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Light Bulb Efficiency and Environmental Impacts

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The most important global environmental issue of our times is climate change and global warming. In the decades to come, no one will be untouched by the impacts of rising temperatures, droughts, violent storms, rising sea level and weather extremes that are being induced by human activity. Governments around the world have committed to slowing and eventually controlling global warming (Paris Accord 2015 and Kigali Accord 2016) but those efforts seem to focus on large scale targets such as energy production, major industries and transportation systems. Individuals seem to have little or no possible role in addressing this major problem. Yet, we all use energy and the choices we each make about the automobile we drive, home appliances we use, and even the light bulbs in our homes will have a collective impact on the emissions of greenhouse gases and the rate of global warming. In this study, students, working in groups, evaluate the three major forms of electric light bulbs, incandescent (I), compact fluorescent (CF) and light emitting diode (LED). Students design and conduct experiments to compare light bulb efficiencies, visible light outputs, and waste heat outputs. The purpose of this work is for each student group to make recommendations on which light bulb type is the best buy and which would be best for the environment.

Keywords: guided-inquiry, CURE, light bulb alternatives, climate change, global warming, electrical efficiency

Introduction

Perhaps one of the most vexing issues facing biologist who teach the science of climate change and global warming, is that the problem is so huge that student may mistakenly conclude that there is nothing individuals can do to address this environmental problem. It is indeed true that most of the targets of government actions to control climate change have been large-scale systems such as our electrical generation and transmission systems and the control of CFCs and HFCs in cooling systems, automobiles and appliances. Yet, the energy efficiency of our personal transportation, our home heating and cooling, our home appliances and lighting are subject to our individual choices. Those choices can collectively have a significant impact on the emissions of greenhouse gases and consequently on the rate of global warming. This laboratory protocol was designed to provide students with the opportunity to explore the choices that we must make as individuals when we purchase electric light bulbs, and evaluate the electrical efficiencies of different lighting types and the environmental impacts of those choices. I have used this study in a non-majors Science and Society course that was taught in a studio format (laboratory and mini-lectures fully integrated), and in the laboratory of our Environmental Studies course, a junior-senior level science majors course that serves as an elective in our Biology major as well as a required course in our Sustainability minor and an elective in our Environmental Studies minor. I designed this protocol to be taught as a course-based undergraduate research experience (CURE) and as a guided-inquiry activity.

Student Outline

Objectives

- Design and perform a set of experiments to evaluate the efficiencies, visible light outputs, and heat outputs, of incandescent, compact fluorescent and light emitting diode light bulbs.
- Collect data on the purchase costs and functional lifespans of each light bulb type.
- Perform an analysis (based on your findings and the purchase costs of each light bulb type) to provide guidance on which type of light bulb would be the best buy for consumers and which would be best for the global environment.

Introduction

The most important global environmental issue of our times is climate change and global warming. In the decades to come, no one will be untouched by the impacts of rising temperatures, droughts, violent storms, rising sea level and weather extremes that are being induced by human activity. Governments around the world have committed to slowing and eventually controlling global warming (Paris Accord 2015 and Kigali Accord 2016) but those efforts seem to focus on large scale targets such as energy production, major industries and transportation systems. Individuals seem to have little or no possible role in addressing this major problem. Yet, we all use energy and the choices we each make about the automobile we drive, home appliances we use, and even the light bulbs in our homes will have a collective impact on the emissions of greenhouse gases and the rate of global warming.

In this study, you will evaluate the three major forms of electric light bulbs: incandescent (I), compact fluorescent (CF) and light emitting diode (LED). In research teams, you will design and conduct experiments to compare light bulb efficiencies, visible light outputs, and waste heat outputs. The purpose of this work is for you to make recommendations on which light bulb type is the best buy and which would be best for the environment.

Materials

In class, each research team will be provided with each of the three light bulb types, and a light bulb fixture for illuminating individual light bulbs while connected to a WattsUp meter (see Figure 1) that displays the instantaneous power consumption (watts) of each light bulb. You also will have access to a light meter to measure visible light output intensity, and an infrared laser thermometer to measure heat output. Rulers, meter sticks and opaque white cards also will be available.

Figure 1. Light bulb fixture with measurement devices. Each of three light bulb types may be evaluated individually using a WattsUp meter (black unit on left), light meter (center) and laser thermometer (right).

Safety

The experimental materials you will be using can be hazardous to you. Several warnings:

1. Use a power strip to control the electrical current flowing to the WattsUp meter (and the light bulb fixture) and be sure the power is **off** before changing light bulbs in the fixture.

2. Light bulb may get hot when illuminated. Incandescent and compact fluorescent bulbs may get very hot. Let light bulbs cool for a few minutes after switching off the power before even thinking of touching them.

Experimental Design

Your task is to design experiments (and collect information from the light bulb packaging and retail vendors of light bulbs) to address the following questions: Which type of light bulb is the most efficient? What does efficiency mean for a light bulb? What should you evaluate to determine which type of light bulb would best help you reduce your electric bill? What are the visible light outputs of each light bulb type? If the efficiencies are not the same, what is happening to the excess energy used by some types of light bulbs? Which light bulb type would be the best buy for consumers? Which light bulb would be best for the environment? What are the costs and benefits of each type of light bulb?

After you have read the background information and before the laboratory class meeting:

- Describe an experimental design for evaluating which light bulb type is the most efficient.
- Predict the possible outcomes for your experiment.
- Identify and list the variables you would manipulate in the experiment.
- Identify and list the variables you would keep constant in the experiment.
- List the data you would collect to determine if your predictions were true.
- Describe the statistical analyses that you would carry out to test your predictions.

Come to class prepared to present your experimental design. Prior to making any measurements, decide on a measurement protocol. At what distance will you make measurements of light output? How long will you leave the light bulb illuminated prior to making measurements? How many replicate measurements will you make on each light bulb? Comparisons between the three light bulbs may be easier if you calculate light intensity output (lux) per electrical power input (watts).

Data Analysis

Prepare your findings in the form of graphs or histograms of the mean values for each light bulb type. Consider standardizing the light output per unit of energy used of each light bulb. For example, the mean light output per unit of power used could be calculated as lux/watt of power input for each light bulb type.

How will you decide which light bulb is the best buy? Are your criteria for the best buy the same as for deciding which light bulb would be best for the environment? What information do you need to know to evaluate the environmental impact of each light bulb type?

Are compact fluorescent bulbs or LED bulbs reasonable means of reducing your electric bill? What prevents people from using these alternatives to incandescent light bulbs? Is the purchase price of these light bulbs an issue? How could you determine whether the greater purchase price of CF or LED bulbs would be worth the extra expense? Create a model to evaluate the time required for a CF or LED bulb to be worth the extra initial expense. How does the cost of electricity (cost per kilowatt hour) influence the time required for this break-even point to be reached?

Cited References

Kigali Accord. 2016. Nations, Fighting Powerful Refrigerant That Warm Planet, Reach Landmark Deal. NY Times, Davenport, C. October 15, 2016. http://www.nytimes.com/2016/10/15/world/africa/kigali-deal-hfc-air-conditioners.html?_r=0

Paris Accord. 2015. United Nations Framework Convention on Climate Change. http://unfccc.int/paris_agreement/items/9485.php

Example Case Study - Student Handout

Our Light Bulbs Are Burning Our Budget!

Lea exclaimed, “This electrical bill is outrageous! It is only early April and our electrical use is going to consume our household budget! There must be some way to reduce our electrical costs without having to completely withdraw from the modern world. What should we do?” All of us will likely be confronted with this dilemma at some point, particularly as energy resources become more expensive and the risks of our carbon fuel economy become more threatening. What would you advise Lea? How could you reduce your own electrical energy use?

All of us use electrical lights where we live and work. Electrical lights are used at all time of the year and in all climates, so electric lights might be a potential target for reducing electrical costs. In our laboratory, you can evaluate three types of screw base electric light bulbs: incandescent (I), compact fluorescent (CF), and light emitting diode (LED). What should you evaluate to determine which type of light bulb would best help you reduce your electric bill? What happens to the electrical energy in a light bulb? Is all the energy converted to light energy?

Electricity use computers, “Watts-Up” meters, are available for your use. Read the Watts-Up manual before connecting them to a power source and a light bulb. Light sensors and meters are available to measure the light output of different light bulbs, and laser thermometers are available to compare the heat output of different light bulbs. Prior to making any measurements, decide on a measurement protocol. At what distance will you make measurements of light output? How long will you leave the light bulb illuminated prior to making measurements? How many replicate measurements will you make on each light bulb? Comparisons between the three light bulbs may be easier if you calculate light intensity output (lux) per electrical power input (watts). Prepare your findings in the form of graphs or histograms of the mean values for each light bulb type.

Are compact fluorescent bulbs or LED bulbs reasonable means of reducing your electric bill? What prevents people from using these alternatives to incandescent light bulbs? Is the purchase price of these light bulbs an issue? How could you determine whether the greater purchase price of CF or LED bulbs would be worth the extra expense? Create a model to evaluate the time required for a CF or LED bulb to be worth the extra initial expense. How does the cost of electricity (cost per kilowatt hour) influence the time required for this break-even point to be reached?

Prepare your findings in poster format for presentation.

Materials

Equipment and Supplies

For a class of 24 students working in groups of 3:

- 8 light bulb display fixtures consisting of one standard light bulb base attached to a circuit box attached to a wood board 10cm x 10cm (Figure 2). Each light bulb base is wired to a standard plug for 120v. Assembly of the components requires 30cm of 2 or 3-wire 10A 120v appliance cable for each unit. The materials to build each fixture will total less than $5.00 US. Alternatively, purchase small inexpensive table lamps and use them without a lampshade as bare bulb fixtures.
- 8 WattsUp or WattsUP Pro Meters (Figure 3) (Carolina Biological #755910, $182 US each, but see Notes for the Instructor for much less expensive alternatives)
- 4 60w incandescent light bulbs (standard medium E-26 screw-in base)
- 4 60w equivalent (15w) compact fluorescent light bulbs
- 4 60w equivalent (12w) light emitting diode light bulbs
- 8 white form boards 30cm x 30cm x 0.5cm
- 8 30cm rulers
- 8 wood meter sticks
- 8 light meters, each uses a 9v battery (Fisher Scientific #06-662-63 $177 US each)
- 8 infrared laser gun thermometers, uses a 9v battery (Fisher Scientific #S90202 $101 US each or ThermoWorks IR-GUN-S $49.00 US each)
- 8 outlet strips with switch
- 8 hot pads for safely handling hot light bulbs

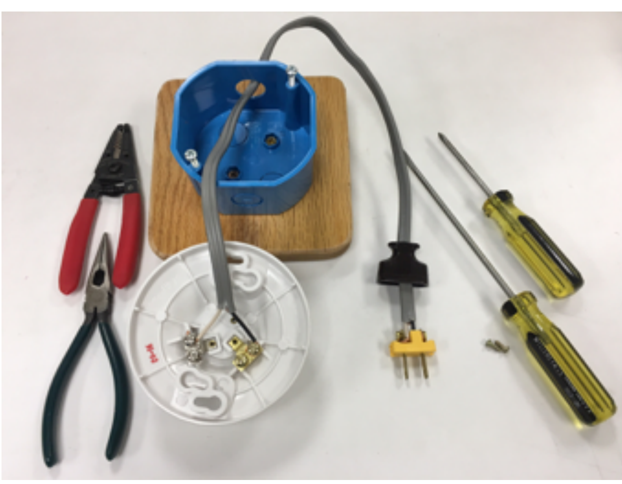

Figure 2. Light bulb display fixture. Each light bulb display fixture consists of the components shown: A standard light bulb base wired with 14 gauge 10A 120v rated braided or solid copper electrical cable. The bulb base is attached to a corresponding plastic circuit box that is attached to a wood base. Self-adhesive rubber feet on the underside of the wood base keep it from sliding on the bench when in use. You may use electrical cable with either two or three wires (one is a ground line); either will be safe in this application. If you are unsure about the wiring, ask your Physical Plant staff for assistance. Tools needed to assemble each fixture include a wire cutter-stripper, needle nose pliers, and a screwdriver.

Figure 3. WattsUp Meter. This device measures the instantaneous power (watts) use of any 120v device plugged into its outlet (15A current or less). The WattsUp meter must be plugged into a 120v power supply, ideally, in this application, a switch controlled power strip.

Notes for the Instructor

Presentation of the Study to Students

The format of the Student Handout is not the only way to present this study to students. In the past, I have presented this to students in the form of a case study (see example at the end of the Student Handout), or we simply begin with a discussion about global warming and practical measures students could pursue to reduce their personal ecological footprint. Having students evaluate their ecological footprint (see Weglarz, 2011) (www.footprintnetwork.org/en/index.php/GFN/ or alternatively http://earthday.net/footprint.index.html) prior to conducting this study is a good introduction to this work.

Generally, I find that it helps to briefly describe the three light bulb types (Table 1) in class to ensure that everyone knows what they are evaluating. Asking students to conduct some Internet research prior to class to define the three light bulb types in pictures and words helps too.

Table 1. Light bulb types. Three light bulb types (incandescent, compact fluorescent, and light emitting diodes) are described here with the source of light and a brief description of light conversion process for each type (see Wikipedia 2017a-c).

Light bulb type	Source of light	Light conversion process
Incandescent (I)	glowing wire (tungsten)	Electrical current flows through a wire that has high resistance, so the wire heats and glows, producing visible light. Only 10% of the electrical energy used by an incandescent bulb is actually released a visible light.
Compact Fluorescent (CF)	fluorescent coating inside bulb	Electrical current flows through a gas (argon with mercury vapor) causing the gas to ionize and emit UV light. UV photons are absorbed a chemical (phosphor mix) coating inside the bulb causing the coating to produce visible light (fluorescence).
Light Emitting Diode (LED)	light emitting semiconductor	Electrical current flows through a semiconductor (p-n junction diode) that produces light. The individual light emitting diodes are very small (mm in diameter) and a single diode is not very bright, so functional light bulbs are made using an array of LEDs inside a light bulb shaped device.

The ecological and environmental gorilla in the room that must be addressed prior to having students conduct this study is the connection between electricity generation, carbon dioxide emissions, and global warming. I spend a significant part of my lecture courses introducing the carbon cycle and the relationship between greenhouse gas concentrations and biosphere-level energy flow (NASA 2017). Our use of carbon-based fossil fuels (petroleum, coal and natural gas) since the start of the industrial revolution is responsible for the exponential increase in the global concentration of CO_2 since 1750 (UN IPCC 2013), presently just exceeding 400 ppm (NOAA 2017). Carbon dioxide is the most abundant of the greenhouse gases (but all are trace gases) and its effect is to absorb and retain heat in the lower atmosphere, causing global warming. The scientific evidence on this process is overwhelming and beyond reasonable doubt (UN IPCC 2013). The political debate ultimately concerns the economic interests of the fossil fuel industry, the rate of global warming, how fast we need to respond, and who pays for the new energy systems that will be necessary to replace fossil fuels. We are already paying for the consequences of global warming in the form of more severe storms, more intense droughts, higher sea levels, and more intensely hot summers (UN IPCC 2013). This laboratory activity focuses on the choices we can individually make that change how much energy, and consequently how much fossil fuel combustion, is required to meet our needs.

One of the recurring misconceptions some students have with this study is correctly realizing that the WattsUp meter is measuring power demand by (input to) the light bulbs, not the light energy output of the light bulb (which could be measured with a pyranometer in watts/m^2 of light energy output, see Measuring Devices below). This misconception may be addressed by having students connect other devices to the WattsUp meter. For example, connecting the WattsUp meter to a telephone or computer charging transformer, small motor devices (fan or stirrer), or other small laboratory equipment that may be available. This could lead to a conversation about power "vampires", the transformer based devices that draw power continuously even when the main device is off. The best way for students to confront misconceptions is to ask them to work in small groups and discuss what the WattsUp meter is actually measuring when connected to each device.

Light Bulb Display Assembly and Safety

If you are uncertain about the safe wiring of the light bulb bases, the physical plant staff at your college or university will easily be able to assemble this for you. All the components necessary to build these display units will be readily available at any hardware store, Walmart, Home Depot or Lowes stores in the US or Canada. An alternative to building the light bulb fixtures would be purchasing some inexpensive table lamps ($10 US or less at Target, Amazon, Walmart and others). Using a small table lamp without the shade would permit you to do the experiments in exactly the same manner as described in this study.

An empty light bulb base is dangerous when the power is on. Any contact with an empty bulb base will complete a circuit and could result serious injury. Having a switch controlled power strip is an attempt to ensure safety in this study. Students should be warned to switch the power strip off before changing light bulbs in the bulb fixture. The WattsUp meter is plugged into the power strip and the light bulb base is plugged into the WattsUp meter (Figures 1 and 3).

The light bulbs you provide to students to evaluate may be changed depending on what is available to you. When I began conducting this study with students in 2007, CF bulbs were the new light bulbs that we compared to incandescent bulbs. LED bulbs were not in large-scale commercial production and they were prohibitively expensive. Currently, incandescent bulbs are being phased out of production in the US and LED bulbs are readily available and affordable for a laboratory study. If you adopt this study in your teaching, it is worth continuing to check the kinds of light bulbs that are available, since the technology will change as will the pricing. Much has changed in the past 10 years.

Measuring Devices

The most important measuring instrument for this study is the WattsUP meter as it permits student to directly measure the power use of each light bulb type in watts. This is very basic physics, but students will need to be asked (or reminded) what is actually being measured. There are at least two options that would be less expensive alternatives to using a WattsUP meter. One is the P3 P4400 Kill A Watt electric usage monitor (Amazon for $20 US or less). The Kill A Watt meter unit plugs into an outlet (or a power strip) and the device you wish to evaluate then plugs into the Kill A Watt meter. Another alternative would be a standard voltage-current meter. A digital clamp (non-contact) type meter would be the safest meter to use. The clamp (jaws) on the top of this type of meter is put around the electrical wire that provides electricity to the light bulb you wish to evaluate eliminating the need to use probes to directly touch live wires. This type of AC voltage-current meter can be purchased for less than $20 US (check Walmart and Amazon websites). Measuring voltage and current would permit students to calculate wattage (V x A = W).

The output for which we purchase light bulbs is visible light, so a ratio between the light intensity output and the power consumed (watts input) would be the efficiency of the light bulb. Therefore, some measure of light intensity output is needed. Students may measure the light intensity output using a light meter (photometric sensor) and make measurements in foot candles (fc) or lux. An alternative could be a pyranometer, if you already have them (such as the LI-COR, LI-200R sensor connected to the LI-250A light meter). A pyranometer sensor is normally used to measure full spectrum sunlight intensity for photosynthesis studies (W/m^2). Inexpensive light meter apps for smart phones are not likely to provide the consistent accurate light output values needed for this study. In the absence of a light meter, students could use the light output rating listed on the light bulb packaging. The light output value on light bulbs is typically listed in lumens, in which 1 lux = 1 $lumen/m^2$.

The IR laser thermometer is used to compare the temperature differences between the three light bulb types. Other less expensive thermometers (analog or thermistor) could be used for this purpose. IR laser thermometers can yield deceptive measurements if they are not pointed directly at the object whose temperature is being measured. The most accurate way to evaluate the temperature of each light bulb is to place the IR laser thermometer above the bulb and point down to measure the temperature at the top of each light bulb. This measurement is not used to make a calculation but simply to ask where the energy is going if it is not going to visible light. Both the incandescent and compact fluorescent bulbs will get hot. Warn students to let the incandescent bulb cool before even thinking of touching it. The Materials list includes hot pads. A 60W incandescent light bulb will reach temperatures in excess of 100°C. Some of you may remember the old "Easy Bake Oven" whose heating element was an incandescent light bulb (Newsfeed, 2011)!

Experimental Design

I use a guided-inquiry method to begin this study, by posing a starting question for students to use as the basis for their first experiment using this apparatus. The students decide the details of the experiment to be conducted, such as how long each light bulb should be illuminated before measurements are taken. How many repeated measurements should be made? How light intensity should be measured? Whether the distance between the light sensor (or the laser thermometer) and the light bulb matters?

Data Analysis

Power use (watts), light output, lux per watt of power input (foot candles per watt or lumens per watt), and light bulb temperatures may each be summarized by calculating mean values. Means for different light bulb types may be compared graphically is a histogram format. Discussing possible data analysis methods with your class prior to them writing reports, presenting seminars or preparing posters should push them to do more than a superficial analysis of their findings. Since the light output of each light bulb type will not be the same, it may be useful to calculate the light output per unit of electrical power input (for example, lux/watt) so the efficiency (conversion of electrical power to light) of different light bulb types may be compared more clearly.

Typically, students need to be coached to look at this system more deeply. Addressing questions about which light bulb type is the best buy and which is best for the environment requires information about the light bulb purchase cost, light bulb longevity, and the cost of electricity. Your light bulb purchase costs could be provided to the students. Longevity is listed on each light bulb package. The cost of electricity, cost per 1000 watt-hour (Kwh), will depend on your location. Providing students with some sample electricity bills, or the electrical rate paid by your college, would permit them to estimate the cost of using each light bulb type, and whether the LED bulb is ever a better buy than the CF bulb. I sometimes have students model the total cost (purchase price and energy use costs) of each light bulb type in an iterative model (such as STELLA) that tracks cost over time. This kind of modeling may show that LED bulbs eventually become the best buy for consumers, but it takes time for the higher purchase cost of LED bulbs to "pay for themselves". Keep in mind that CF bulbs contain small amounts of mercury so there are other environmental impacts other than energy use and cost. The environmental impact of each light bulb type depends largely on how electricity is produced to operate the light bulbs. If electrical generation is from burning coal or natural gas, one Kwh of electricity will result in the release of a known quantity of CO_2 to the atmosphere, so efficiency matters. If the electricity is from a hydroelectric dam or from a solar panel array, the environmental impact from greenhouse gases is zero.

Previous Results

Students in our non-majors Science and Society (BIO 200) course collected data on incandescent (I) and compact fluorescent (CF) light bulbs. They found the power consumption to be 61.1±0.4w (mean±SE) for I bulbs and 14.6±0.3w for CF bulbs (n=7 of each light bulb type). The respective mean light intensities were 1329±70 lux (I) and 1446±104 lux (CF) (n=5 of each light bulb type, each measured at the same distance from the bulb surface), so the efficiencies (lux per watt) were 21.8 lux/w (I) and 99.3 lux/w (CF). The CF bulbs were approximately 4.5 times more efficient than I bulbs and they had a longer expected useful life (10,000 hours versus 2500 hours). The light bulb temperature differences account for the very different electrical efficiencies of CF and I bulbs. The mean temperature of I bulbs was 117±16°C (n=6) compared to 60±7°C (n=5) for the CF bulbs. Given that the CF bulbs used only 25% of the power required of the I bulbs and the CF bulbs had a greater light intensity than did the I bulbs, more than 75% of the electrical energy used by the I bulbs was converted to heat rather than visible light. CF bulbs initially cost more than incandescent bulbs but they are much more efficient in converting electrical energy to visible light.

Students in our majors Environmental Studies (BIO 497, Spring 2017) laboratory course collected data on 60w incandescent (I), and compared those to compact fluorescent (CF) and light emitting diode (LED) light bulbs that were advertised to be 60w equivalents. They found the power consumption to be 64.4±0.7w (mean±SE) for I bulbs compared to 13.8±1.1w for CF bulbs and 12.0±0.9w for LED bulbs (n=7 of each light bulb type). The respective mean light intensities were 2632±1634 lux (I), 2248±1230 lux (CF) and 2075±1342 lux (LED) (n=7 of each light bulb type, but measurements were not made from the same distance from the bulb surface by each group so the variation is large). The efficiencies (lux per watt) were 40.9 lux/w (I), 162.9 lux/w (CF) and 172.9 lux/w (LED). The CF and LED bulbs were approximately 4.0 and 4.2 times more efficient respectively than incandescent bulbs and they are expected to have a longer useful life (10,000 and 25,000 hours versus 2,500 hours). The light bulb temperature differences accounted for the very different electrical efficiencies of CF and LED compared to incandescent bulbs. The mean temperature of incandescent bulbs was 93±36°C compared to 62±9°C for the CF and 36±6°C for LED bulbs.

Students report their results in my classes in the form of research posters that they present to me and to their fellow students. My evaluation rubrics for both the poster content and my interview of each student are provided in Appendix A.

Cited References

Newsfeed. 2011. Hasbro's New Easy-Bake Oven Ditches the Light Bulb. http://newsfeed.time.com/2011/09/16/hasbros-new-easy-bake-oven-ditches-the-light-bulb/

NASA. 2017. Website of the US National Aeronautics and Space Administration, Earth Observatory, Climate and Earth's Energy Budget. https://earthobservatory.nasa.gov/Features/EnergyBalance/page6.php

NOAA. 2017. Website of the US National Oceanic and Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division. https://www.esrl.noaa.gov/gmd/obop/mlo/

UN IPCC. 2013. Climate Change 2013: The Physical Science Basis. http://www.ipcc.ch/report/ar5/wg1/

Weglarz, TC. 2011. Behind the Numbers: An Exploration of Human Population Demographic Data. Pages 406-421, in Tested Studies for Laboratory Teaching, Volume 32 (K. McMahon, Editor). Proceedings of the 32nd Conference of the Association for Biology Laboratory Education (ABLE), 445 pages. http://www.ableweb.org/volumes/vol-32/v32reprint.php?ch=49

Wikipedia. 2017a. Incandescent light bulb. https://en.

wikipedia.org/wiki/Incandescent_light_bulb

Wikipedia. 2017b. Compact fluorescent lamp. https://en. wikipedia.org/wiki/Compact_fluorescent_lamp

Wikipedia. 2017c. Light-emitting diode. https://en. wikipedia.org/wiki/Light-emitting_diode

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About the Author

Larry Blumer earned his Ph.D. from the University of Michigan in 1982 and he is Professor of Biology and Director of Environmental Studies at Morehouse College where he has been on the faculty since 1990. He teaches ecology, environmental studies, and introductory biology. Blumer has taught in the SEA PHAGES program (Freshmen research immersion) at Morehouse for the past six years. His research interests are in the development of effective pedagogy in the sciences, and the evolutionary biology and social behavior of insects and fishes.

Appendix A

Research Poster Evaluation Rubric

Poster Title _____________________________

Poster Author _________________________ Score (_____ 110 points possible)

Poster (80 pts possible) _______

Interview (30 pts possible) _______

Title (______ out of 5 points possible)

Title describes both the question and the system being studied: 5 points

Title describes either the question or the system: 2 points

Title not descriptive, such as “Experiment #1” or missing: no points

Introduction (______ out of 15 points possible)

Statement of question addressed, statement of hypotheses to be tested, and context for the current study provided: 15 points

Statement of question and alternative hypotheses given, but context missing: 7 points

Statement of alternative hypotheses missing: 5 points

Statement of question missing: no points

Methods (______ out of 5 points possible)

Description of the treatments including the control and a summary of the study protocol: 5 points

Description of treatments and summary of protocol, but control not identified: 3 points

Descriptive summary of protocol given but treatments not described: 2 points

Description of methods limited to a list of materials: 1 point

Methods missing: no points

Results (______ out of 20 points possible)

Statistical summary of findings (average values, total counts for each treatment) in prose **and** in the form of graphs or tables, and a prose description of the findings: 20 points

Statistical summary of findings (average values, total counts for each treatment) in prose **and** in the form of graphs or tables, but no prose description of the findings: 10 points

Statistical findings only in the form of graphs or tables: 5 points

Raw data presented without statistical summaries: no points

Discussion (______ out of 20 points possible)

Interpretation of results to reject hypotheses and address the question posed in the Introduction, **and** provide a broader context on the meaning of the findings: 20 points

Interpretation of results to reject hypotheses and address the question posed in the Introduction, but no context on the meaning of the findings provided: 10 points

Interpretation of results to reject hypotheses provided but the question posed in the Introduction not addressed: 5 points

Interpretation of results to reject hypotheses and address the question posed in the Introduction not provided: no points

Literature Cited (______ out of 5 points possible)

Scientific literature (minimum of five books or journal articles, government or university researcher websites) cited in both the Introduction and the Discussion to provide context. In text, citations use Author, year method and full citation provided in Literature Cited: 5 points

Scientific literature cited in both the Introduction and the Discussion to provide context. In text, citations use Author,year method, but Literature Cited missing or contains references not cited in the prose of the Poster: 4 points

Scientific literature cited in either the Introduction or the Discussion but not both. In text, citations use Author,year method: 3 points

Scientific literature not cited in prose of Poster, but a Literature Cited or References list provided: 2 point

Scientific literature not cited and Literature Cited or References missing: no points

Format (______ out of 10 points possible)

Poster is appropriately organized with Introduction, Results, Discussion, and Literature Cited sections. Writing is for an informed external audience: 10 points

Poster is appropriately organized with Introduction, Results, Discussion, and Literature Cited sections. Audience inappropriately focused on the instructor or the class context: 5 points

Poster is organized with Results and Discussion confused or one section of Poster format missing: 2 point

Poster is not organized with Introduction, Results, Discussion, and Literature Cited sections: no points

Academic Honesty

If any one of the following is true, the score for the entire assignment is zero.

Direct quotations from another student or a published source without quotations marks **or** without attribution.

Direct quotations (with minor editing) presented without quotation marks **or** without attribution.

Extensive use (more than one sentence) of direct quotations with quotation marks and attribution.

Reprinting graphs or tables prepared by another student.

Reprinting graphs or tables from published source without attribution.

Research Poster Interview Rubric

Poster Title ______________________________

Poster Author __________________________ Score (_____ 30 points possible)

What question did your experiment address?

5 points: Concisely stated the experimental question.

3 points: Correctly stated the experimental topic but stated a question not addressed by the experiment conducted.

1 point: Only stated the general topic of the experiment.

0 points: Could not state the experimental topic.

What was the null hypothesis?

5 points: Clearly stated the null hypothesis.

3 points: Stated an alternative hypothesis.

1 point: Stated an hypothesis not addressed by the experiment.

0 points: Could not state an hypothesis.

What were the treatments in the experiment? What was (were) the control treatment(s)?

5 points: Clearly stated the experimental and control treatments.

3 points: Clearly stated either the experimental or control treatments but not both.

1 point: Incorrectly described the treatments.

0 points: Could not state any treatments.

Summarize the results of your experiment and the statistical tests of our results.

5 points: Described a) data means or total outcomes b) comparing controls to treatments and c) noted whether differences were statistically significant.

3 points: Described two of the above.

1 point: Described one of the above.

0 points: Could not describe any of the above.

What is the main conclusion from your study?

5 points: Clearly and concisely stated conclusions.

3 points: Conveyed the main conclusion, but lacked clarity

1 point: Only restated the results.

0 points: Response addressed neither results nor conclusions.

Based on your conclusions, what future experiment(s) would you propose?

5 points: Clearly stated at least one potential future experiment related to the conclusions.

3 points: Stated at least one future experiment related to the topic but not related to the conclusions.

1 point: Stated at least one experiment but not related to the current experimental topic.

0 points: Could not propose any future experiments.

Mission, Review Process & Disclaimer

The Association for Biology Laboratory Education (ABLE) was founded in 1979 to promote information exchange among university and college educators actively concerned with teaching biology in a laboratory setting. The focus of ABLE is to improve the undergraduate biology laboratory experience by promoting the development and dissemination of interesting, innovative, and reliable laboratory exercises. For more information about ABLE, please visit **http://www.ableweb.org/.**

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