Exploring New Light and Color In and Color Instrumentsfor Multidisciplinary Students' Use: Empirical Properties of Existing Building Illumination and the Effects of Light on Color Samples

Hebert, P.R., Petrova, A., Clare, G., & Pei, Y.
Department of Design, Housing, and Merchandising, College of Human Sciences, Oklahoma State University
paulette.hebert@okstate.edu, adriana.petrova@okstate.edu, greg.clare@okstate.edu, yang.pei@okstate.edu

Abstract

The effects of light and color are vital concerns in design and architecture education. This study describes the strategic acquisition of instruments to support the curriculum of a large, multi-disciplinary department in the south central United States. The addition of a spectrometer data logger, simultaneous color viewer system and smart and color matching booth enhanced the capabilities of the design-oriented program to increase student understanding of color theory. The new equipment supports curricula throughout the diverse courses offered within the program and provides students with applied skills transferable to multiple industry sectors who use similar technologies.

Keywords: color, light, students, multidisciplinary

1. Introduction

Understanding how light source colors and other attributes vary and understanding the resulting effects of light on material color are important for many diverse professionals to grasp. The concept that light modifies the appearance of color is essential across different industries including: apparel design and production, architecture, construction technology, industrial design, interior design and merchandising. Indeed, the Council for Interior Design Accreditation[1], which accredits interior design education programs in the United States, requires evidence of students' competence related to light and color[1]. Standard 12: Light and Color "…ensures graduates understand the art and science of light and color" (p. il-26).Personal communications with apparel industry partners and with board members of the American Apparel and Footwear Association (AAFA) education foundation, which endorses apparel design programs in the United States, indicate that understanding of color andcolor application is of vital importance for the education of the future professionals entering the textile-related industries[2]. With the increase in the use of Light Emitting Diodes (LED) in buildings[3]and the widespread use of a various fluorescent lighting[4], with varying associated color and light characteristics, the need for experiential student learning has grown. Knowledge of color and light interactions is essential for successful specification and maintenance of illumination systems for buildings.

2. Purpose

One University in the Southern Midwest of the USA desired to supplement their existing and aging interdisciplinary light and color laboratory with portable instruments intended for use by multidisciplinary users. Researchers acquired several additional instruments through internal and external funding.

The first instrument, a hand-held Smart Spectrometer Data Logger, was acquired to measure lighting attributes at various locations of an existing on-campus building.

Two other instruments – a Simultaneous Color Viewer (SCV)[5]and a Color Matching Booth[6], were purchased for the exploration of light effects on colored material samples. These instruments featured Light Emitting Diode (LED) sources not previously installed in the university's light and color laboratory. The SCV allowed users to view a sample under four different standard light sources simultaneously, while the Color Matching Booth provided adequate space for two or more samples to be viewed together under each of the (same) four standard light sources. The SCV makes it possible to see the effect of different light sources on the color of a sample. The Color Matching Booth allows for assessing the perceived color difference between two or more samples under the selected standard light source and allows users to match samples by color.

Lastly, a handheld spectrophotometer was used to measure the color of samples using a standard internal light source that matched one of the light sources in the SCV and the Color Matching Booth. While the SCV and the Color Matching booth allowed for color differences to be perceived and assessed visually, the spectrophotometer allowed for sample color to be measured and recorded using standard color coordinates in a chosen color space. Corrected color temperature (CCT) is a metric for describing the spectral contributions to a light source curve and is expressed in degrees Kelvin (K)[7]. Color rendering index (CRI) describes the quality of light and how the light source impacts the color appearance of objects when compared to another light source of the same CCT[7]. CRI is denoted as Ra and the highest value attainable is 100. The International Commission on Illumination (CIE) established standards for color-matching properties of normal color vision observers that pairs of colors match in the same lighting conditions[8].

This study examined University-setting use of recently acquired instruments for evaluation of color and light phenomena interactions for a variety of interior and textile materials. The purpose of this research was 1) to provide "real-life" experiences to students and 2) to test recently acquired instruments for use by students. Real-life experiences for students included manipulating color samples in the SCV; witnessing the independence of the CRI and CCT variables; observing firsthand the range of color spectra, lumens, wattage, lumens/watt etc. in one on-campus building; visually evaluating and matching color samples; and measuring the color of samples under standard lighting conditions. These activities were developed and implemented by three disciplines during a 6-month period. It was anticipated that students in various disciplines would benefit from hands-on experiences with new instruments, which are widely used in their respective industries for color evaluation.

3. Methods

3.1. Instrument #1: Smart Spectrometer Data Logger

The researchers selected locations in the public areas of the library basement to examine and document the existing lighting conditions with a new instrument, the Lighting Passport, smartphone spectrometer, manufactured by Asensetek, catalog number #ALP-01[9]. The Lighting Passport (see Fig. 1) measures up to 90 lighting parameters through supporting software applications with up to 8nm optical resolution and illumination in the range of 50-50,000 LUX. The device's measurable wavelength visual spectrum ranges 380-780 nm. The Lighting Passport hand-held data logging instrument combines a spectrum meter connected via Bluetooth (BT 4.0, Low Energy) with iOS and Android devices which process lighting measurement through the Spectrum Genius Mobile applications including general purpose, agricultural, television/movie studio, and transmittance lighting design concerns. An IPOD was used to download the spectral reading data from the Spectrum Genius Mobile software application via WIFI connection which was then emailed from the Lighting Passport device to collaborating members of the research team immediately after it was collected by the researcher. The real-time collection, analysis and communication of spectrometer data is a useful tool for field research, education, and client communication supporting lighting designs.

Using an IPOD, a student photographed the light fixtures in situ in the selected areas. The student used the smart spectrometer instrument to collect lighting data including: color temperature, color rendering (for colors R1-R15), light output, peak intensity, and illuminance. The instrument was held at 2'-6" above finished floor such that horizontal light level readings (illuminance), color metrics and light output were measured. The data was automatically logged and available for exporting. The current Illuminating Engineering Society (IES)[7] recommendations for illumination were consulted and the researchers determined compliance of the existing spaces with the recommendations.

Figure 1: Smart Spectrometer Data Logger

3.2. Instrument #2: Simultaneous Color Viewer

A GTI Simultaneous Color Viewer with 4 simultaneously visible light sources and a separately controlled UV source, was acquired[5]. The booth included Cool White Fluorescent (CWF) "store light", incandescent "home light",an optional LED light, and a D65 artificial daylight source, which was requested at the time of purchase in order to comply with industry-standard evaluation methods. Fig.2 shows the SCV and the labeling of each light at the front panel of the instrument. The SCV measured 15 1/8"D x 15 ¾"Wx 25 1/8"H. The SCV uses 120V and consumes 125 Watts.

In a required lighting course, students evaluated material color samples under the new SCV instrument by viewing a variety of materials and interior finish samples including: colored paper, carpet, fabrics and wall covering. Students evaluated each sample under the four light sources during a one-hour class period. In a required class on textile design students also observed the effects of various light sources on the color of fabric samples that they have dyed (see Fig. 3). Light data and comments of light effect on color were recorded.

Figure 2: GTI Simultaneous Color Viewer (left). Icon labels for SCV light sources (right).

Figure 3: Study of effects of light on material color using SCV

3.3 Instrument #3:Color Matching Booth

A GTI MiniMatcher® Series model MM-4e Color Matching Booth [6] (see Fig. 4) was acquired and used for this study. The booth was equipped with D65 (per request at the time of purchase) artificial daylight, CWF store light, incandescent A home light, an optional LED light, and additional Ultraviolet light. Light source switches labeled with icons were located at the top of the front panel of the instrument. The overall dimensions of the booth were 19"H x 25.6"W x 19"D with viewing area of 14.25"H x 24"W x 16"D.An appropriate size VS-45DC - 45 degree viewing stand was also purchased to allow for recommended [10] viewing procedures to be carried out. The stand and the booth interior were both painted in standard Munsell N7 grey color, which is typically required in standard color evaluation procedures. The booth used standard 120V at 135 Watts.

Figure 4: GTI MiniMatcher MM-4e Color matching Booth (left). Light source switches with icon labels (right).

Students evaluated the color differences of a pair of textiles samples (see Fig. 5). The two samples had same fiber content but different fabrications; both samples were batch dyed in the same dye bath. The samples were visually evaluated: (a) under typical fluorescent classroom lighting and (b) under the standard D65 artificial daylight in the Color Matching Booth. Variation of perceived color differences between the two samples were assessed by visually matching the color of each sample in each lighting condition to standard color paint chip book produced by Sherwin Williams. The catalog number of the paint swatch perceived to be the closest match to the fabric color in each condition was recorded.

Figure 5: Pair of fabric materials and standard paint swatches used in the study utilizing the Color Matching Booth

3.4 Instrument #4: Handheld spectrophotometer

Students evaluated the color differences of a pair of textiles samples (see Fig. 5). The two samples had same fiber content but different fabrications; both samples were batch dyed in the same dye bath. The samples were visually evaluated: (a) under typical fluorescent classroom lighting and (b) under the standard D65 artificial daylight in the Color Matching Booth. Variation of perceived color differences between the two samples were assessed by visually matching the color of each sample in each lighting condition to standard color paint chip book produced by Sherwin Williams. The catalog number of the paint swatch perceived to be the closest match to the fabric color in each condition was recorded.

Figure 6: Datacolor CHECK 3 sphere spectrophotometer

In several exercises students used the handheld spectrophotometer to quantify the color of samples (see Fig. 7) using color coordinates CIE L*, a*, and b*: The color of the following samples was measured: 1). A selected Munsell chip from a Munsell hue chart and the four adjacent color chips (top, bottom, left, and right); 2). Three ready-to-wear garments of the same style and size and at the same location on the garment. 3). Two samples of fabrics with same fiber content but different fabrication dyed in the same dye in a batch dyeing process. Values for color differences were extracted and discussed.

The SCV, the Color Matching Booth, and the handheld spectrophotometer, along with other materials such as a Munsell Color Tree, were housed together on a rolling lab bench (see Fig.8) forming a portable Mini Color Lab. The bench was outfitted with a power strip with multiple outlets, accommodating the equipment on the bench. The Mini Color Lab thus required a single electrical outlet. This setup allowed for the Mini Color Lab to be wheeled to a classroom and be used in various classes by different instructors for class demonstrations and teaching units. When not in use, the Mini Color lab was stored in a secure storage room.

Figure 7: Color measurement exercises completed using the handheld spectrophotometer: 1). Measuring adjacent colors on a Munsell hue chart (left). 2). Measuring color differences of ready-to-wear products (middle). 3). Measuring color differences of fabrics with same fiber content but different fabric tion dyed in the same dye bath (right).

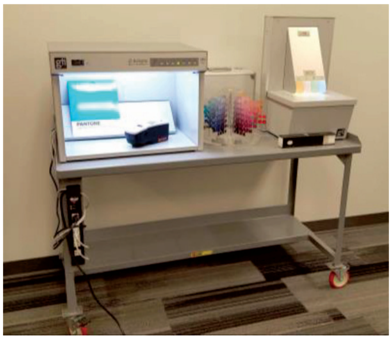


Figure 8: Portable Mini Color Lab

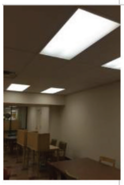
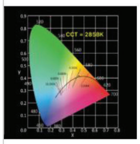
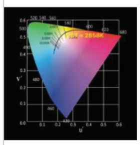
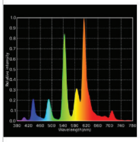
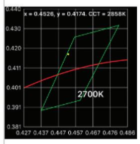
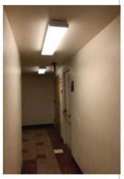
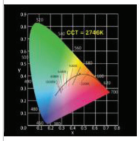
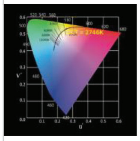
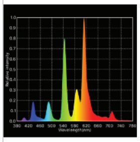
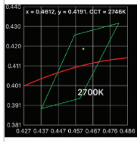
4. Results

4.1. Instrument #1: Smart Spectrometer Data Logger

One student (see Fig. 9) collected data at each of 10 locations (N=10) in the University library. There were two luminaire types: 1). 2x4 troffers and 2).surface mounted wraparounds. It was found that all (100%) of the existing ten luminaires studied were lamped with fluorescent and featured acrylic lenses. The horizontal light levels ranged from a low of 332 lux (31 footcandles) to a high of 667 lux 62 footcandles) with a mean of 511 lux (47 footcandles). The recommended light levels for reading in libraries was found to be: 6.97 -23.23 fc for visual age of observers less than 25 years old; 13.94-46.45 fc for 25-65 years old; and 27.87-92.90 fc for over 65 years old. It was determined that all (N=70, 100%) of the light levels fell within the acceptable ranges of recommended light levels and therefore complied with the IES recommended levels for all age groups. The correlated color temperature of all of the luminaires was found to range from a high of 2858 CCT to a low of 2746 CCT. The mean was 2807 CCT. Numerous color images of Chromacity Diagrams and Spectral Distributions were created using the instrument and the Genius app. Refer to TABLE 1 for examples of results. A total of 70 data points were collected. The Lighting Passport device uses a 5V DC, 500 mA lithium ion rechargeable battery. Refer to Fig. 9for students-in-action.

Figure 9: Student using the Spectrometer Data Logger

Table 1: Smart Spectrometer Data Logger data

Luminaire in Situ	CCT, K	CRI	Illuminance lux	fc	CIE Diagram		Spectral Distribution	
Fluorescent 	2858	86	667	62.0				
Fluorescent 	2746	86	569	52.9				

4.2. Instrument #2: Simultaneous Color Viewer

The four light sources of the GTI SCV had been labeled by the manufacturer on the surface of the instrument with only descriptors or icons (seeFig.2). After opening the lamp chamber, some identifying lamp information was discovered on the individual lamps. By observing the writing on the bulbs, the researchers found that two of the lamps were manufactured by Sylvania and one by Philips. The other lamp was labeled “GTI Graphic Technology, Inc.”

By searching for the manufacturer and lamp types on manufacturers’ websites[12-14]additional attributes (i.e. lumens and lamp life) were found. Refer to Fig. 1 and TABLE 1. The researchers then calculated lumens/watts. The SCV was found to have been lamped with three light sources: Incandescent, Light Emitting Diodes (LED) and Fluorescent. The LED lamp color name was “warm white”. There were two lamp colors for fluorescent: “Cool White” and “Natural Daylight”. Incandescent had the highest CRI (100) and the lowest color temperature (2850 K). By contrast, fluorescent had the lowest CRI (62). Fluorescent “natural daylight” had the highestand coldest color temperature (6500 K) however it had a relatively high CRI (96).

Table 2: GTI SCV and MiniMatcher booth lamps matrix

SCV Logos	Light Source	Lamp Manufacturer	Lamp Color Name	CRI	Color Temp, K	LAMP, Lumens	Wattage	Lumens/ Watt	Lamp Life, hours	Approximate Bulb Length
A Image of a house	Incandescent	Sylvania	NA	100	2850	415	40	10.375	1,000	6"
LED 3500	Light Emitting Diode	Philips	Warm White	85	3500	825	10	82.5	40,000	24"
CWF and image of an office buildng	Fluorescent	Sylvania	Cool White	62	4100	1200	20	60	9,000	24"
Image of the sun and mountains	Fluorescent	GTI Graphic Technology, Inc.	Natural Daylight	96	6500	1563	17	91.941	2500	24"

Seventeen students participated in a light and color study utilizing the new SCV instrument. The students placed various materials into the instrument (see Fig. 3). Fig. 10 shows students gathering data using the SCV.

Figure 10: Simultaneous Color Viewer used in studies on effect of lighting on sample color.

4.3. Instrument #3: Color Matching Booth

The GTI MiniMatcher MM-4e was used in a visual matching color exercise with textile samples (see Fig. 4). The Color Matching Booth operates under only one light source at a time.

The available light sources and their indicators on the front panel of the instrument (see Fig. 4) were the same as for the GTI SCV as shown in TABLE 2. For this exercise D65 artificial light was used, which is commonly used for color evaluations for textiles[10].

Seven students performed color matching exercises. The color of fabric that students have dyed was compared to Sherwin Williams standard paint swatches and the closest swatch was selected. Matching was done under (a) the ambient classroom lighting (average Color Temperature 2900 K, CRI 85)and (b) under the D65 light in the Color Matching Booth(Color temperature 6500K, CRI 96) (seeFig. 11). Results were documented using the company swatch numbers (see Fig. 12).

Figure 11: Lighting conditions in study of sample color matching – ambient classroom lighting (left) and Color Matching Booth (right)

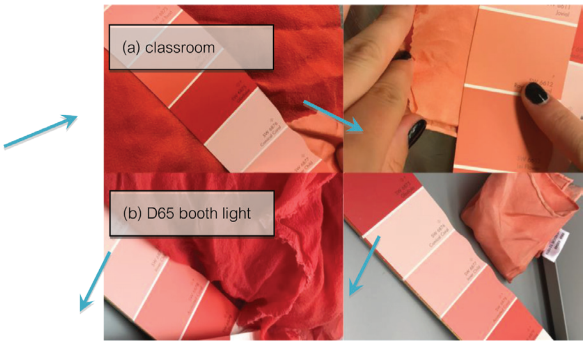


Figure 12: Two test fabrics – Fabric 1 (left) and Fabric 2 (right) matched to standard paint swatches in (a) classroom ambient lighting (top row) and (b) under D65 light in matching booth (bottom row).

4.4. Instrument #4: Spectrophotometer

Seven students used the spectrophotometer to take color measurements in the CIE L*, a*, b* color space. Records of the L*, a*, b* coordinates of the standard (the sample to which comparison was to be made) and the sample, and of the standard-sample difference were recorded from the spectrophotometer display and reported. Comments on the observed differences were provided.

In the first exercise the color of one Munsellcolor chip and all four surrounding chips– i.e. chips with lower and higher chroma and lower and higher value, were measured. For the second exercise, three pairs of ready-to-wear pants of the same style and size were measured at the same location. The differences among pairs of pants were compared and discussed. For the third exercise the color of Fabrics 1 and 2 in the Color Matching exercise were measured and their color coordinates and differences recorded and discussed.

5. Discussion & Conclusions

The following summary regarding the instruments was created by the instructors based on their observations.

5.1. Instrument #1: Smart Spectrometer Data Logger

The instrument was easy to transport and use. Although a separate app must be downloaded it was found to be a quick and effective process. IPods are readily available and were compatible with the instrument. The empirical illuminance and color measurements along with the color images of lighting properties produced by the smart spectrometer and Genius app combination allowed students to understand the color properties or light. The convenient option to supplement the collected light and color data with photgraphs in situ provided for a very complete visualpicture of existing lighting conditions. The Smart Spectrometer Data Logger was purchased at a cost of $2,795.00 (U.S.).

5.2. Instrument #2: Simultaneous Color Viewer

Although the relatively compact, the instrument was part of a Mobile Color Lab and therefore researchers mounted it along with additional equipment on a lab bench with casters (seeFig.8). The lab bench was still found to be somewhat cumbersome to temporarily move into a classroom from its assigned, secure storage area in the building. However, the use of this instrument required only a simple plug-in of the lab bench extension cord to an existing receptacle. University laboratory re-wiring or permanent installation and construction modifications were not needed. This instrument successfully updated the University laboratory with minimal disruption to the existing facility. The Mini Color Lab was found to be advantageous as the equipment can be serve multiples classes and disciplines.

searchers were very interested in knowing the exact light sources, lamps and lamp attributes. This data was not explicitly labeled by the manufacturer. Possibly, some end-users were not interested in the technical details. It was a bit of an effort to open the lamp chambers and look-up associated characteristics.

Using the instrument was easy. It was clearly an advantage to have all light sources energized at the same time, side by side, as the differences in color of a sample could be readily detected, understood and described. The SCV was purchased at a cost of $1,305.00 (U.S.).

5.3. Instrument #3: Color Matching Booth

The Color Matching Booth was easy to use. Following industry recommendations for visual assessment of color differences outlined in AATCC EP9-2017[10], a 45-degree viewing stand was used to rest samples inside the booth. To ensure correct viewing angle, a chair at the appropriate sitting height was also necessary. Per industry recommendations[15], color reviewers must use neutral (e.g. grey) lab coats but such lab coats were not available at the time of this study. The light sources were the same as those in the SCV. Testing in the booth was performed under D65 artificial daylight. D65 lighting indicator stickers in the booth were used to demonstrate the phenomenon of metamerism: a D65 sticker features a metameric pair of colors – two colors that match under one light source but not under others. D65 stickers are used to remind color reviewers to switch the correct light source when a test is to be performed under standard D65 light source.

The exercise demonstrated how different the appearance of textile and paint can be under different lighting conditions and what implication this difference can have for design. Matching textile colors to standard paint colors was found to be difficult. Making a definitive decision about fabric color and paint swatch matching was made more difficult as fabric texture altered the color in significant ways. For example, the decision to select SW6613 vs SW6612 pant swatch for Fabric 2 in the classroom lighting (see Fig. 12) was not taken with confidence. Granted, the photographs additionally alter colors, the image in Fig. 12 shows that the evaluation of an observer is subjective and highly dependable on the lighting. The use of the light booth allowed students to understand the importance of selecting color with respect to the lighting conditions under which a product will be likely used. Checking color for a design under different lighting conditions would ensure preserving the integrity of a design. If evaluation for color constancy needs to be done matching evaluations need to be replicated multiple times and the results evaluated. The Color Matching Booth was purchased at a cost of $2,056.50 (U.S.) which included both the viewing stand and the black insert panels.

5.4. Instrument #4: Handheld Spectrophotometer

The handheld spectrophotometer was easy to use for color measurements and could be easily transported. Adequate time must be allowed for recharging. Prior to making measurements the instrument needs calibration. In “calibration mode” the instrument provides clear instructions for the procedure, making it easy and straightforward to perform.

The exercises completed with the handheld spectrophotometer were designed to demonstrate the correspondence of visual and numerical expressions of color differences. For example, the color differences measured in pairs of RTW pants demonstrated what are the acceptable numerical values for color difference in products to pass manufacturer quality control. At this introductory level of color theory and practice interpretation of numerical values for color differences was difficult. A variety of exercises can be developed to practice the skill of equating perceived visual color differences to numerical values. The Spectrophotometer was purchased at a cost of $10,674.70 (U.S.) which included the servicing software.

5.5. General Notes

The reported instrument costs were based on our experience and may have included educationaldiscounts. Cost may vary if purchased in the future by others dependent upon many factors. Mostly the student participants varied across the four instruments as the students were enrolled in different courses which used different instruments for different activities. The exception was instruments #3 and #4 which were used by the same seven students.

6. Recommendations

Since light and color interaction is important to a variety of interdisciplinary professionals (architects, apparel designers, interior designers, merchandisers, etc.) it is recommended that more Universities consider the acquisition and use of instruments similar to those tested in this study.

References

[1] CIDA, **Council for Interior Design Accreditation Professional Standards 2017**, 2016.

[2] D. Limbaugh, "Personal communication with board members of the American Apparel and Footwear Association education foundation," ed, 2017.

[3] Semiconductor Today, "Philips Lighting delivers billionth LED lamp," 2017, November 27. Accessed on: (2018, March 10). Available: http://www.semiconductor-today.com/news_items/2017/nov/phillipslighting_271117.shtml

[4] P. R. Hebert, G. Peek, and M. Kang, **Light and color.** Oklahoma Cooperative Extension Service Fact Sheet L-428, 2013.

[5] GTI (Graphic Technology Inc.). (2018, February 18). **SCV Simultaneous Color Viewer.** Available: http://www.gtilite.com/products/scv-simultaneous-color-viewer/

[6] GTI (Graphic Technology Inc.). (2018, February 18). **GTI MiniMatcher® Series.** Available: http://www.gtilite.com/products/color-matching-systems/gti-minimatcher-series/

[7] D. L. DiLaura, K. W. Houser, R. G. Mistrick, and G. R. Steffy, **The Lighting handbook: reference and application.** New York: Illuminating Engineering Society, 2011.

[8] The International Commission on Illumination. **CIE Colorimetry - Part 1: Standard Colorimetric Observers**, 2006.

[9] Allied Scientific Pro. (2018, March 10). **Introducing the Lighting Passport TM.** Available: https://www.lightingpassport.com/

[10] The American Association of Textile Chemists and Colorists. **AATCC Evaluation procedur 9-2017: Visual assessment of color difference of textiles**, 2017.

[11] Datacolor. (2018, February 18). **Datacolor CHECK 3 Trusted Portable Color Measurement.** Available: http://www.datacolor.com/business-solutions/product-overview/datacolor-check-3/

[12] Platt Electric Supply. (2018, January 30). **Philips Lighting 10T8/END/24-3500UNV 10 W LED T8 Lamp.** Available: https://www.platt.com/platt-electric-supply/LED-Tube-Type-T8/Philips-Lighting/10T8-END-24-3500UNV/product.aspx?zpid=935310

[13] Elliot Electric Supply. (2018, February 11). **F20T12CW 20W T12 24" Cool White 62 Cri Bi-Pin Fluor Lamp.** Available: https://www.elliottelectric.com/Media/F20T12CW-SYL

[14] Graphiclite. (2018, February 11). **Graphiclite®100 Color Viewing Lamps.** Available: http://www.quantotec.com/PDFS/5000K%20Graphiclite%20100%2

[15] R. Aspland and A. C. Laidlaw. **Color Guidebook: Best Practices for Color Control in the Textile Supply Chain.** AATCC (American Association of Textile Checmists and Colorists), 2011.