Color and its Relationship to Light Intensity

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Abstract

The Bezold-Brücke shift is a psychological phenomenon that describes how color hue changes to the human eye with changes in light intensity [1]. When light of a higher intensity value is reflected off a colorful surface, a person may see that color as lighter or may see a different color completely. The goal of this experiment is to measure the quantitative values of color to measure if the shift is purely psychological or if there is a physical shift in color value. I used acrylic paint on canvas and an LED light source for this experiment and measured the color values in two ways: using a spectrometer and using the RGB color space. These two avenues of measurement allow for thorough investigation of whether or not the change in light intensity on a surface changes the measurable values of color.

1 Introduction

Color is a physical property of an object that can be measured in a variety of ways. The main property thought of when considering color is its hue value. The hue of color determines which colors are red, blue, yellow, etc. Color appears to the human eye through reflection of light and therefore has characteristic wavelength values. A spectrometer or colorimeter can be used to measure a color hue on the visible light spectrum. The visible light spectrum distributes colors that are visible to the human eye over a range of 400 to 700 nanometers (nm), and each color corresponds to a range of values [2]. An image of the visible light spectrum is shown in Figure 1. When using a spectrometer, what is actually being measured is the color of the light reflected off the surface of the object. When light bounces off an object, the colors reflected are detected by the spectrometer while the other colors are absorbed [3]. An instance where all colors are absorbed would be a black object, and an instance where all colors are reflected would be a white object. The spectrometer is able to pick up which wavelengths of light are reflected, and that gives the spectral value of color.

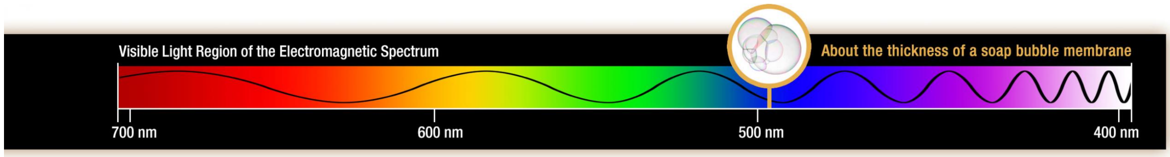

Figure 1: Visible Light Spectrum [2]

Colors can also be measured through a color space. Color spaces were created for digital projections of color, like on a computer monitor or television screen [4]. They are a way to create color combinations in ways other than combinations of light wavelengths. There are a variety of color spaces available, but the two most commonly used and understood color spaces are the RGB and HSL color spaces. RGB and HSL stands for "Red, Green, Blue" and "Hue, Saturation, Luminosity", and these color spaces break down color into those basic components. The hue relates to how color is labeled. Hue can be thought of as a 360 degree circle beginning with red at 0°and flowing through the colors of the visible light spectrum in this order: red, orange, yellow, green, light blue, blue, purple. The saturation of a color describes how close the color is to being white, and the luminosity of a color describes its brightness or how close the color is to being black [4]. A helpful diagram of the HSL color space is shown in Figure 2. Colors can also be broken down into a combination of red, green, and blue. In a color space, each pixel of color has an HSL and RGB value.

This experiment will use both spectral values of color as well as color space information to show whether or not a change in light intensity will change the measurements of the colored canvas. The Bezold-Brücke shift is a psychological response to change in light intensity, so the expected result of the experiment is to show little to no change in color measurements with change in LED intensity. When recording data for a single canvas, I expect the peak values to be the same regardless of what LED intensity is illuminating it. For the spectral analysis, I expect the wavelength value (on the x-axis) where the intensity peaks to be the same for each measurement. For the RGB analysis, I expect the mode value to be the same

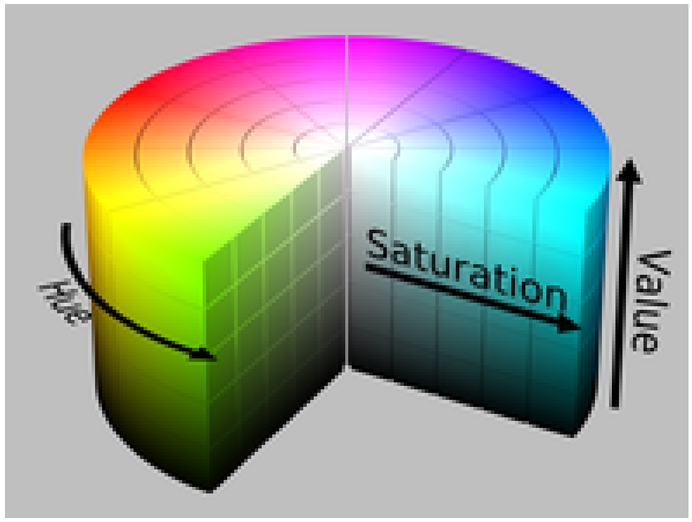

Figure 2: Hue, Saturation, Luminosity diagram [5]

for reach measurement.

To begin the experiment, I had to select a light source and a medium on which to conduct my experiment. The light source that I had chosen was a white LED at levels 40 W, 60 W, and 100 W. I chose these LEDs because, although they are slightly more expensive than a fluorescent or incandescent bulb, LEDs have a longer lifespan than other types of bulbs and the spectra that LEDs produce is similar to that of the human eye [6]. I chose the medium to be acrylic paint on canvas because it is a medium I am already familiar with. Acrylic paint is not as expensive as other types of paint, and the brand that I chose to use dries matte. Other paints, like oil or watercolor, have a tendency to be more reflective, and I did not want the shininess to interfere with the experiment. I painted 5 canvases for the experiment: one red, blue, yellow, purple, and light blue. These canvases are shown in Figure 3.

Figure 3: Canvases

2 Theory

To begin, I researched the expected spectra of a white light LED, which is the bulb that was used in my experiment. An LED spectrum mimics that of a human eye spectrum, being much more present in the red and yellow portion than in the green [6]. LEDs also have a characteristic peak in the blue end of the spectrum, as the light from LEDs tends to shift slightly blue. This can be altered depending on which "color" LED is chosen. The theoretical spectrum produced by an LED is shown in Figure 4. The LED intensities I chose for my experiment had expected lux values of 385 lux, 685 lux, and 1285 lux. The lux values and comparison to the expected value is shown in Table 1. There was an unexpected difficulty in using the spectrometer on the darker canvases, the blue and the purple. So, to increase the amount of light reaching the canvas, a light tunnel was constructed to surround the LED bulb. The final lumen values at 5 cm from the tunnel are shown in Table 2.

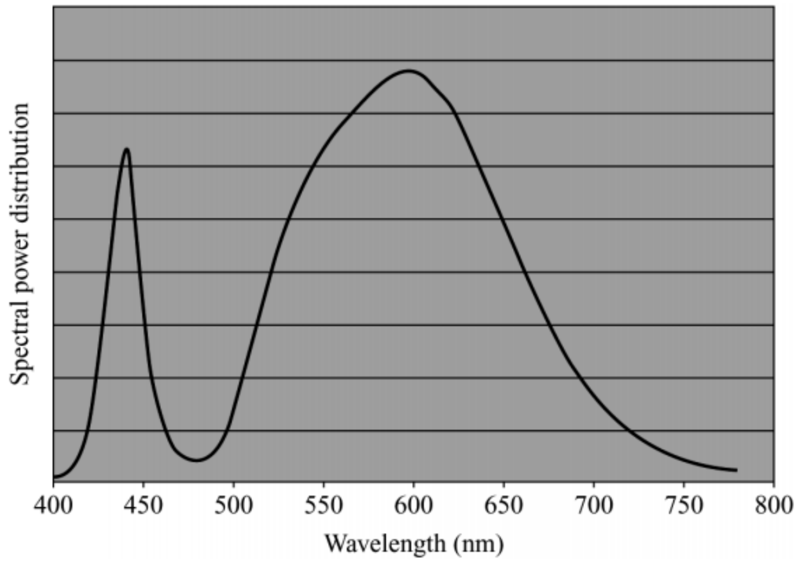

Figure 4: Theoretical visible light spectrum of a white light LED.

Bulb	Expected Lux	Actual Lux	Percent Difference
40 Watt equivalent	385	415	7.2%
60 Watt equivalent	685	680	0.7%
100 Watt equivalent	1285	1367	6.0%

Table 1: Original LED lux output

Bulb	Lux output with light tunnel
40 Watt equivalent	23040
60 Watt equivalent	32240
100 Watt equivalent	77080

Table 2: LED lux output with light tunnel

To analyze the data I collected in this experiment, I used both the PASCO spectrometer software and Jupyter Notebook, a python coding environment. From the PASCO software, I was able to collect the raw data created when I took a run of data. It produced a CSV file with the amplitude for each wavelength value and from that file I was able to determine the wavelength value at which the amplitude was maximum. For the purple, blue, and light blue canvases, there were multiple peak values, not just one, so I used a cursor tool in the PASCO software to determine the specific peak values in the software. I ran three trials per LED per canvas- 9 trials total per canvas- and the spectra created by the PASCO software and by my python script are located in the Appendix. To analyze the color space data, I collected imaged of the illuminated canvas and uploaded them to Jupyter Notebook. I was able to create a code that went through the images I produced and collected the RGB values for each pixel and stored them in individual red, green, and blue arrays. Using these arrays, I was able to determine the average and mode values for each image. Using this information, I compared the peak values of both the spectral data and the image data to see if there were any distinct changes.

3 Methods

I set up the light source by attaching it perpendicularly to a support stand and facing the LED toward the canvas straight on. Using poster board and reflective mirror material, I was able to make a reflective cylinder to be used as a light tunnel that increased the amount of light reaching the canvas. I placed the tunnel around the LED and covered the back to bring all of the light put out by the LED to the canvas. An image of the light tunnel I created is shown in Figures 5 and 6. This tunnel was useful because it allowed me to measure the darker canvases well and move the canvas 20 cm away from the light source and measure from that location consistently. The edges of the tunnel do not touch the bulb and are large enough that I can change the LED bulbs without having to remove the tunnel completely. Once that was set up, I placed the first LED, the 40 W equivalent bulb, in the lamp to begin taking data.

Figure 5: Light Tunnel with reflective mirror material

I used adhesive strips to hold the canvas in place 20 cm from the bulb. When the lamp was on, a circle of light was shown on the canvas; that is the area where I took measurements to ensure that each area I measured was receiving the same amount of light. I set up the spectrometer by connecting it to a computer and running the PASCO Spectrometer software. I used the "analyze light" option and the light sensor to collect data since I was measuring the values of light reflected from the canvas. I held the spectrometer sensor at an angle right at the end of the light tunnel, 5 cm from the canvas. To collected the RGB color space data, I used a Nikon A900 camera, borrowed from the Christopher Newport University Media Center. I focused the camera on the illuminated circle on the canvas and captured three images of the same spot.

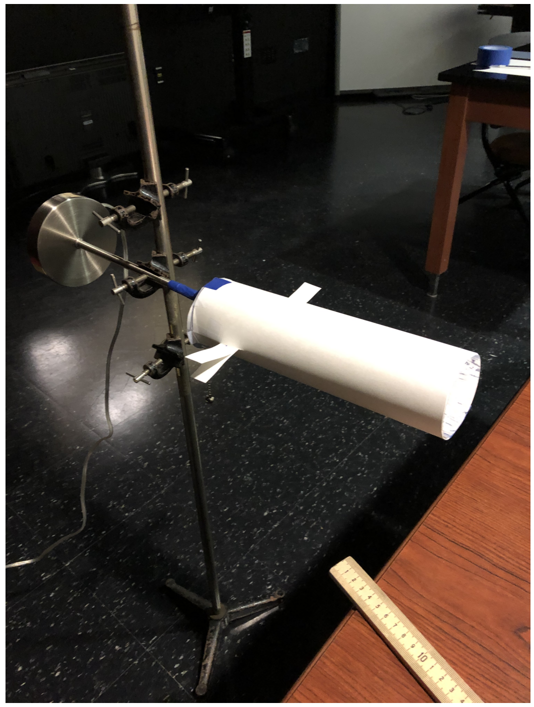

Figure 6: Light apparatus setup

From there, I was able to upload the spectral information produced by the PASCO Spectrometer software and the image data I collected with the Nikon to a Jupyter Notebook script. I created a script that would open the spectrometer CSV data file and reproduce the spectrum created while the software was running. The code also gave me the peak intensity and wavelength values for each graph. The graphs I created are shown in the Appendix.

4 Data

Below are the tables and graphs I have created displaying the results of both the spectral and color space data for each canvas. The color measurements are shown on the x-axis, and the LED values are on the y-axis. It is worth noting that, for the spectral data graphs, the x-axis only displays a portion of the visible light spectrum to better view the error bars on the graphs. For the spectral results plots, each colored shape represents one trial; the blue circle represents the first trial, the red triangle represents the second trial, and the yellow square represents the third trial. In the RGB results plots, each color array is designated by its corresponding color (red, green, or blue), and the trials are labeled by shape; the circle is the first trial, the triangle is the second trial, and the square is the third trial. In looking at the graphs, there is a large amount of overlap between the trials, which supports hypothesis that the color measurement should not change with LED value.

For the yellow canvas spectrometer trials, the largest error on the first trial was 2, the largest error on the second trial was 2, and the largest error on the third trial was 1.76. For the yellow canvas color space trials, the largest error on the first trial was 8.69, the largest error on the second trial was 8.02, and the largest error on the third trial was 8.62.

For the red canvas spectrometer trials, the largest error on the first trial was 0.66, the largest error on the second trial was 0.66, and the largest error on the third trial was 1.33. For the red canvas color space trials, the largest error on the first trial was 1, the largest error on the second trial was 0.66, and the largest error on the third trial was 2.03.

For the purple canvas spectrometer trials, the largest error on the first trial was 2.66, the largest error on the second trial was 2.66, and the largest error on the third trial was 3.33. For the purple canvas color space trials, the largest error on the first trial was 2.66, the largest error on the second trial was 16.05, and the largest error on the third trial was 3.21.

For the light blue canvas spectrometer trials, the largest error on the first trial was 2.33, the largest error on the second trial was 2.4, and the largest error on the third trial was 2.66. For the light blue canvas color space trials, the largest error on the first trial was 2.85, the largest error on the second trial was 2.65, and the largest error on the third trial was 2.19.

For the blue canvas spectrometer trials, the largest error on the first trial was 2.33, the largest error on the second trial was 2.33, and the largest error on the third trial was 2.65. For the blue canvas color space trials, the largest error on the first trial was 7.54, the largest error on the second trial was 8.14, and the largest error on the third trial was 8.74.

YELLOW SPECTRAL DATA

	100 W LED eq.		60 W LED eq.		40 W LED eq.	
TRIAL	λ (nm)	Amplitude	λ (nm)	Amplitude	λ (nm)	Amplitude
Trial 1	613	34.43	613	17.83	615	9.43
Trial 2	615	34.04	613	16.25	615	9.43
Trial 3	917	31.77	613	17.24	613	9.91

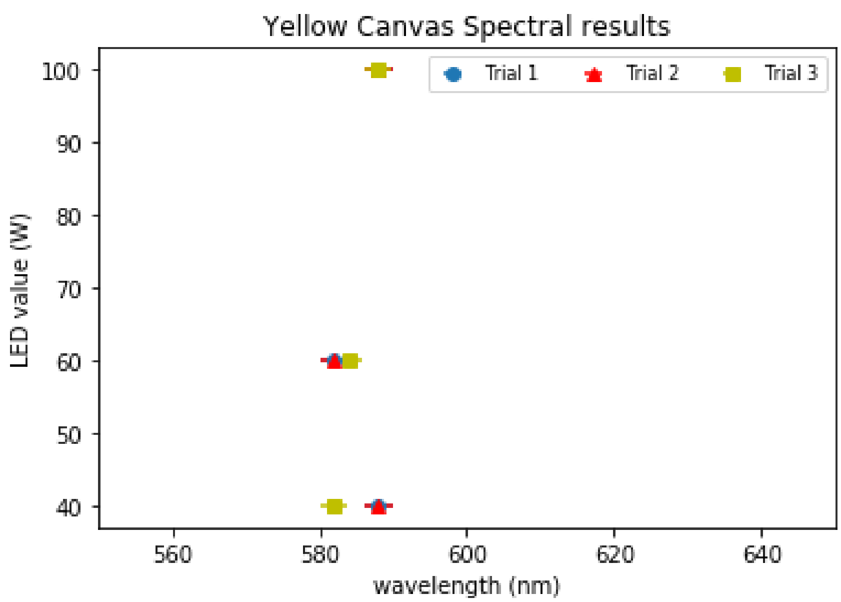

Figure 7: Yellow canvas - Spectrometer results

YELLOW RGB DATA

	100 W LED eq			60 W LED eq			40 W LED eq		
TRIAL	red	green	blue	red	green	blue	red	green	blue
Trial 1: mean	236	140	1	245	152	0	227	130	8
Trial 1: mode	255	171	0	255	158	0	237	141	0
Trial 2: mean	244	151	2	239	147	0	237	140	0
Trial 2: mode	255	174	0	242	149	0	246	151	0
Trial 3: mean	244	151	1	255	132	3	234	138	3
Trial 3: mode	255	173	0	238	145	0	242	150	0

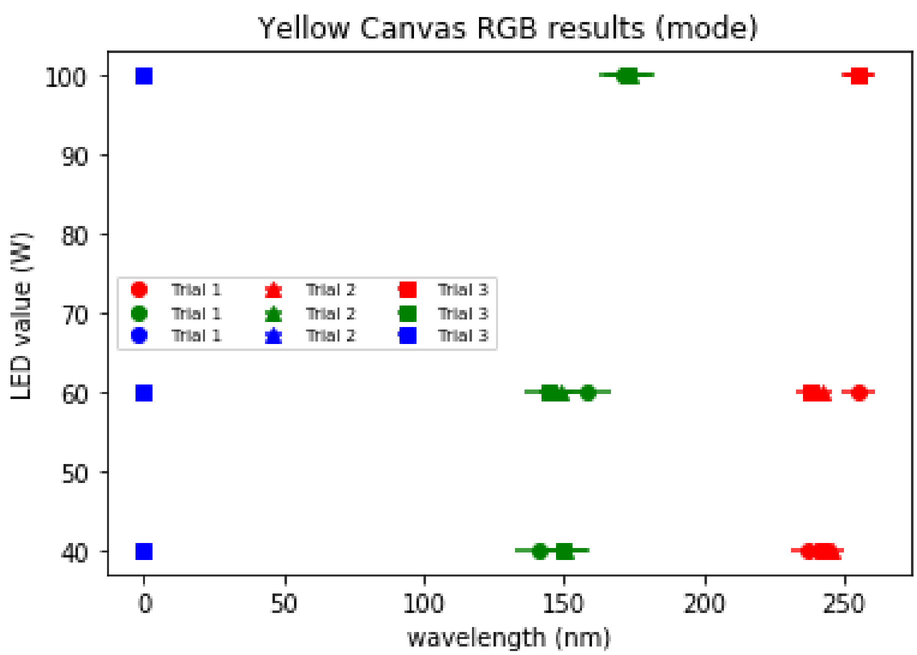

Figure 8: Yellow canvas - RGB results

RED SPECTRAL DATA

	100 W LED eq.		60 W LED eq.		40 W LED eq.	
TRIAL	λ (nm)	Amplitude	λ (nm)	Amplitude	λ (nm)	Amplitude
Trial 1	613	34.43	613	17.83	615	9.43
Trial 2	615	34.04	613	16.25	615	9.43
Trial 3	617	31.77	613	17.24	613	9.91

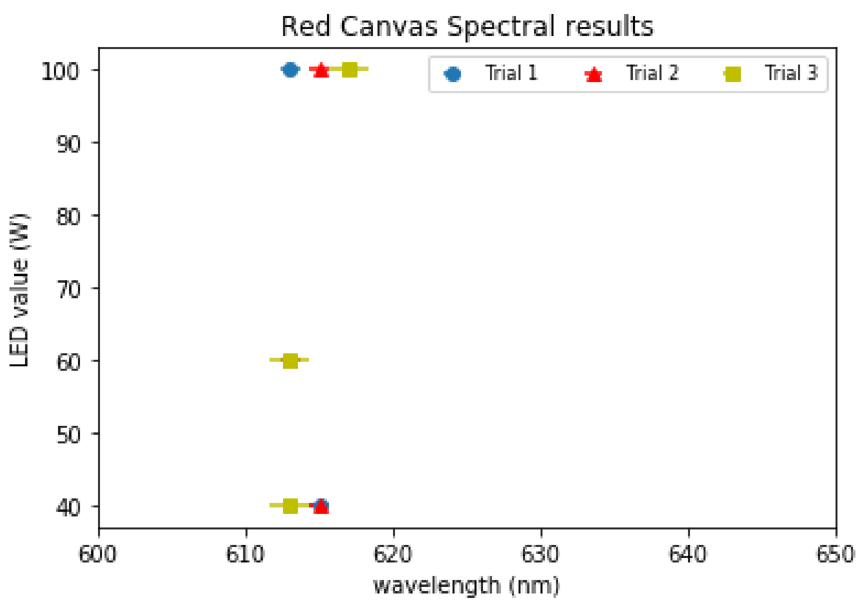

Figure 9: Red canvas - Spectrometer results

RED RGB DATA

	100 W LED eq			60 W LED eq			40 W LED eq		
TRIAL	red	green	blue	red	green	blue	red	green	blue
Trial 1: mean	234	38	13	227	35	11	238	13	15
Trial 1: mode	255	18	0	255	18	0	255	18	0
Trial 2: mean	235	39	14	234	41	14	137	43	15
Trial 2: mode	255	18	0	255	21	0	255	21	0
Trial 3: mean	235	38	14	239	44	15	236	41	14
Trial 3: mode	255	18	0	255	25	0	255	21	0

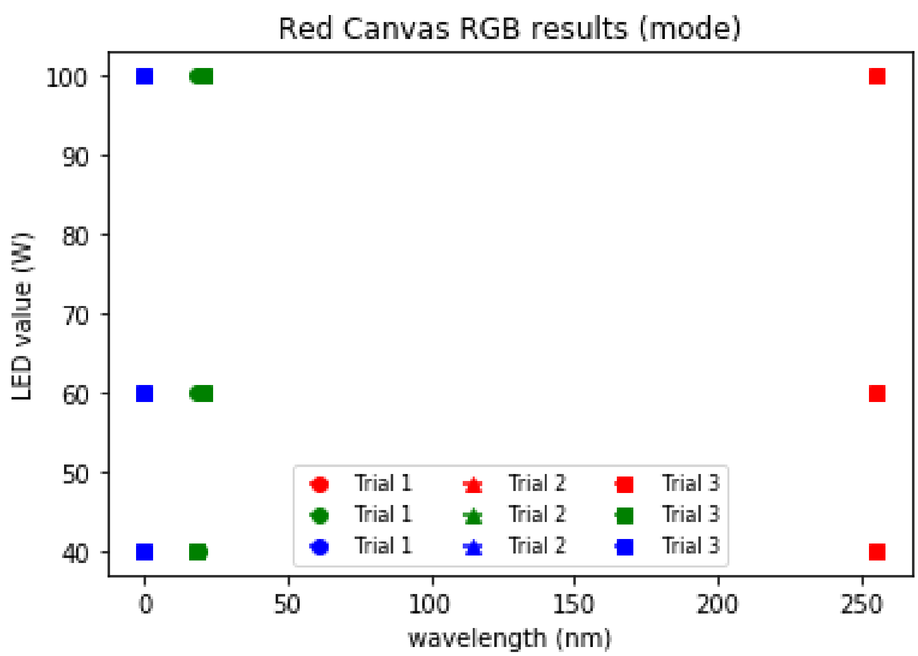

Figure 10: Red canvas - RGB results

PURPLE SPECTRAL DATA

	100 W LED eq.		60 W LED eq.		40 W LED eq.	
TRIAL	λ (nm)	Amplitude	λ (nm)	Amplitude	λ (nm)	Amplitude
Trial 1	453	5.79	445	5.03	445	4.03
	588	9.57	588	6.3	588	4.49
	646	6.79	651	4.69	651	3.81
Trial 2	453	6.79	445	5.06	445	4.01
	591	9.45	589	5.81	588	4.49
	646	6.47	652	4.49	654	3.86
Trial 3	455	5.57	445	5.08	445	3.93
	588	8.67	588	6.03	588	4.32
	646	6.18	650	4.54	649	3.69

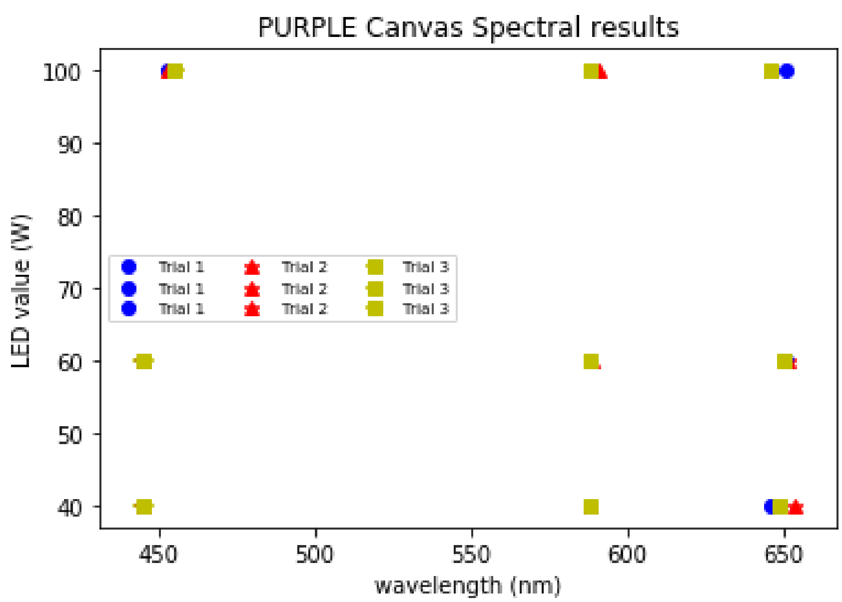

Figure 11: Purple canvas - Spectrometer results

PURPLE RGB DATA

	100 W LED eq			60 W LED eq			40 W LED eq		
TRIAL	red	green	blue	red	green	blue	red	green	blue
Trial 1: mean	187	110	118	190	112	130	185	110	121
Trial 1: mode	210	135	145	205	129	147	202	128	141
Trial 2: mean	187	110	118	186	107	125	186	111	121
Trial 2: mode	210	85	145	205	128	146	206	137	145
Trial 3: mean	189	112	119	189	111	128	185	110	121
Trial 3: mode	213	139	147	207	132	150	202	128	141

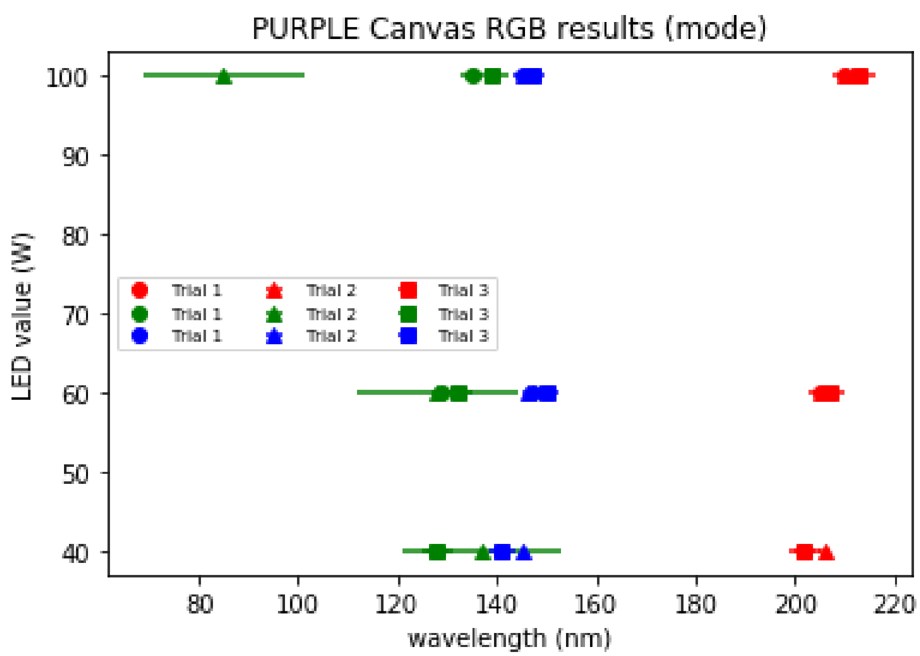

Figure 12: Purple canvas - RGB results

LIGHT BLUE SPECTRAL DATA

	100 W LED eq.		60 W LED eq.		40 W LED eq.	
TRIAL	λ (nm)	Amplitude	λ (nm)	Amplitude	λ (nm)	Amplitude
Trial 1	453	13.11	445	8.90	449	4.94
	523	16.03	524	11.69	524	6.13
	580	15.74	572	10.57	575	5.74
Trial 2	453	15.12	445	9.11	451	5.10
	524	18.08	524	11.75	524	6.64
	577	18.01	573	10.61	572	6.22
Trial 3	453	14.73	445	9.77	450	5.61
	524	17.52	523	12.45	524	7.08
	580	17.39	572	11.50	572	6.69

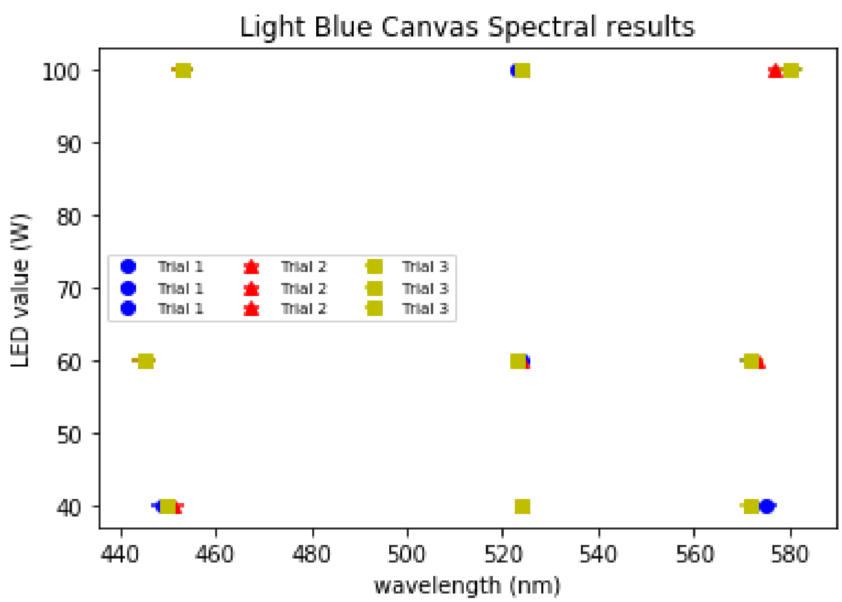

Figure 13: Light blue canvas - Spectrometer results

LIGHT BLUE RGB DATA

	100 W LED eq			60 W LED eq			40 W LED eq		
TRIAL	red	green	blue	red	green	blue	red	green	blue
Trial 1: mean	173	175	140	153	158	121	167	173	142
Trial 1: mode	180	183	149	175	182	150	183	187	158
Trial 2: mean	170	173	138	158	164	126	164	170	138
Trial 2: mode	178	180	146	182	188	152	181	185	155
Trial 3: mean	171	173	138	157	162	125	164	170	158
Trial 3: mode	182	184	151	182	188	152	182	187	158

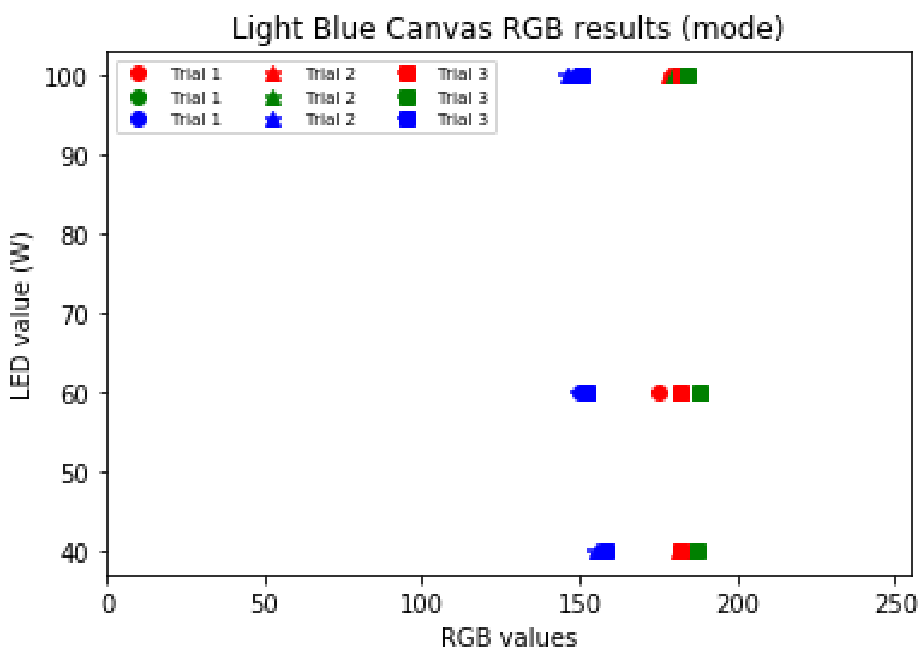

Figure 14: Light blue canvas - RGB results

BLUE SPECTRAL DATA

	100 W LED eq.		60 W LED eq.		40 W LED eq.	
TRIAL	λ (nm)	Amplitude	λ (nm)	Amplitude	λ (nm)	Amplitude
Trial 1	453	8.99	445	7.17	450	4.77
	500	6.68	500	5.54	499	4.14
	580	4.77	575	4.12	580	3.48
Trial 2	453	9.19	445	5.82	450	4.77
	500	6.74	500	4.55	501	4.15
	584	4.67	580	3.81	580	3.46
Trial 3	454	9.30	445	5.72	451	4.80
	500	6.84	501	4.55	500	4.18
	584	5.44	580	3.72	580	3.47

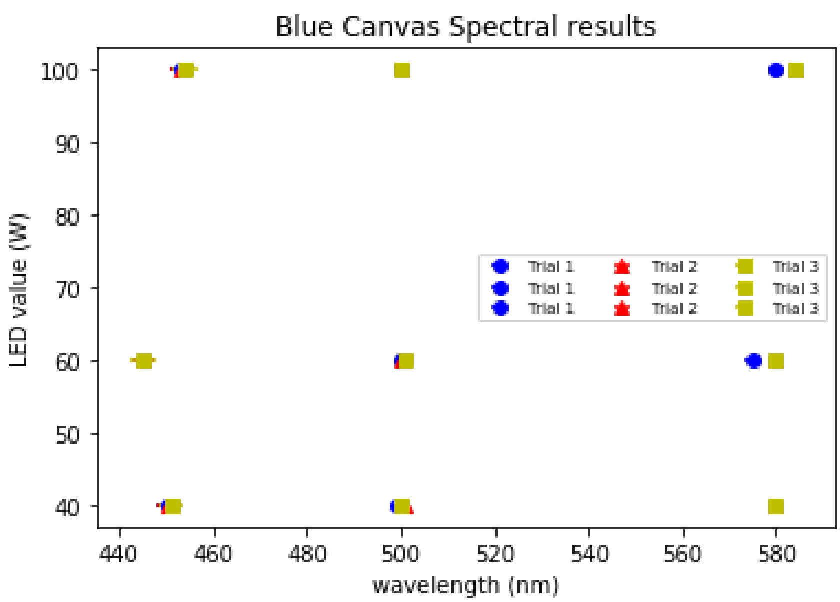

Figure 15: Blue canvas - Spectrometer results

BLUE RGB DATA

	100 W LED eq			60 W LED eq			40 W LED eq		
TRIAL	red	green	blue	red	green	blue	red	green	blue
Trial 1: mean	133	169	204	112	143	172	107	147	185
Trial 1: mode	151	180	218	140	166	198	125	166	204
Trial 2: mean	131	165	199	111	142	174	105	147	185
Trial 2: mode	151	182	217	134	165	200	123	165	203
Trial 3: mean	131	165	200	102	138	177	107	152	192
Trial 3: mode	150	182	217	122	160	201	126	166	206

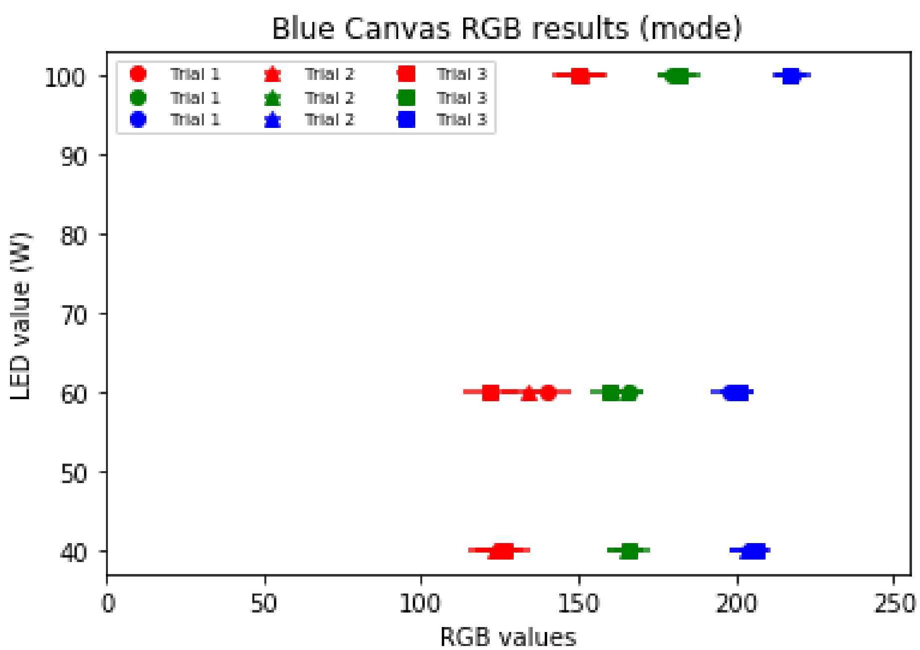

Figure 16: Blue canvas - RGB results

5 Discussion and Conclusions

For the results of the spectrometer data, the canvases ranked from highest error to lowest are: purple, light blue, blue, yellow, red. For the results of the color space data, the canvases ranked from highest error to lowest are: purple, yellow, blue, light blue, red. The purple canvas may have the highest error because it was the hardest canvas to get data from with both the spectrometer and the Nikon camera. On the other hand, the red canvas shows the lowest error, and that could be attributed to the ease of collecting data. The error shown in the color measurements could have appeared due to human error in movement. The color space errors specifically could also have come from a darkness around the edge of the image that came from the camera focusing.

If this experiment were to be conducted again in the future, there are a few changes I would recommend to reduce error. Firstly, choosing high enough LED values to consistently get information from the darker canvases would improve the results for the spectral data. Secondly, I would recommend setting up a stand to hold the measurement equipment, the spectrometer sensor and the camera, in a consistent location to reduce the amount of human movement error that occurred. Finally, choosing an alternative medium would be an interesting spin on this project. I chose acrylic paint on white canvas, however there are many other types of paint that could be used. Also, a different colored canvas could also change the results. It would be interesting to investigate that further in the future.

Overall, the results of my experiment are aligned with what I expected. I expected to have slight human error and equipment error measurements, but the trends in the graphs show very little, if any, change in color measurement value as the LED intensity increases. This supports my hypothesis that physical color measurement is not changed with a change in light intensity. Furthermore, the experiment supports the notion that the Bezold-Brücke shift is a purely psychological phenomenon that does not affect the physical color measurement of an object.

6 Appendix

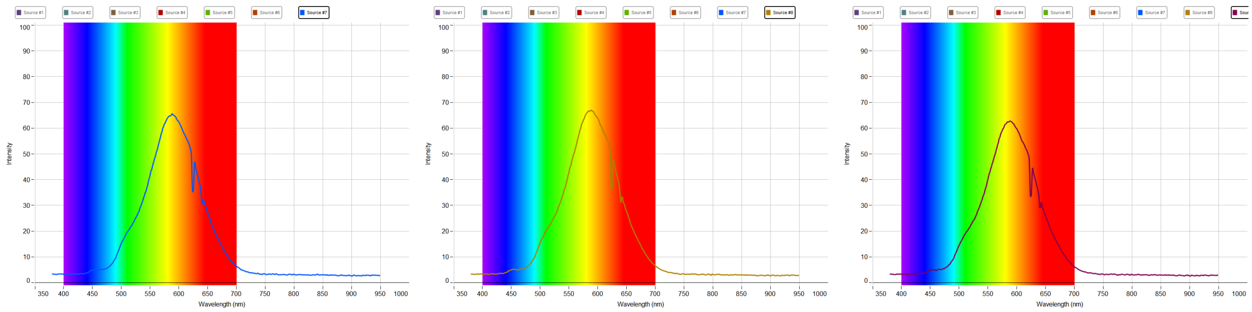

Figure 17: Yellow canvas - 100 LED

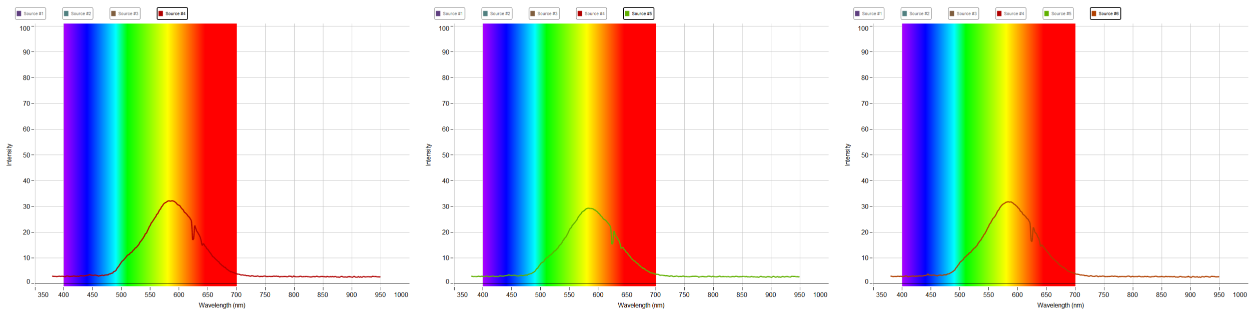

Figure 18: Yellow canvas - 60 LED

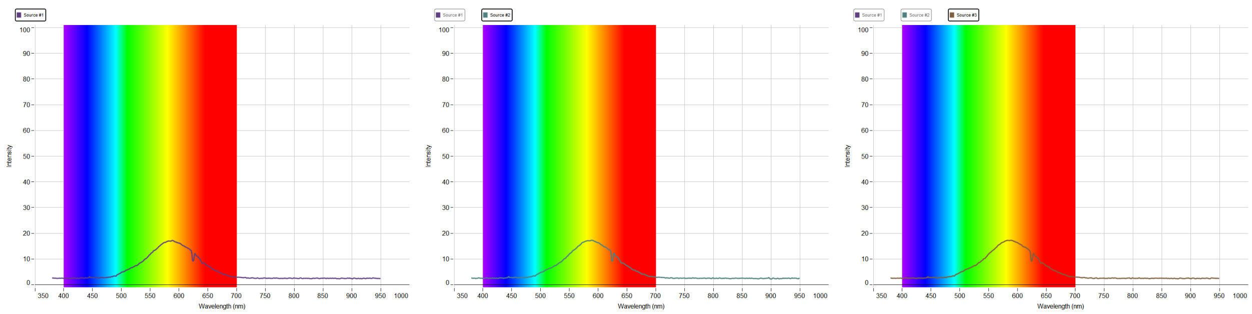

Figure 19: Yellow canvas - 40 LED

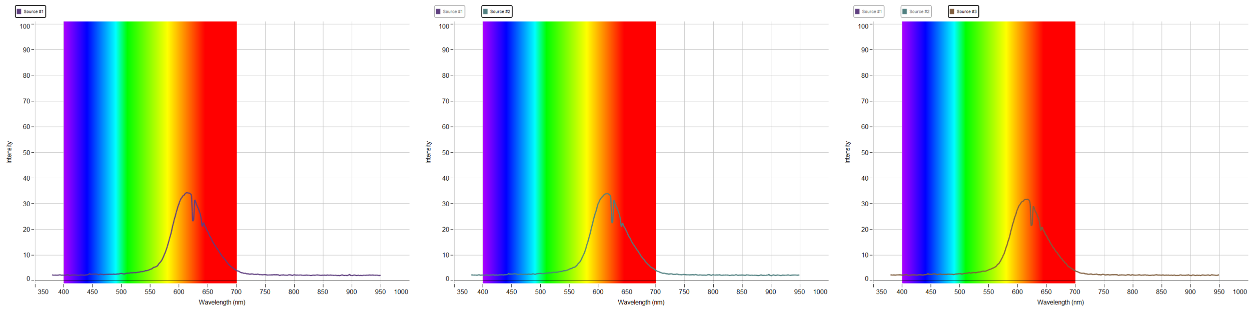

Figure 20: Red canvas - 100 LED

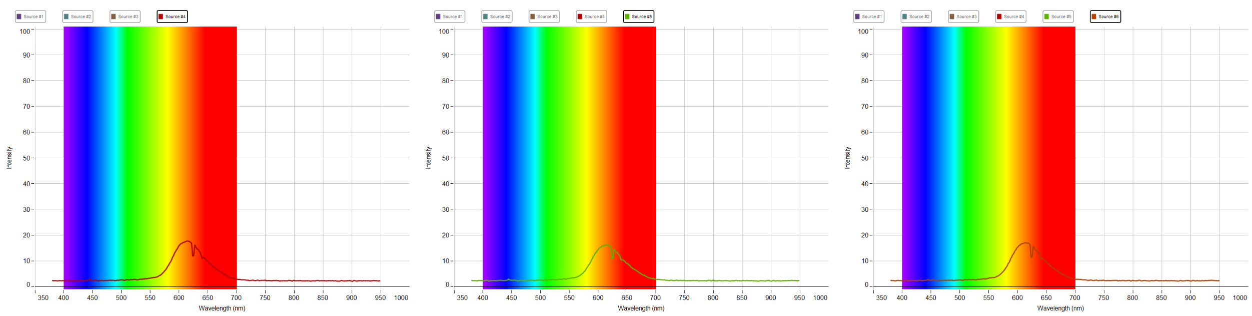

Figure 21: Red canvas - 60 LED

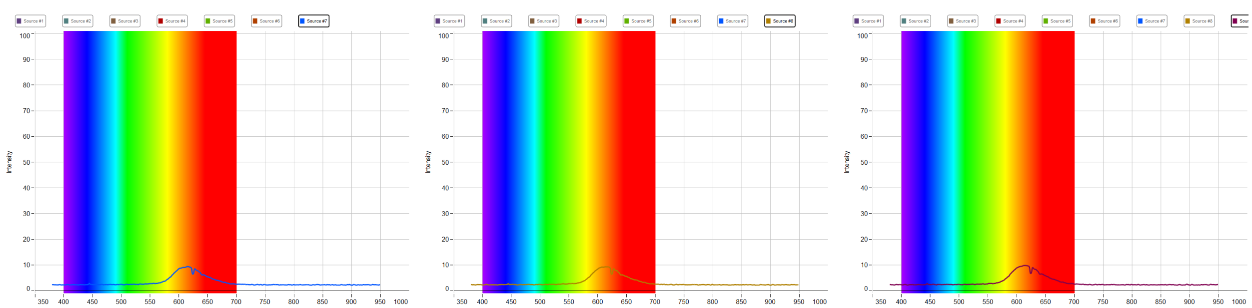

Figure 22: Red canvas - 40 LED

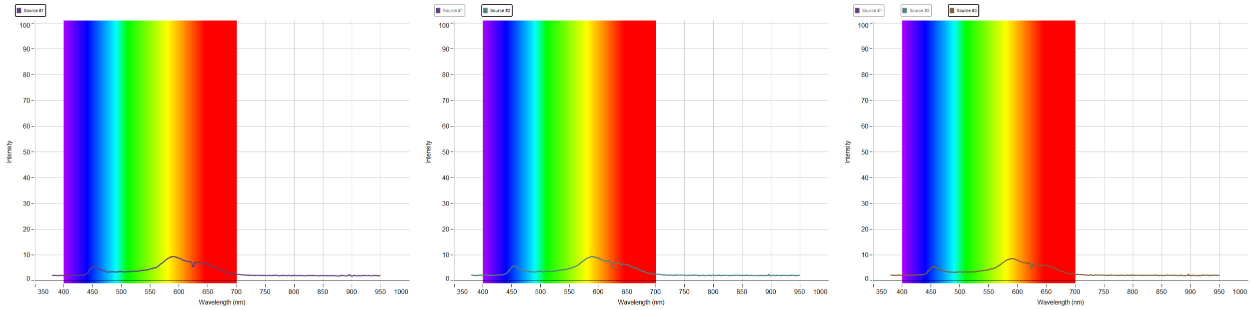

Figure 23: Purple canvas - 100 LED

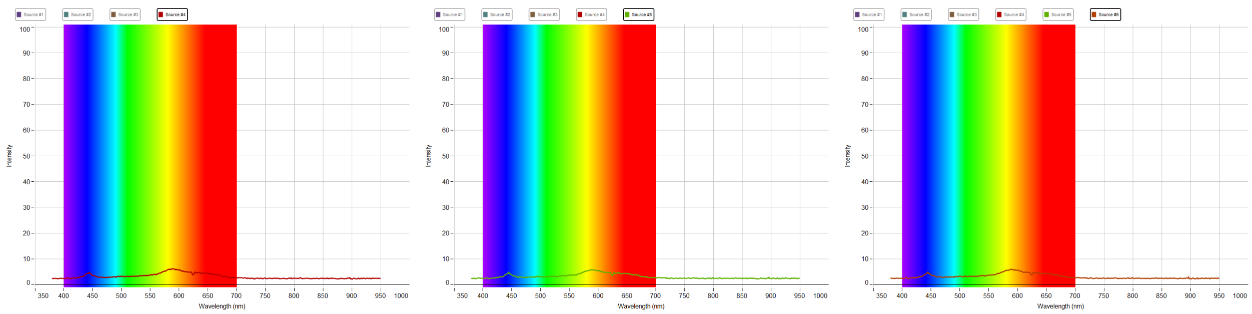

Figure 24: Purple canvas - 60 LED

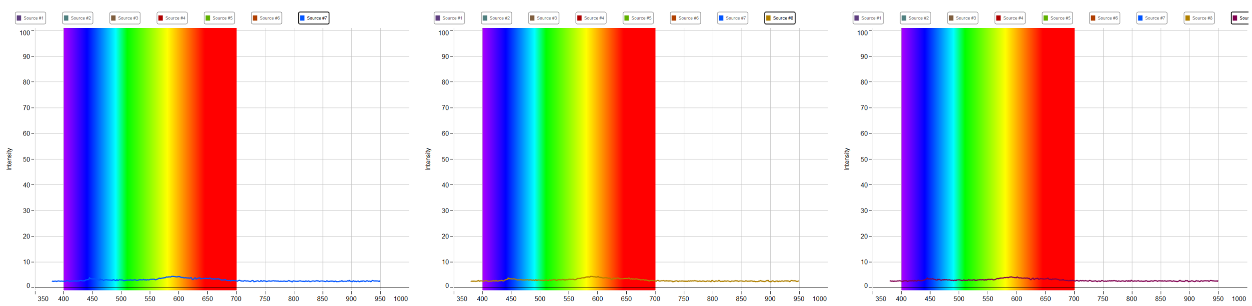

Figure 25: Purple canvas - 40 LED

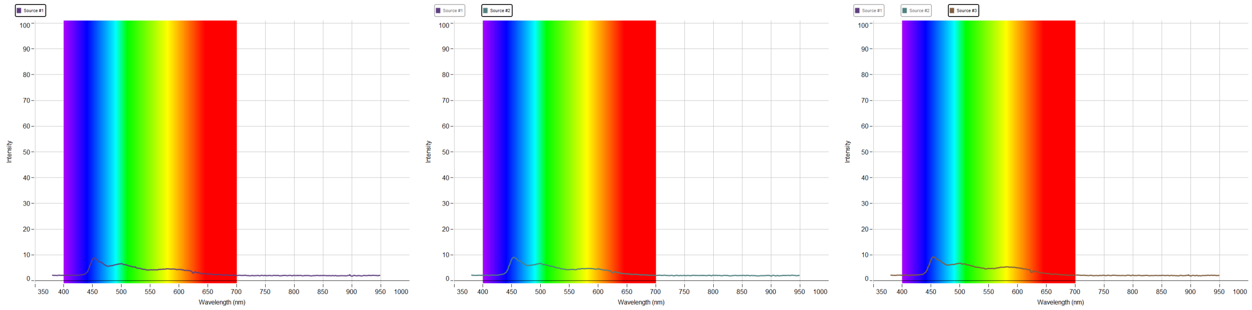

Figure 26: Blue canvas - 100 LED

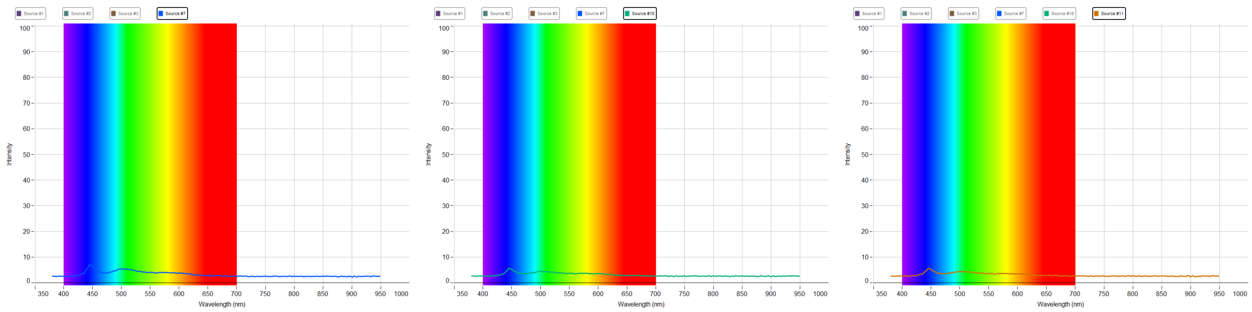

Figure 27: Blue canvas - 60 LED

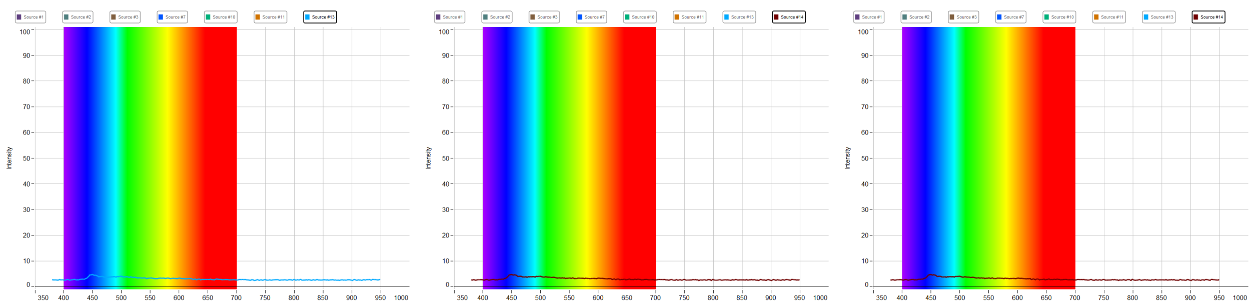

Figure 28: Blue canvas - 40 LED

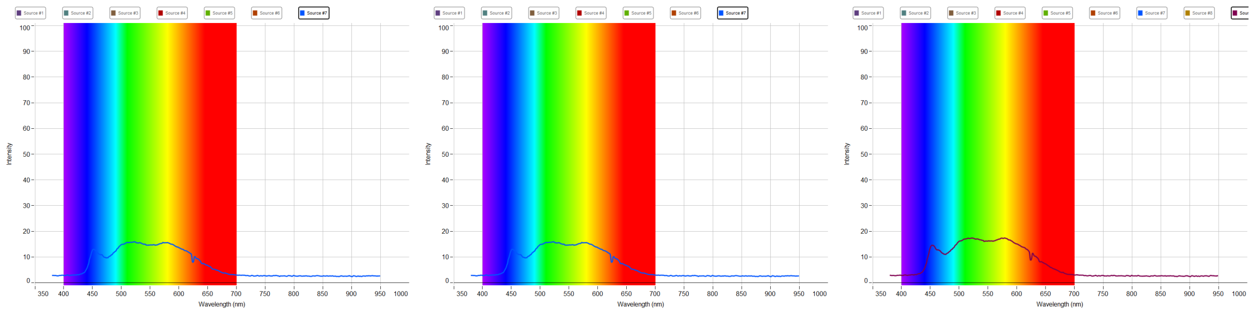

Figure 29: Light blue canvas - 100 LED

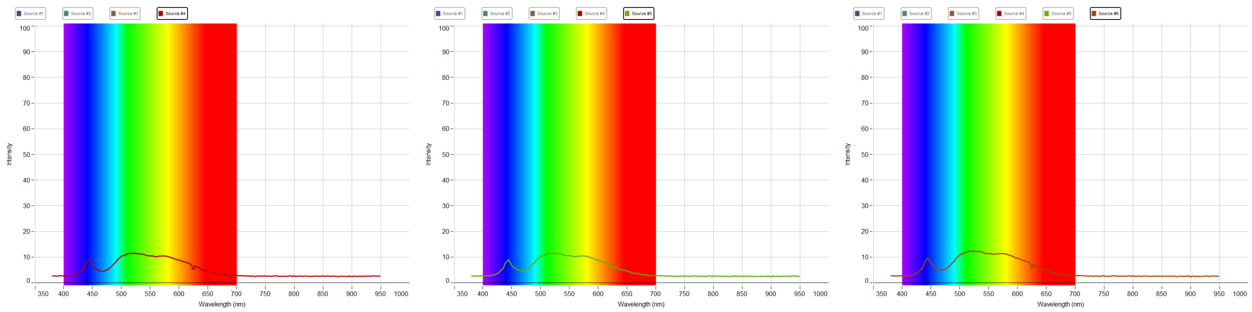

Figure 30: Light blue canvas - 60 LED

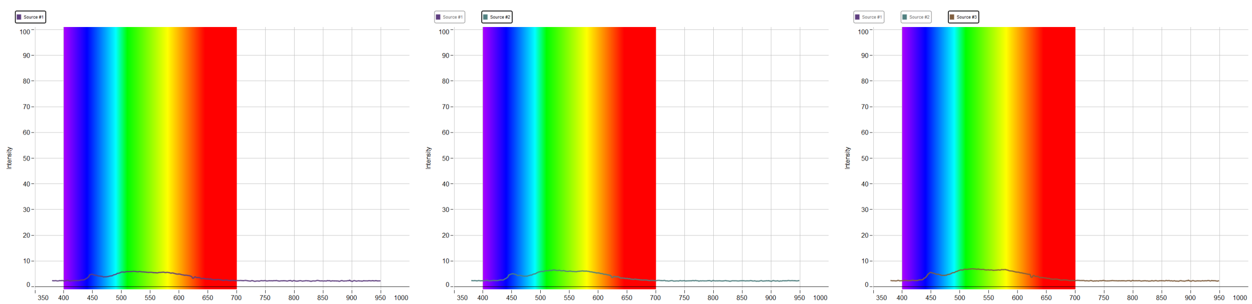

Figure 31: Light blue canvas - 40 LED

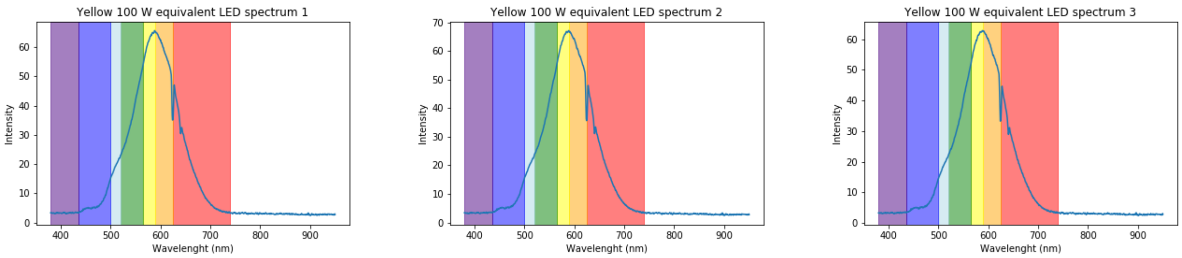

Figure 32: Yellow canvas - 100 LED

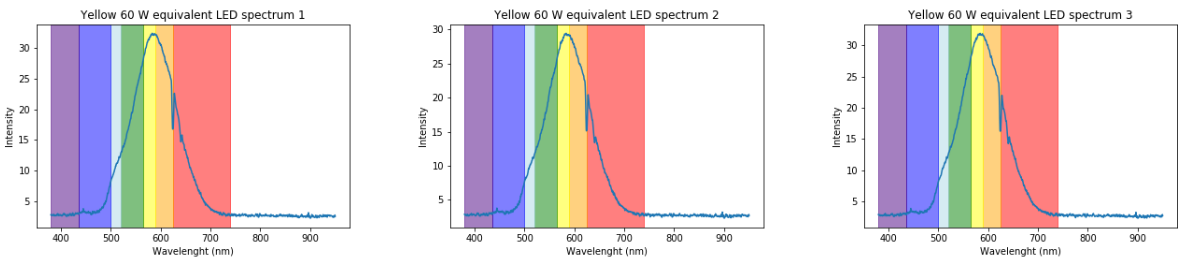

Figure 33: Yellow canvas - 60 LED

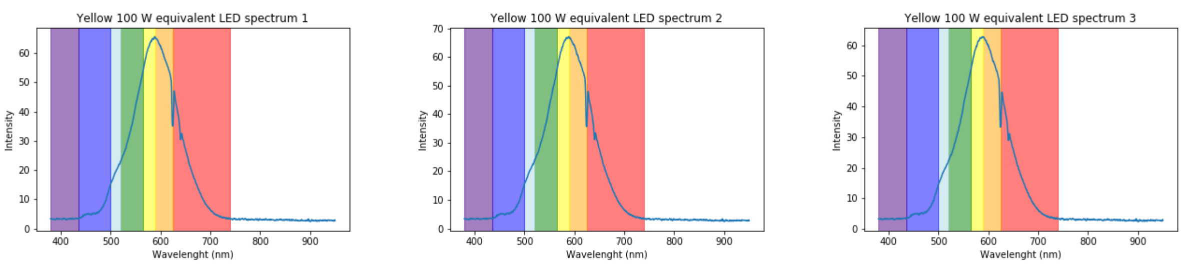

Figure 34: Yellow canvas - 40 LED

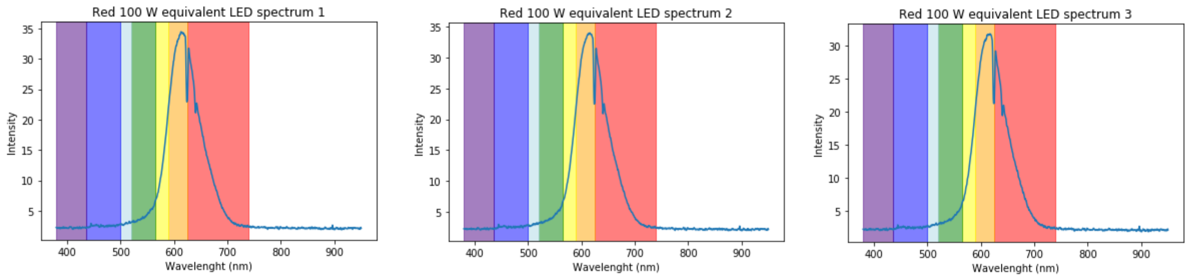

Figure 35: Red canvas - 100 LED

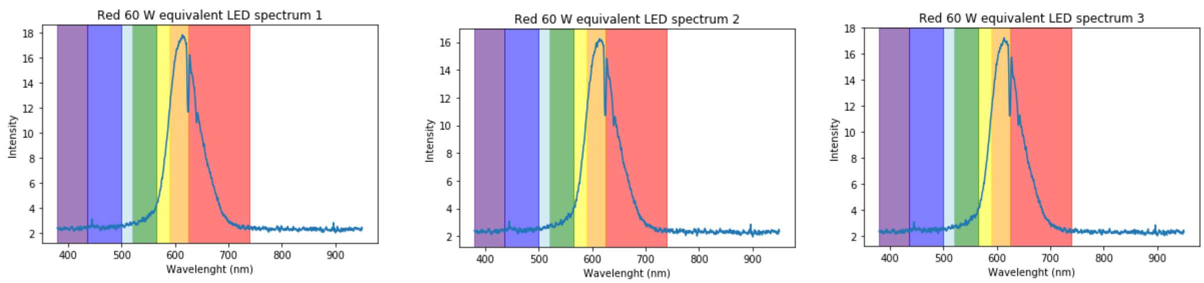

Figure 36: Red canvas - 60 LED

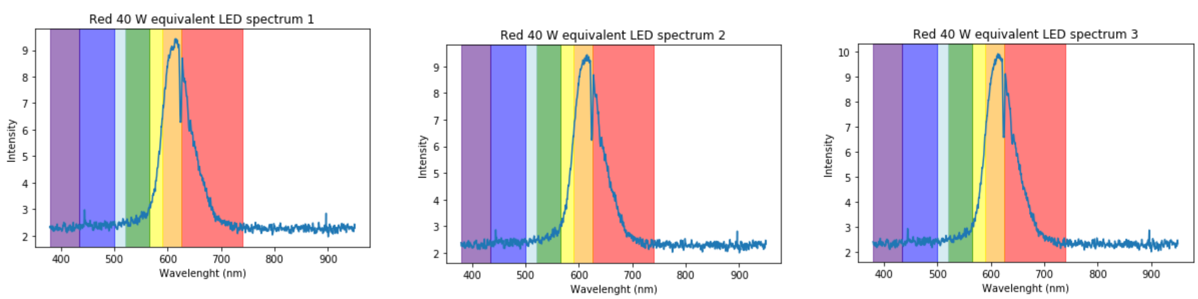

Figure 37: Red canvas - 40 LED

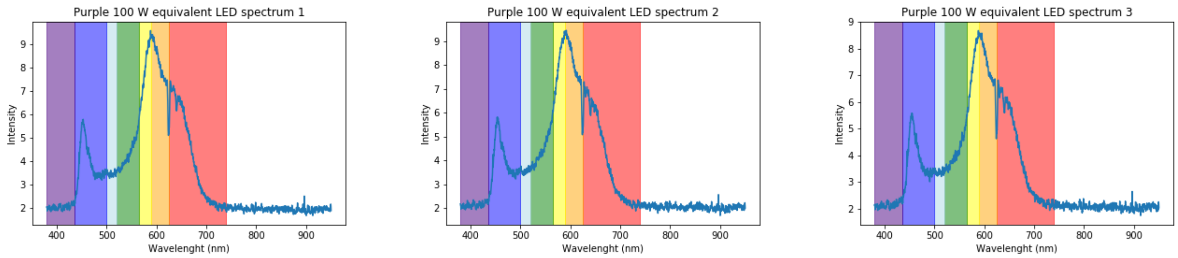

Figure 38: Purple canvas - 100 LED

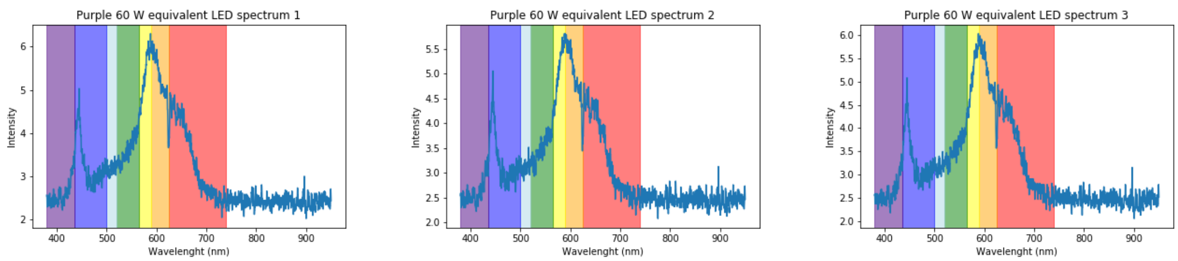

Figure 39: Purple canvas - 60 LED

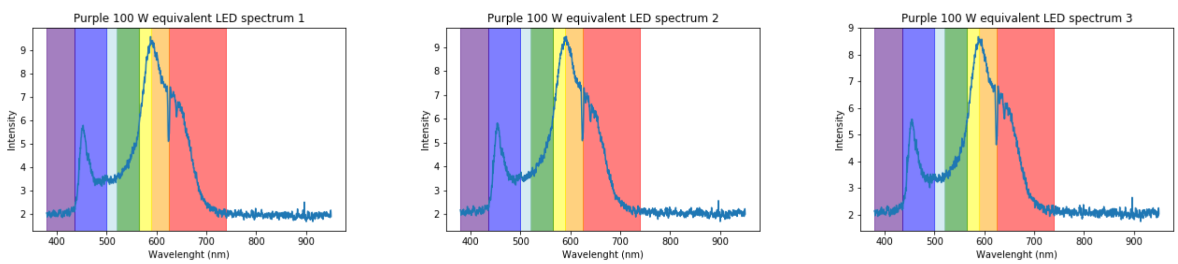

Figure 40: Purple canvas - 40 LED

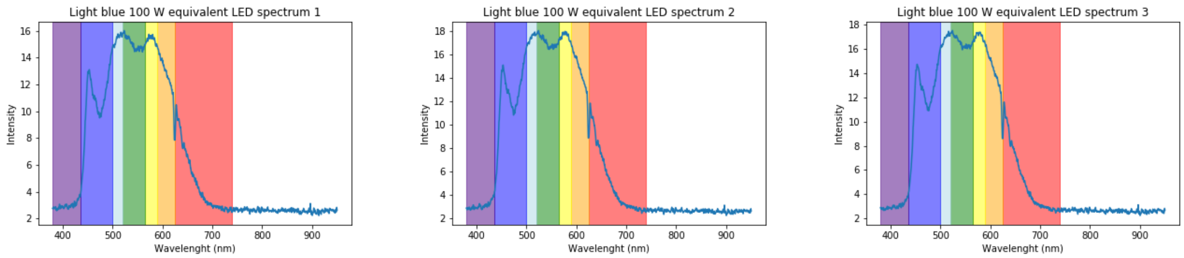

Figure 41: Light blue canvas - 100 LED

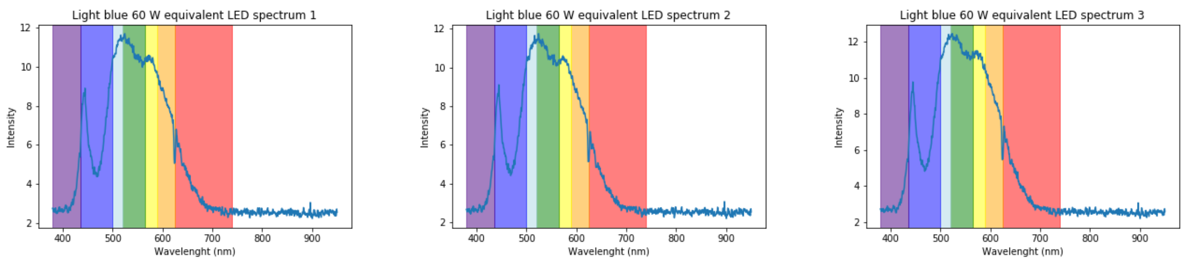

Figure 42: Light blue canvas - 60 LED

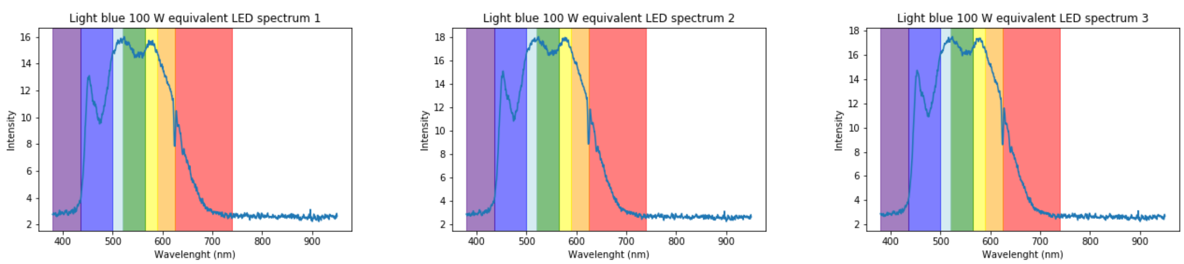

Figure 43: Light blue canvas - 40 LED

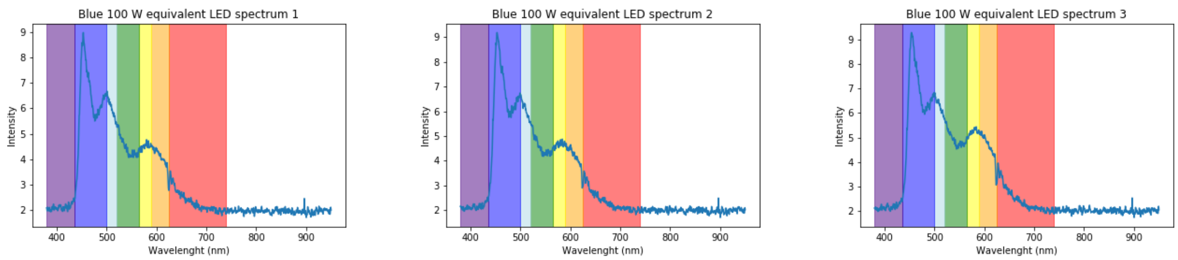

Figure 44: Blue canvas - 100 LED

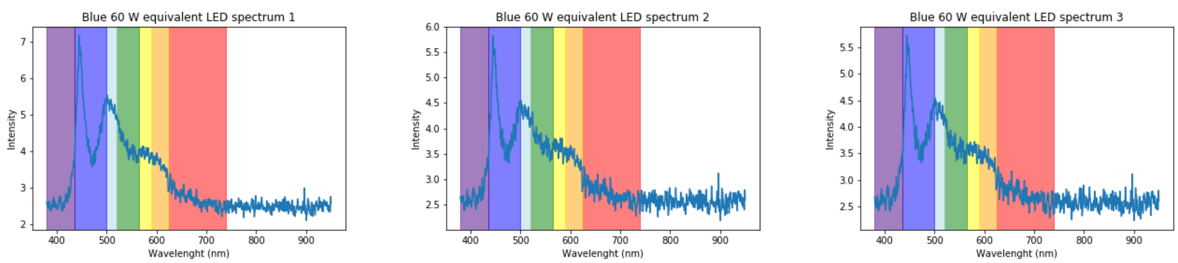

Figure 45: Blue canvas - 60 LED

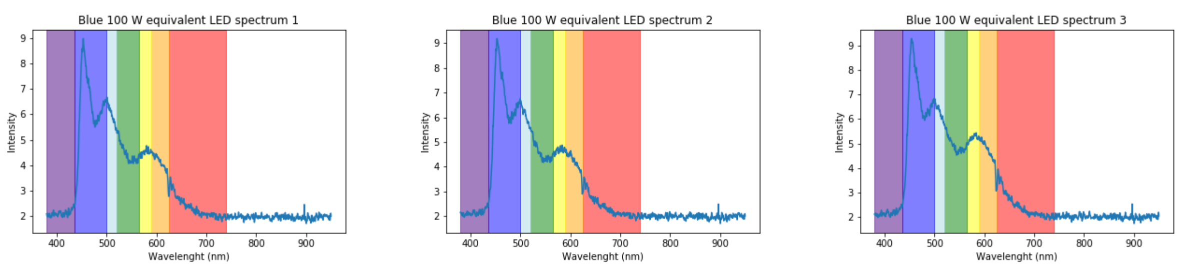

Figure 46: Blue canvas - 40 LED

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