Better Ways to Illuminate: Effects of Box Type

During the development of this module several suggestions were made regarding the experimental set up used to collect data on light and temperature emitted by the different lamps. Specifically, the suggested improvements included:

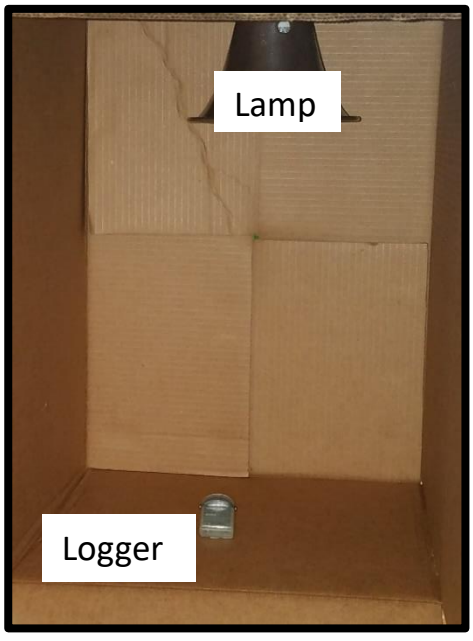
1. To get more accurate light level data install a rough textured white paper lining within the box
2. To get more accurate light level data install a baffle between the light source and the rest of the box.

These two approaches were tested using three different lamp types and three different boxes. First, an initial experiment was conducted to discover how long until temperatures and light levels in the boxes stabilized. This **first experiment (Exp. 1)** was conducted using the following lamps:

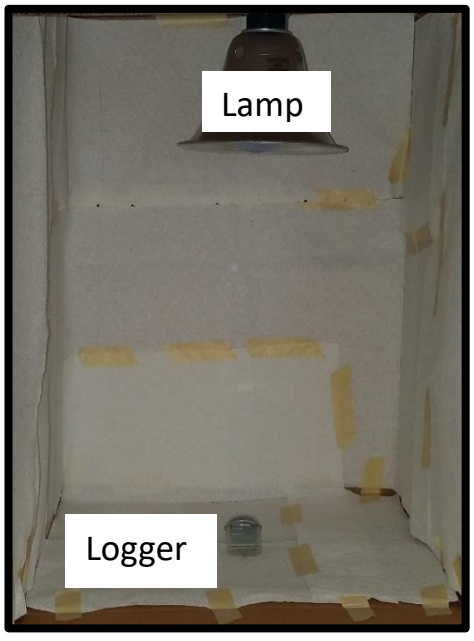
1. CFL rated at 1300 lumens and 20W
2. LED rated at 1100 lumens and 17W
3. Incandescent (Inc) rated at 790 lumens and 53W

Each lamp was tested in a plain cardboard box that measured 31.5 x 34 x 45 cm that was purchased from a local shipper (see Figure 1A). Temperature (°C) and light levels (Lux) were recorded using HOBO light/temperature loggers set to log at five-minute intervals for one hour.

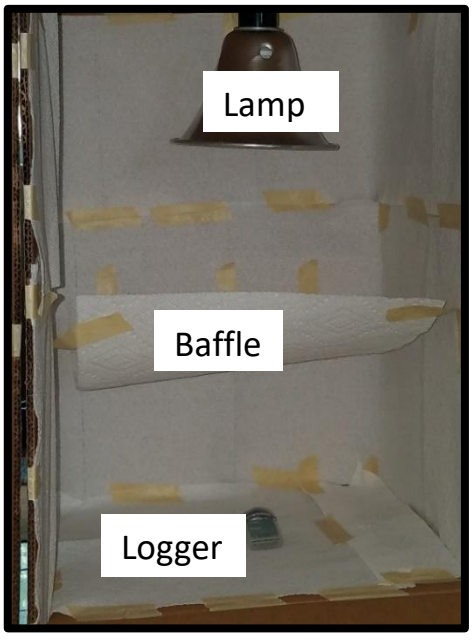
Figure 1. Treatment boxes



A. Control: plain cardboard box



B. Paper: cardboard box lined with paper towels



C. Paper: cardboard box lined with paper towels plus a baffle

Figure 2. Lamp temperatures vs time

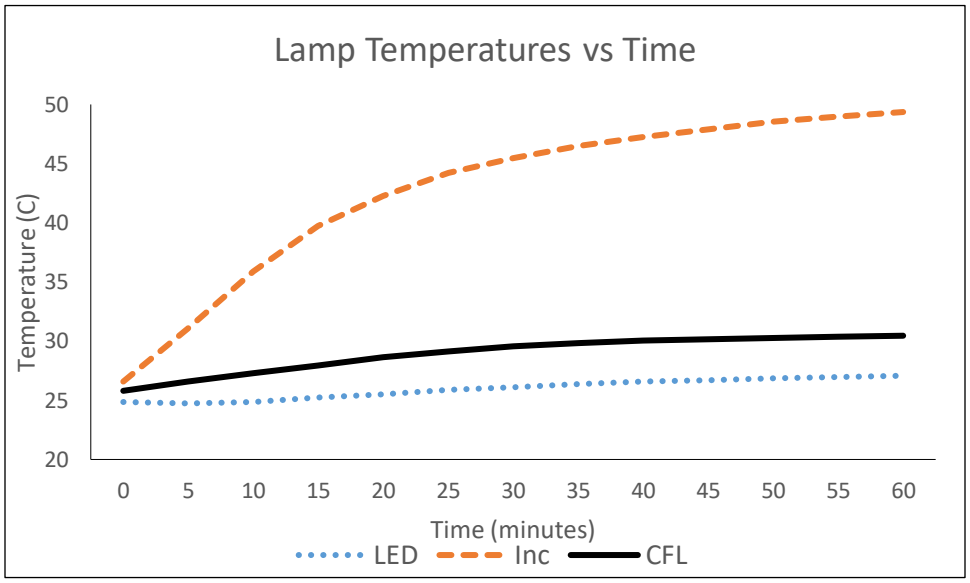
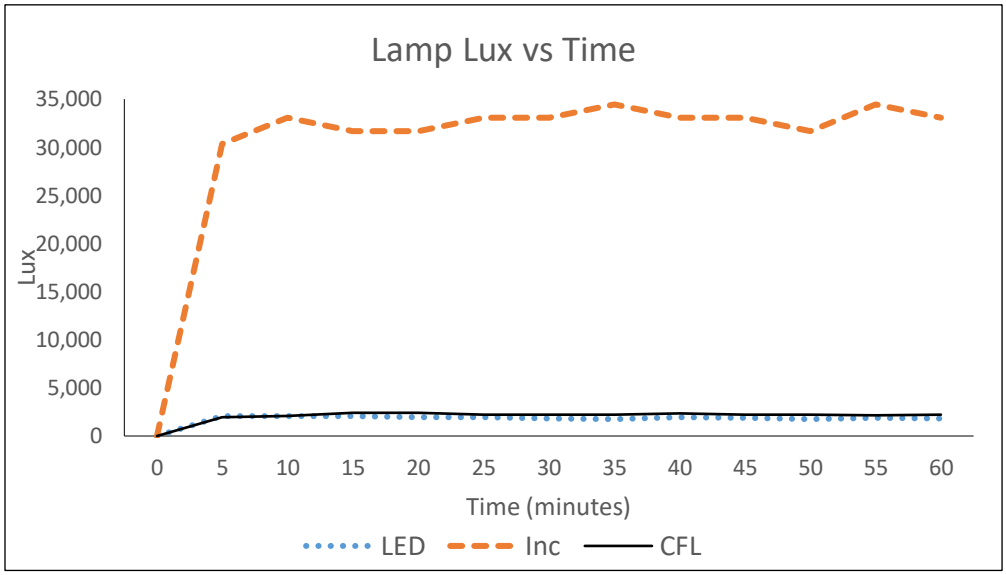


Figure 3. Lamp light levels vs time



These results indicate that the temperatures of each lamp increased over the course of the experiment and appeared to stabilize after about thirty minutes in the case of the LED and CFL lamps. For these lamps there was only about a 1-degree difference in the temperatures recorded at 30 minutes compared to the temperatures recorded at sixty minutes. For the incandescent lamp temperatures continued to climb and after sixty minutes there was an increase of about 4 °C over what was recorded at thirty minutes (Figure 2).

Light levels for each lamp stabilized after ten minutes with some fluctuations thereafter (Figure 3). For the next set of experiments each replicate ran for one hour.

The second experiment (Exp. 2) was designed to see if the box type had an effect on the temperature and light given off by each lamp. There were three box types (treatments) and each box measured 31.5 x 34 x 45 cm (Figure 1A-C):

1. A plain cardboard box (Control)
2. A plain cardboard box lined with white paper towels (Paper)
3. A plain cardboard box lined with white paper towels plus a baffle (a sheet of paper towel) placed between the lamp and the data logger (Baffle)

For the second experiment new lamps were purchased that were equivalent to a 60W bulb. These lamps were purchased because the lamps used in the first experiment were purchased in 2012 and thus were relatively "old" technology. Also, I tried to keep the lumen ratings for each lamp as close together as possible but it was not possible to find these bulbs with exactly the same lumen rating.

1. CFL rated at 850 lumens and 13W
2. LED rated at 800 lumens and 9.5W
3. Incandescent (Inc) rated at 750 lumens and 43W

Each lamp was randomly assigned to a treatment (box) and turned on for one hour; the logger recorded data every ten minutes. After each run the bulbs were randomly assigned to another treatment. While the bulbs were being exchanged among the treatments a floor fan was used to blow air into the boxes (about 4 to 6 minutes). This was done to reduce the temperatures in the box and bring it closer to ambient levels. Each lamp was replicated five times in each treatment (see Appendix C) and the logger data downloaded to an Excel spreadsheet.

The data were analyzed as a two factor ANOVA with contrasts where one factor was the lamp type and the second factor was the box type. I used contrasts to compare the Control vs Treatments (Paper and Baffle) and then the Paper vs Baffle treatments. An analysis was done for temperature and then light (in lumens); all data were analyzed using SAS 9.4.

Table 1. Experiment 2 variable temperature (°C) with contrasts

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
BOX	2	182.500831	91.250416	18.31	<.0001
BULB	2	2964.161604	1482.080802	297.32	<.0001
Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
CONTROL VS TREATMENTS	1	0.0661511	0.0661511	0.01	0.9089
PAPER BOX VS BAFFLE BOX	1	182.4346800	182.4346800	36.60	<.0001

Figure 4. Box plots of temperature for by treatment

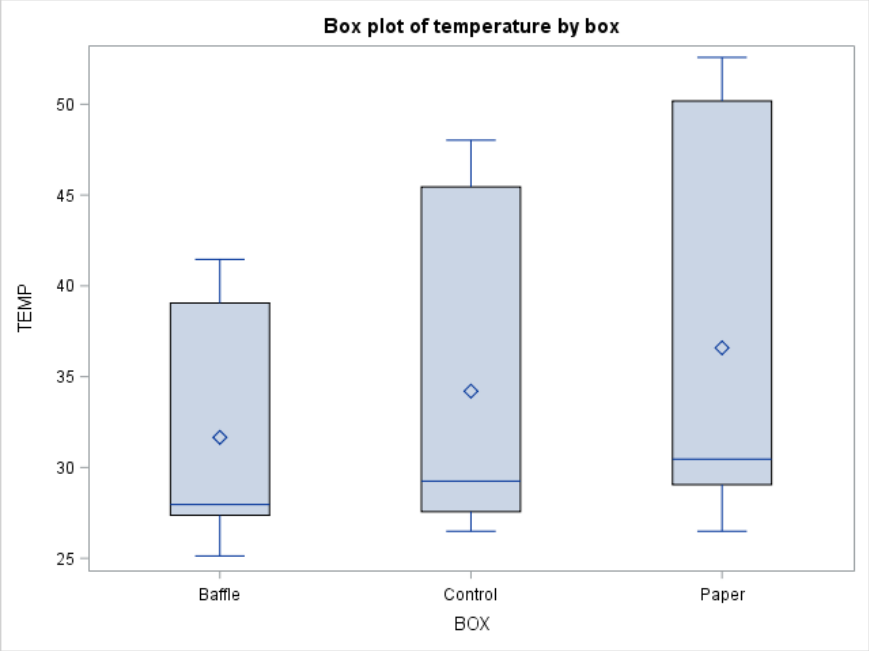


Table 2. Experiment 2 variable lumens with contrasts

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
BOX	2	7182731.4	3591365.7	10.11	0.0003
BULB	2	108355936.7	54177968.4	152.51	<.0001
Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
CONTROL VS TREATMENTS	1	139554.844	139554.844	0.39	0.5344
PAPER BOX VS BAFFLE BOX	1	7043176.533	7043176.533	19.83	<.0001

Figure 5. Box plots of lumens by treatment

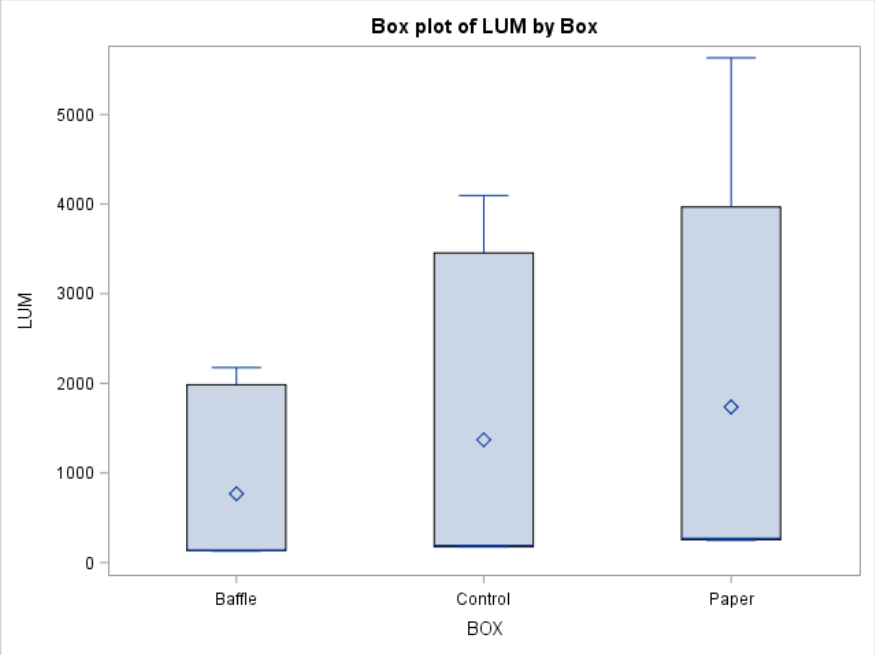


Figure 6. Box plots of temperature by lamp (bulb) type and treatment (box) for Experiment 2

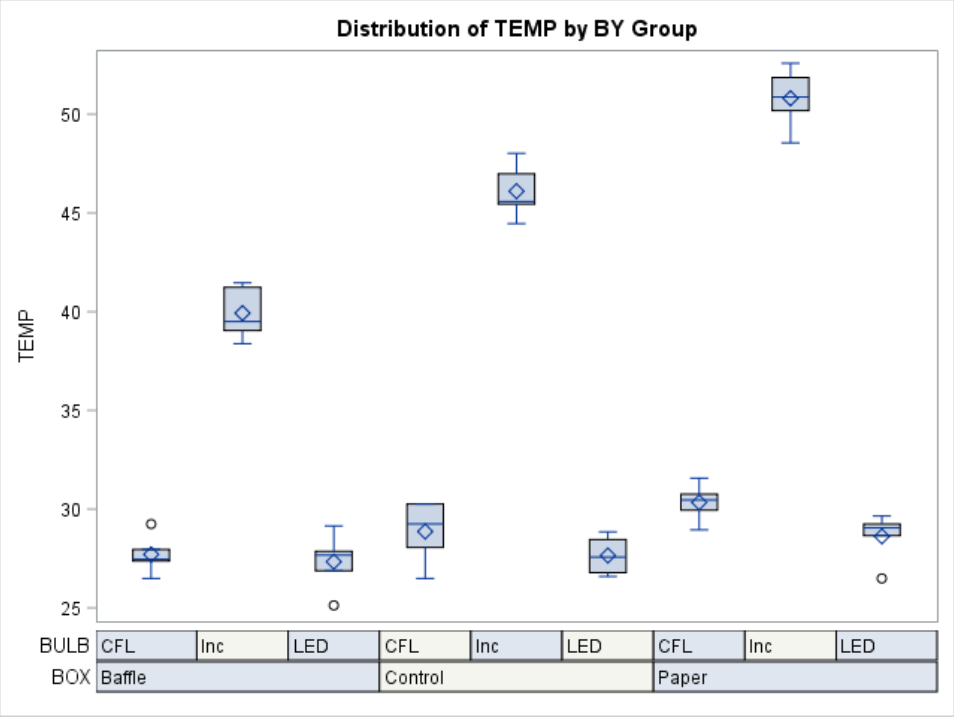
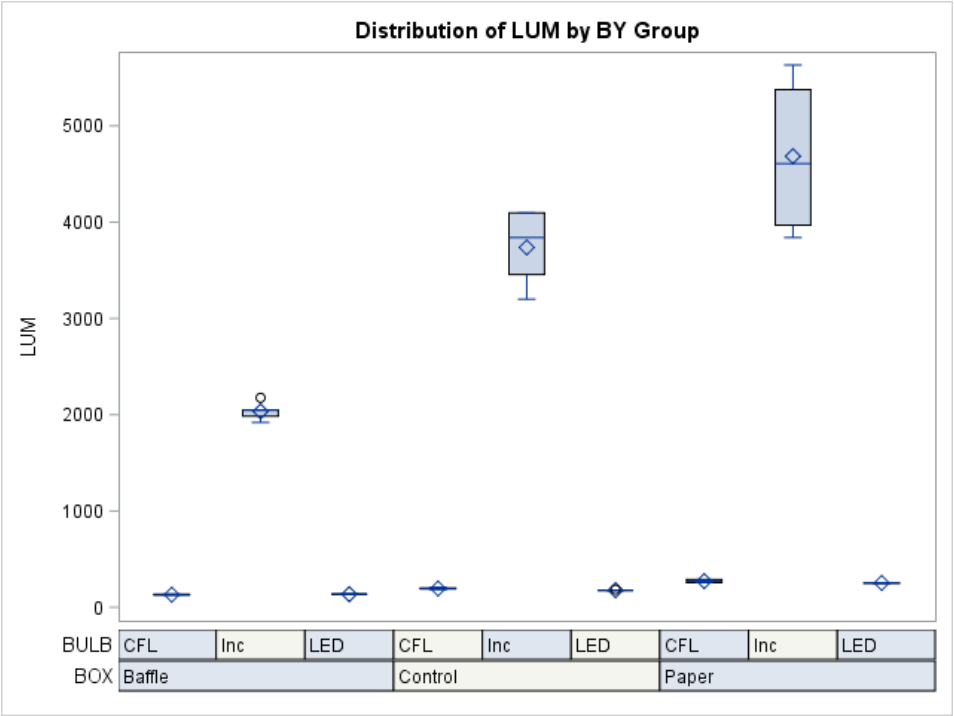


Figure 7. Box plots of lumens by lamp (bulb) type and treatment (box) for Experiment 2



Discussion

These results showed that there was a significant effect of box type but that there was no difference between the control versus the two treatments (i.e., the paper and baffle boxes) for either temperature or light level. The control box had a temperature (°C) (mean +/- SD) of 34.20 +/- 8.81 which laid between the paper (36.59 +/- 10.50) and the baffle box (31.66 +/- 6.17) (Figure 4). Similarly, with light levels (lumens); the control box had a lumen mean of 1370 +/- 1745.88 which laid between the paper (1736.53 +/- 2200.69) and the baffle box (767.47 +/- 929.28) (Figure 5). It appears that lining the box with paper towels causes an insulating effect raising the temperature while the baffle had an effect of lowering the box temperature probably by shielding the logger from the light source. In terms of the light levels a similar pattern was found where paper lining increased the lumens reading but the baffle reduced the lumen readings in comparison to the control box.

As expected there was a significant effect of lamp on temperature and light level. Post hoc Tukey tests showed that the Incandescent lamp had significantly higher temperatures (°C) (mean +/- SD) of 45 +/- 4.80 than either the CFL (28.97 +/- 1.59) or the LED lamps (27.87 +/- 1.29) (Figure 6). It also emitted significantly more lumens (3485 +/- 1233.64) than either the CFL (199.47 +/- 60.43) or the LED lamps (188.80 +/- 50.12) (Figure 7).

Recommendations:

- The length of time to record temperature should be at least 30 to 40 minutes to allow the temperature to stabilize.
- The type of box used in the experimental design won't affect the overall results that the heat and light generated by an incandescent lamp will be much greater than either the CFL or LED lamps so I recommend using the plain cardboard box.
- Because the temperature and light levels are so similar for the CFL and LED lamps the students won't detect a difference between the two so you could use either lamp to compare against the incandescent.

APPENDIX

A. Experiment 1 data for temperature for each lamp type

	Temp		
Time	LED	Inc.	CFL
0	24.835	26.585	25.8
5	24.738	31.064	26.585
10	24.835	35.864	27.272
15	25.222	39.729	27.961
20	25.513	42.282	28.655
25	25.902	44.211	29.152
30	26.097	45.452	29.552
35	26.39	46.465	29.853
40	26.585	47.238	30.054
45	26.683	47.892	30.154
50	26.879	48.554	30.255
55	26.977	48.955	30.356
60	27.075	49.36	30.457

B. Experiment 1 data for light (lux) for each lamp type

	Lux		
Time	LED	Inc.	CFL
0	0.00	0	0
5	2,066.70	30,311.30	1,980.60
10	2,066.70	33,066.90	2,066.70
15	2,066.70	31,689.10	2,411.10
20	1,980.60	31,689.10	2,411.10
25	1,980.60	33,066.90	2,238.90
30	1,808.30	33,066.90	2,238.90
35	1,722.20	34,444.70	2,238.90
40	1,980.60	33,066.90	2,325.00
45	1,894.50	33,066.90	2,238.90
50	1,722.20	31,689.10	2,238.90
55	1,894.50	34,444.70	2,152.80
60	1,808.30	33,066.90	2,238.90

C. Experiment 2 data – Temperature and light levels recorded after 50 minutes
Box A = Control; B = Paper; C = Baffle

Temp	Lumens	Lux	Box	Lamp
26.49	200.00	2152.80	A	CFL
26.59	176.00	1894.50	A	LED
45.45	4096.00	44089.20	A	Inc
28.06	208.00	2238.90	A	CFL
45.58	3456.00	37200.20	A	Inc
27.57	176.00	1894.50	A	LED
46.98	3840.00	41333.60	A	Inc
28.46	176.00	1894.50	A	LED
29.25	184.00	1980.60	A	CFL
26.78	176.00	1894.50	A	LED
44.46	3200.00	34444.70	A	Inc
30.26	192.00	2066.70	A	CFL
48.02	4096.00	44089.20	A	Inc
28.85	184.00	1980.60	A	LED
30.26	192.00	2066.70	A	CFL
26.49	256.00	2755.60	B	LED
48.55	3968.00	42711.40	B	Inc
30.46	256.00	2755.60	B	CFL
52.58	5376.00	57867.00	B	Inc
28.66	248.00	2669.50	B	LED
28.95	272.00	2927.80	B	CFL
29.65	248.00	2669.50	B	LED
29.95	288.00	3100.00	B	CFL
50.18	3840.00	41333.60	B	Inc
31.57	256.00	2755.60	B	CFL
29.25	256.00	2755.60	B	LED
51.86	5632.00	60622.60	B	Inc
29.05	256.00	2755.60	B	LED
30.76	288.00	3100.00	B	CFL
50.87	4608.00	49600.30	B	Inc
39.05	1920.00	20666.80	C	Inc
27.96	136.00	1463.90	C	CFL
26.88	136.00	1463.90	C	LED
25.13	136.00	1463.90	C	LED
26.49	128.00	1377.80	C	CFL
39.50	2048.00	22044.60	C	Inc
27.37	136.00	1463.90	C	CFL
38.38	1984.00	21355.70	C	Inc
27.67	136.00	1463.90	C	LED
41.46	2048.00	22044.60	C	Inc
29.25	128.00	1377.80	C	CFL
27.86	136.00	1463.90	C	LED

27.47	128.00	1377.80	C	CFL
41.23	2176.00	23422.40	C	Inc
29.15	136.00	1463.90	C	LED