic setting of classrooms. The conceptual framework for this study juxtaposes prior research with this study (see Figure 1 for a summary of the conceptual framework of the study in relation to previous research).

### **Dynamic Lighting in the Classroom**

#### *Artificial Lighting Design and Specifications<sup>1</sup>*

Light illumination intensity and color temperature are two main variables in lighting systems used for artificial lighting indoors. Light intensity is measured via “Lux” and typically 500 lux horizontally on the workplane is the minimum used to create enough illumination for teachers and students to see given the lack of natural light available in classrooms. Color temperature, as measured in Kelvin, refers to the quality of light hue and runs from “cool” (blue and white) to “warm” (red and yellow) along the radiation spectrum of light. Each lighting fixture (or panel) contains three lamps, with

the two outer lamps generating a “cool color temperature” and the single inner lamp producing a “warm color temperature.” The lamps within the lighting panel are incrementally “decreased (dimmed)/increased in light output per selected scene [setting] to create the light effect per scene.” Furthermore, the luminaires consist of a diffuser plate to mix the colors and to prevent direct view in the lamps.

### *Settings*

As previously outlined, sound scientific research exists on the topic of lighting and its effects on humans, including sleep patterns, vision, learning and cognitive development, mood (which affects motivation and concentration), and finally ORF. Based on this research, the authors conducted the current study utilizing a lighting system, *SchoolVision*<sup>1</sup>, specifically designed for schools. SchoolVision, is an intended “teaching tool” created to positively influence school performance, aiding via desirable behavior during the different tasks like being focused during tests, being cooperative or creative during art sessions or reducing restlessness when children are too excited for the instruction. Based on research that attests to the relationship of lighting quality and color temperature to the body and mind, four distinct light settings were engineered within this dynamic classroom lighting system (see Figure 2).

These four settings consist of *Normal*, *Focus*, *Energy*, and *Calm* and they are designed to correspond with various classroom activities. These settings can be selected by the teacher “via [a] control panel.” The *Normal* setting can be used “for regular classroom activities;” whereas, the *Focus* setting can be employed “when children have to concentrate, such as for tests.” *Energy* is a setting designed for use during times of day

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<sup>1</sup> Technology developed by the Philips Corporation, NA. Research conducted independently.

when students experience a reduction in energy, usually, “in the morning and after lunch.” Finally, the *Calm* setting is designed for group activities requiring cooperation or supporting the students to settle down when students are “overactive.” Results of previous experimental studies using SchoolVision have proven the system an effective and energy efficient learning aid. Consequently, the current study sought to identify effects for SchoolVision Focus light setting as it relates to concentration, motivation, and ORF.

### **Objectives**

The objective of the current study was to evaluate an artificial lighting system with four discrete settings (Focus; Energy; Calm; and Normal) designed for the classroom environment. Sub-objectives were to incrementally examine the lighting system “Focus” setting effect on student concentration and motivation and to extend the previous body of research from The Netherlands, Germany, and Great Britain (Slegers, 2012; Schulte-Markwort, 2011) to discern possible effects on student ORF performance.

### **Participants, Method and Instrumentation**

Eighty-four grade 3 children in four different classrooms from a public school in the mid-South region of the United States were randomly assigned, by classroom, to either “Focus” or “normal” light conditions. “Focus” lighting consisted of 1000 lux with a temperature of 6500 kelvin, whereas “normal” lighting consisted of 500 lux and 3500 kelvin (see Figure 3). Focus light setting for the treatment group was utilized during all “fluency” instruction however the other three settings (calm, energy, and normal) were utilized at the teachers’ discretion. Normal lighting was used for all testing to ensure equivalent test conditions. Classroom blinds were drawn thus mitigating weather and

atmospheric conditions during the study.

Students participated in either treatment or normally lit classrooms for the full calendar year. Repeated measures were used with three instruments at the beginning (September), middle (January) and completion (May) of the study using ORF - a key index of reading comprehension, and motivation and concentration (see Figures 4 and 5).

#### *AIMSweb CBM Test of Oral Reading Fluency*

ORF was assessed with the AIMSweb (Kame'enui, Simmons, Good, & Harn, 2001; Good, Kaminski, Simmons, & Kame'enui, 2001) validated measure to explore possible effects for the focus light setting on reading performance. AIMSweb ORF is a curriculum-based measurement meaning the test items are in alignment with classroom fluency instruction consisting of teaching the students how to read with accuracy, speed and expression. Christ and Silbergitt (2007) evaluated benchmark AIMSweb ORF scores for 8,200 students in grades 1 through 5 from five rural and suburban school districts in the upper Midwest using AIMSweb scores for 3 of the probes. The data was collected during 8 consecutive school years. Each of the 3 ORF benchmark scores was the median of the other 5 probes indicating strong comparative validity technical characteristics.

#### *Motivation Questionnaire*

Student motivation was evaluated with an instrument adapted from Pintrich and DeGroot (1990) specifically for the grade 3 students in the mid-Southern region of the United States. The researchers adjusted motivation questions so that grade 3 students responded with assurance. Items were pilot tested by the researchers. Sample items included:



1. I do schoolwork because I enjoy it
2. I know I can learn the material in class
3. Getting good grades is important to me

Students experienced the items individually in a relaxed and quiet environment in the hallway or corner of their classroom as recommended by Fink and Kosecoff (1985).

### *d2 Test of Concentration*

The d2 Test of Concentration (Brickenkamp, 1994) was used to explore effects for focus lighting on student ability to concentrate, a key component to learning. The d2 Test measures processing speed, rule compliance, and performance, allowing for an estimation of individual attention and concentration ability. Test takers respond to prompts requiring them to strike through various symbols according to a variety of rules. The test can be administered in approximately 8 minutes. Reliability and the validity are well supported (Brickenkamp & Zillmer, 2010) with internal consistency above .90 (Cronbach's alpha) and construct and comparative validity established in Europe and the United States.

## **Results and Discussion**

A mixed-model ANOVA was conducted on each of the three dependent measures using group as a between-subjects factor and testing occasion as a within-subjects factor. Huynh-Feldt adjustments indicated no violations of the sphericity assumption. For our purposes, we were only interested in the group by lighting interaction effect on each of the three measures. We found such an effect for ORF. An examination of slopes revealed

the nature of the interaction effect. Although students in the lighting group initially scored slightly lower ( $M = 94$ ) than those in the control group ( $M = 103$ ), by mid semester their performance increased at a greater rate (by 34 points on average) compared to the control group (by 18 points on average). Increasing the quality of artificial light positively affected students' ORF achievement, a key component of reading comprehension and the reason for reading. For concentration and motivation, we did not find significant group by lighting interaction effects. In the following we discuss the different research outcomes more elaborately.

### *Oral Reading Fluency*

Although prior research (Schulte-Markwort 2011) has revealed effects for oral reading fluency and focus lighting when students engage in test taking, the current study implicated focus light setting used *during teaching and learning* for all oral reading fluency instruction during the school year with control and treatment groups testing in normal light conditions. There was an interaction of lighting by testing occasions,  $F(2, 154) = 9.86$ ,  $MSE = 116.35$ ,  $p < .001$ , providing evidence that focus light setting (see Figure 3 for light setting presets) used as an instructional technology improved the reading performance of the experimental group greater than the improvement experienced by the control group. Such a finding (see Figure 6), in light of previous research on lighting effects for well being (mood, concentration, focus, motivation and cognition), reading speed (Schulte-Markwort, 2011) and reading performance (Heschong, 2002) behooves educational researchers to examine lighting effects on reading comprehension as well as other academic content learning taking place in authentic classroom settings.

### *Motivation and Concentration*

Although previous research found effects of lighting on motivation (Knez, 1995), our study found no effects for either motivation or concentration,  $F_s < 1$ . It is important to note, that although statistically nonsignificant, motivation did descriptively increase for the experimental group, whereas it decreased for the control group (see Figure 7). This may be important because in a similar study conducted in the Netherlands, the motivation of the intervention group increased more than that of the control group over the school year.

Although students in Europe are familiar with the d2 Test of Concentration, students in the United States in the current study were not familiar with this test. Additionally, the test is designed for age 9 and above and the average age for the students in this study was closer to 8 than to 9 based upon age requirements for admittance into the 3<sup>rd</sup> grade. It is our recommendation that, when using the d2 Test of Concentration, for ages under 9, that an abbreviated version be used to off-set validity issues due to the developmental challenges we observed.

### **Significance of the Study**

Light qualities of illumination and color temperature were found to affect student reading. Artificial light settings vary greatly in classrooms leading to important questions of how educational and industrial designers and constituents in the educational process select lighting for optimizing teaching and learning. The current study found a significant main effect of focus lighting during instruction, on student oral reading performance indicating a need for further evaluation of the effects of illumination level and color temperature variables on the learning process.

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## Figures

Figure 1. Conceptual Framework of the Study.

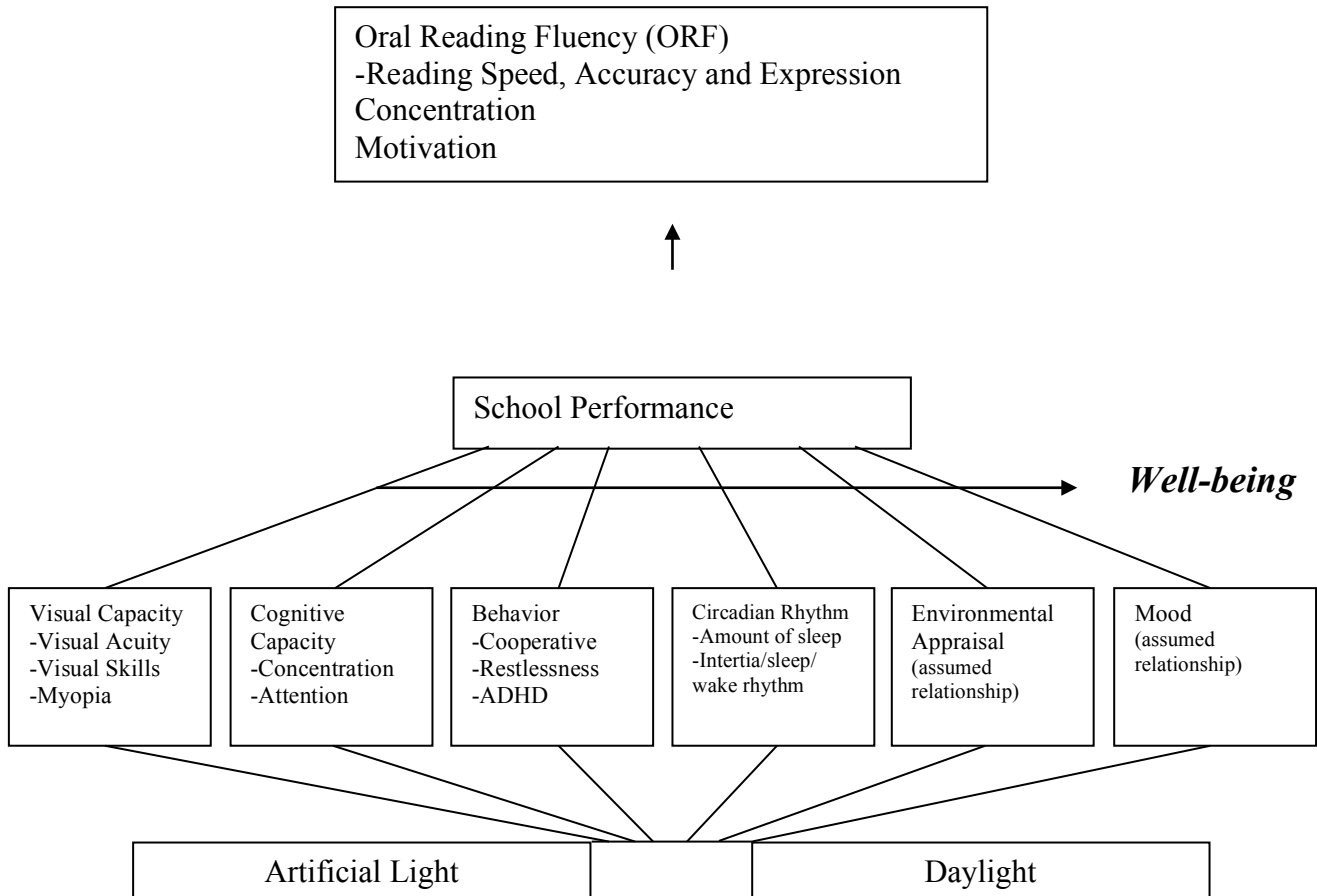


Figure 1. places previous research and theoretical rationale in juxtaposition to the current Mott, Robinson, Walden, Burnette & Rutherford study. The Mott et. al study shares the theoretical rationale and incrementally adds to previous research by examining Oral Reading Fluency as measured via the AIMSweb validated norm-referenced assessment.



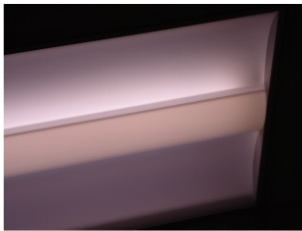


Figure 2. Light Selection Panel.

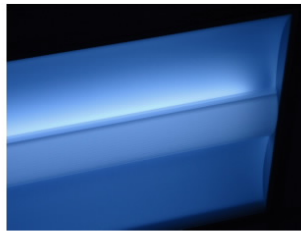
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### Lighting Presets and Approximate Outputs

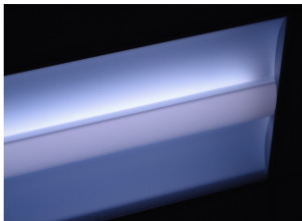
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**Preset 1: Normal**  
(3500K, 50fc average maintained)



**Preset 2: Energy**  
(12000K, 65fc average maintained)



**Preset 3: Focus**  
(6000K, 100fc average maintained)



**Preset 4: Calm**  
(2900K, 50fc average maintained)

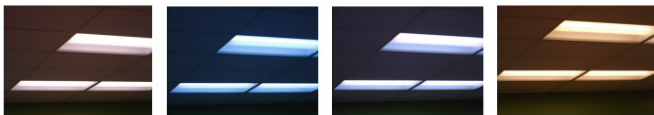


Figure 3. Lighting Presets and Approximate Outputs.

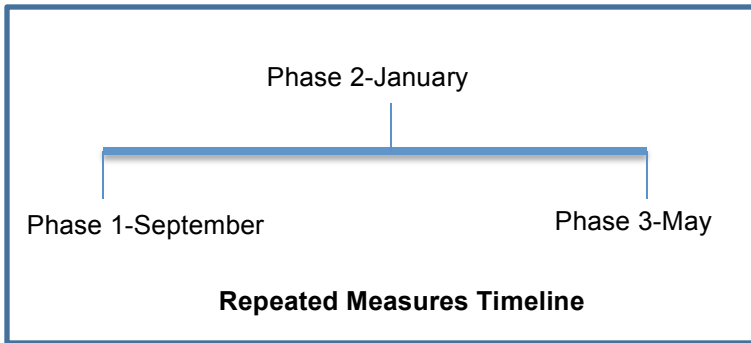


Figure 4. Study Timeline.

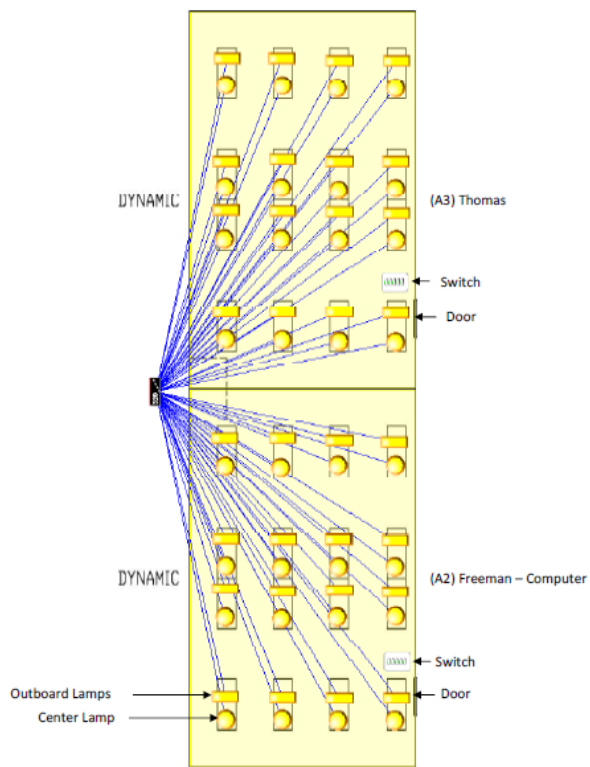


Figure 5. Dynamic Light Map.

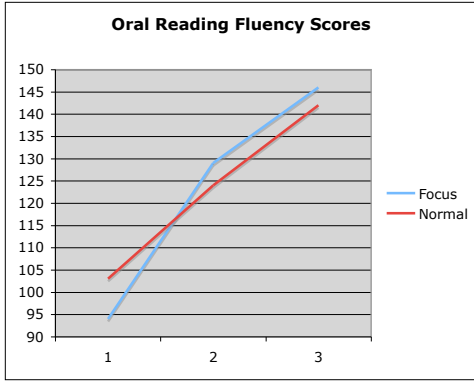


Figure 6. Results for the main effect for Oral Reading Fluency.

<sup>1</sup>Repeated measures ANOVA with Huyn-Feldt follow-up test for within subjects main effect of Focus light was significant  $F(2, 1.735)=9.85$ ,  $MSE=1322.5$ ,  $p=.05$ .

<sup>2</sup>Repeated measures 1, 2 and 3 were school year Sept., Jan and May of 2010-2011.

<sup>3</sup>AIMSweb Oral Reading Fluency scores technically examined and found to contain high reliability and validity (Shinn & Shinn, 1999; Gough, Hoover & Peterson, 1996; Hosp, 2001).

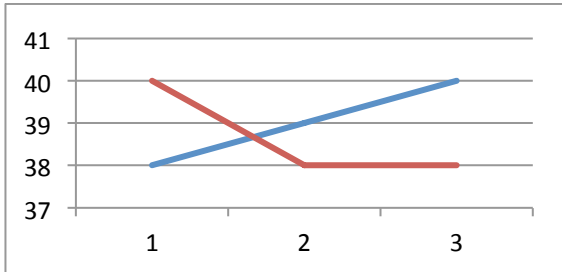


Figure 7. Results for the main effect of Motivation.

Notes-Repeated measures ANOVA test for the effect of Motivation was not significant  $F(2, 1.93)=7.36$ ,  $MSE=136.7$ ,  $p=.16$ .

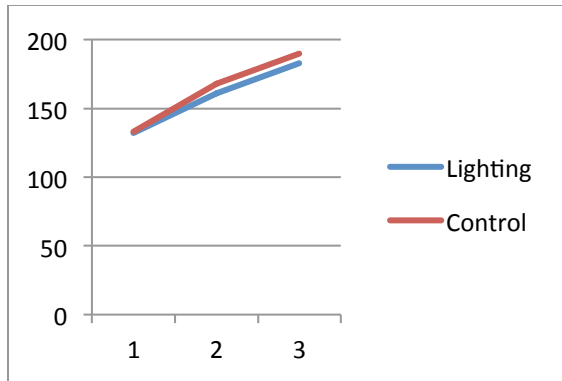


Figure 8. Results for the main effect of Concentration.

Notes-Repeated measures ANOVA test for the effect of Concentration was not significant  $F(2, 1.84)=225.4$ ,  $MSE=1203.5$ ,  $p=.08$ .