IRISE
Illinois Researchers In Partnership With Science Educators
WWW.IRISE.ILLINOIS.EDU

Light Emitting Diode Circuit Design

Developed by Gloria See

Description:
This project allows the students to apply and further develop their knowledge of electricity and basic circuits to design, prototype, and test for the brightest and most power efficient lighting circuits using basic circuit components.

Next Generation Science Standards Addressed:
MS-ETS1-3 & MS-ETS1-4

Prerequisites:
It is expected that students have previously been exposed to basics of electric circuits, specifically voltage, current and resistance and Ohm's Law voltage equation. Parallel and series circuits and power calculations are also very useful knowledge for this lesson.

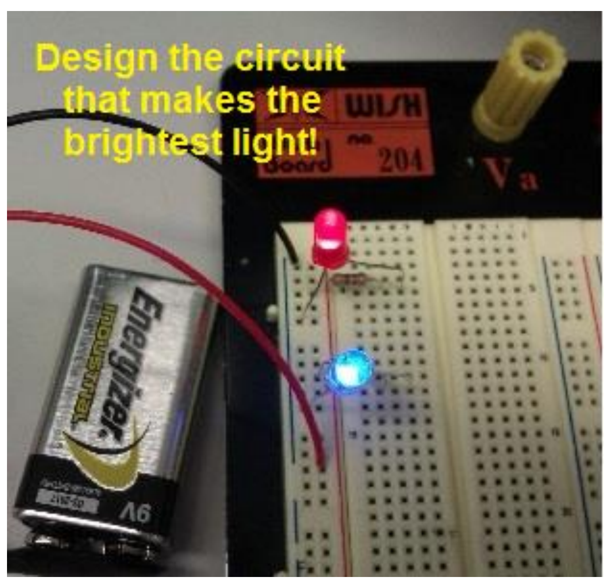
Instruction Time:
Project requires 90 minutes without any addition extension activities

Audience:
This lesson plan is designed for 7th-8th grade students who have been exposed to the prerequisite knowledge.

Lesson Objective:
Students will be able to build and explain the basic operation of a light emitting diode circuit of their own design.

Page **Contents**

Page	Contents
2	Lesson Overview
2	Background Information
3	Learning Objectives & Assessment
4	Alignment to NRC Framework
5	Key terms / vocabulary
6	Materials
10	Lesson plan
15	Additional Information & Links
16	Appendix



Lesson Overview:

This lesson provides students with a hands on opportunity to use a prototyping circuit board and electric circuit components to build a light-emitting diode (LED) circuit. The engineering design cycle is introduced and students experience the different stages of the design process. The final circuits produced by students are evaluated for brightness and power efficiency, allowing for a discussion of the tradeoffs that are often necessary within engineering design.

Background Information:

Units and Abbreviations:

P – Power, in units of Watts
I – Current, in units of amps
V – Voltage, in units of volts

Ohm's Law: It is the basic relationship describing current and voltage as related by the resistance of a circuit component, using the equation V=IR. This states that voltage equals current multiplied by resistance, and is used to characterize individual components within a circuit.

Power: Power and power efficiency are values calculated from the characteristics of the components within a circuit. The power dissipated by the circuit is found by multiplying the battery voltage and current: $P=I\text{x}V$.

Power efficiency indicates how much of the total power is delivered to the LED versus being wasted in the resistor (where it is converted to heat, rather than light). However, the resistor is necessary because it limits the current supplied by the battery and keeps the LED from being burned out. The efficiency is calculated by dividing the power consumed by the LED by the total power dissipated within the circuit.

The power efficiency as described above is somewhat abstracted for this project. In reality, not all of the power used by the LED will become usable light, some is lost as heat, or light that our eyes can't see. Commercial and industrial uses of the term "power efficiency" will usually refer to the useful power.

In light bulbs, the useful power is in terms of the lumens of light produced per watt of power consumed. A watt of radiant power is defined as 635 lumens, so an LED which produces 80 lumens of light per watt of electricity consumed will have a useful power efficiency of about 12%. Such metrics are frequently given when buying commercial bulbs.

Since quantifying the output lumens of the LEDs is difficult in a classroom setting, this project has a visual comparison between the students' final circuits. There is an Excel Worksheet at the end which emphasizes the additional losses introduced by the different resistors selected by the students and the corresponding impact of those resistors on efficiency of power consumption through the entire circuit.

LEDs: Light emitting diodes are a type of semiconductor device. When electric current flows through an LED, the equilibrium of the energy distribution inside the device is unbalanced. The semiconductor inside the LED "rebalances" the energy inside by emitting electromagnetic radiation in the form of light. Most LEDs use semiconductors that will emit light visible to the eye, although one common location of infrared (a non-visible part of the electromagnetic spectrum) LEDs is in remote controls.

A likely question is how LEDs are different from incandescent or fluorescent light bulbs. Essentially, incandescent bulbs use the flow of electricity through a resistive filament (the thin wire inside the bulb) that dissipates the electric power as heat. The filament gets so hot that it starts to glow. Fluorescent bulbs use electricity to excite electrons of the gas molecules in the tube. The excited electrons emit light as they return to their normal states.

Additional information about these topics is listed in the Additional Information and Links section.

Learning Objectives & Assessment:

Objectives	Assessment
Students will be able to:	
(1) Describe the tradeoffs between power consumption, lifetime, and brightness in their design by recognizing that increased brightness requires more power consumption and decreases battery lifetime (identify constraints and engineering trade space),	(1) Part 3 worksheet, informal discussion after testing
(2) Build a three component flashlight using the engineering design cycle after selecting the components that produce the brightest light output (choose an approach, build prototype),	(2) Testing performed after circuit completion - does the circuit work?
(3) Demonstrate their prototype solution and recognize the improvements (such as packaging and component choice) they would make in their final design (testing and redesign),	(3) Testing performed after circuit completion, questions on Part 3 worksheet
(4) Identify the role that each component (LED - produces light, resistor - controls current/voltage to LED, battery - provides power) plays within the electric circuit	(4) Part 2 worksheet, Slide 5 and discussion

The worksheets for Parts 1-3 provide valuable feedback on student learning over the course of the unit. The questions that students have can be addressed in the following portions of the lesson.

Next Generation Science Standards:

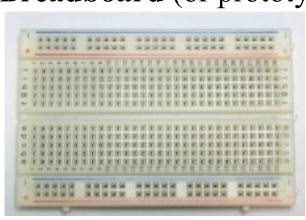
MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Vocabulary:

Battery clip - This clips onto a battery case holding two AA batteries, or onto a 9V battery and the wires can then be plugged into the breadboard.

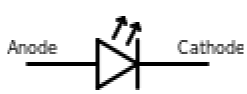
Breadboard (or prototyping board) - This is used for prototyping because components can easily be clipped into the perforated plastic cover. Underneath the plastic, there is a spring clip under every hole, and the spring clips in any given short or long row are electrically tied together. Each hole can have a single component plugged in to it.



Circuit - The connection of different electrical components. The connection may be drawn out in a circuit diagram, as shown in the worksheets.

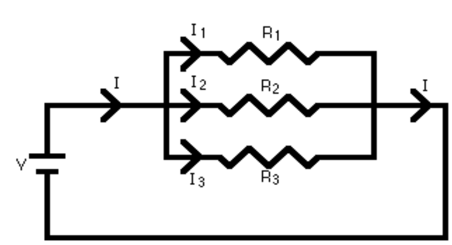
Current - The flow of electric charge, often represent by the letter *I* and an arrow indicating the direction the current is flowing in the circuit.

LED - A light emitting diode. This is the circuit component that produces light. Visible LEDs were first made practical by Nick Holonyak, Jr. now a Professor at the University of Illinois at Urbana-Champaign. They come in a variety of colors and sizes. Standard sizes are 5mm, but other sizes can be used for this project as long as they do not require a voltage larger than the battery can provide. LEDs are represented as shown on the left in circuit diagrams. They have an anode (positive side) and cathode (negative side). To function correctly, the negative side (which will have a flat spot above the wire) must be connected towards the negative end of the battery and the positive side (which will have a slightly longer wire) should be connected towards the positive end of the battery. There may be resistors or other components between the battery and the LED, it's the orientation that is most important.



Node – The connection point for two or more circuit components meet. On the prototyping board, each row of electrically tied holes is a single node that can be connected to as many components as there are holes in the row.

Parallel circuit - A circuit with parallel components has multiple components connected at the nodes on each end of those components. All the components sharing the same two nodes will have the same voltage.

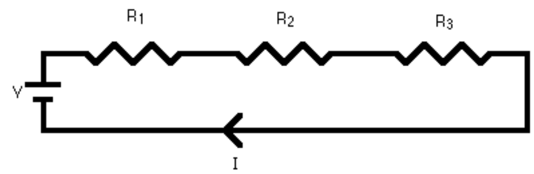


Prototype - A basic model built to test how a design will function.

Resistor - A circuit component that limits the amount of current flowing through it. As per

Ohm's Law, if a certain voltage *V* is applied to the resistor, the amount of current, *I,* that results can be calculated as $I=V/R$. The resistance is proportional to the ratio of the voltage to the current. They are used to step down the voltage in the circuit to an amount the LED can use without being burned out. In circuit diagrams, it is represented as a set of zigzagging lines, as shown in the circuit diagram in the Appendix.

Series circuit - A series circuit has components that are connected in a single path with a single flow of current through the circuit, as shown in the image to the right.



Voltage - The electric potential between two points, usually denoted as *V* in equations and circuit diagrams.

Note: Series and parallel circuit images are from: http://physics.bu.edu/py106/notes/Circuits.html

Materials:

Paper and Classroom Resources:
Each group requires one copy of worksheets 1-3.
Each group requires a calculator and whiteboard with a marker.

Technology and Multimedia Resources:
A computer and projector are required to show the slides during class explanations and discussion. PowerPoint and Excel will be needed to run the files included in this project.

Physical Resources:
The electronic materials can be purchased online at RadioShack.com, Amazon or Digikey.

Cost per group

Breadboard/Prototyping Board
$3-$7 each depending on size, can be reused
http://www.amazon.com/BB830-Solderless-Plug--BreadBoard-tie-points/dp/B0040Z4QN8/

*Batteries (9V or 2AA) $0.50 average/group

Case (for AA batteries) $1.00 average
http://www.radioshack.com/product/index.jsp?productId=2062252
http://www.amazon.com/2AA-Battery-Holder-Wires-Switch/dp/B003YD8NPO/

Battery clip connectors $0.60 each, can be reused
Necessary for 9V batteries, and cases that aren't wired
http://www.amazon.com/Gino-Leather-Housing-Battery-Connector/dp/B00BXX42LQ/

Resistors $0.25, can be reused
http://www.amazon.com/Elenco-365-Piece-Resistor-Kit/dp/B0002HBQHW

*LEDs $0.50
http://www.amazon.com/NightFire-Assorted-Colors-pieces-Resistors/dp/B008D5K68K/
http://www.digikey.com/product-detail/en/OPAKIT-100/365-1362-ND/1543413
LEDs should come with a data sheet that will list their maximum forward voltage and current. Depending on the source, the LEDs will not have such a datasheet, and you should ask the seller for this information.

*These items are likely to be consumed after a few uses. The remaining items will be reusable.

Demonstration
To initially demonstrate the LED circuit, use the same LEDs, resistors and batteries as the students will receive. However, instead of the breadboard, four alligator clip cables ($2.40 each, reusable) will be used to connect the components

Group circuit construction

- Wire cutters in case any of the wires break and need to be stripped
- A tape measure for testing
- A large white sheet or piece of paper to compare the brightness of the different circuits during testing

Each group needs a kit. Give half the groups Kit 1 and give the other half Kit 2.

Kit 1	Kit 2
1 - 9V battery	2 - AA batteries, loaded into a case
At least one resistor of each range: 300-500 ohms, 600-1000 ohms, 2000-4000 ohms, 5000-8000 ohms	At least one resistor of each range: 10-50 ohms, 50-150 ohms, 200-500 ohms, 1500-2500 ohms

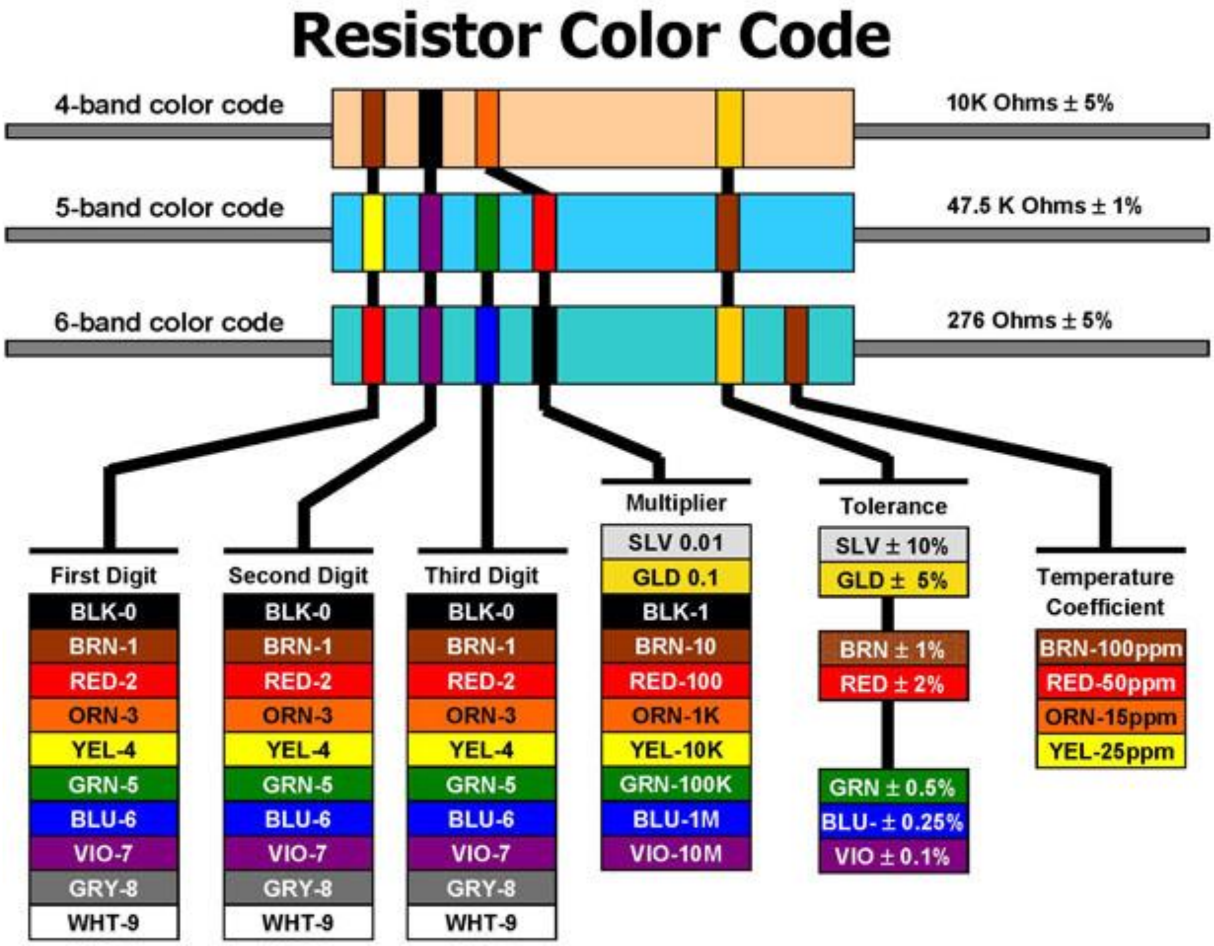
Both Kits 1 & 2 will contain:

- 2-3 LEDs of different voltages and colors. The forward voltage on the LEDs should vary from 1.9 up to 3V. These values can be found on a data sheet or specifications that are listed online or accompany the LEDs when purchased.
- A prototyping board
- A battery clip connectors

If the resistors come in bulk and are not individually labelled, there will be 4-6 colored bands on the resistor to help you identify them. Start from the three or four bands that are closest together and do not look metallic. The last band in that section will be an order of magnitude multiplier, and the color bands in front of it are color coded to the significant figures of the resistor values. The remaining bands on the resistor are not critical for this lesson plan, but they indicate the tolerance (allowable deviation from the stated value of the resistance) and possibly a temperature coefficient.

A schematic of the resistor color bands and the color code is included on the next page.

Optional extension: If students are familiar with scientific notation, they can find the resistor values themselves.


Resistor Color Code
4-band color code
10K Ohms ± 5%
5-band color code
47.5 K Ohms ± 1%
6-band color code
276 Ohms ± 5%
First Digit
BLK-0
BRN-1
RED-2
ORN-3
YEL-4
GRN-5
BLU-6
VIO-7
GRY-8
WHT-9
Second Digit
BLK-0
BRN-1
RED-2
ORN-3
YEL-4
GRN-5
BLU-6
VIO-7
GRY-8
WHT-9
Third Digit
BLK-0
BRN-1
RED-2
ORN-3
YEL-4
GRN-5
BLU-6
VIO-7
GRY-8
WHT-9
Multiplier
SLV 0.01
GLD 0.1
BLK-1
BRN-10
RED-100
ORN-1K
YEL-10K
GRN-100K
BLU-1M
VIO-10M
Tolerance
SLV ± 10%
GLD ± 5%
BRN ± 1%
RED ± 2%
GRN ± 0.5%
BLU- ± 0.25%
VIO ± 0.1%
Temperature Coefficient
BRN-100ppm
RED-50ppm
ORN-15ppm
YEL-25ppm

Lesson plan:

Preparation

1. Prior to the lesson assign students to groups of 3-4.
2. Before the demonstration in Part 1, bring several LEDs, resistors, batteries, and four alligator clip cables.
3. Before going through the equations in the class, determine the voltage over the resistor for several combinations to be demonstrated as a class and calculated on the worksheets.

   Voltage of battery – Forward Voltage of LED = voltage over resistor

   Voltage over resistor/ Maximum LED Forward Current = Resistance needed

   For example, for an LED with 1.2V Forward Voltage using a 9V battery:

   Yellow: 9V - 1.2V = 7.8V over the resistor

   Assuming a maximum forward current of 0.02 Amps:

   7.8V/0.02A = 390 Ohm Resistor

   This value is the smallest resistor that can be used without burning out the LED. Larger resistor values are fine and should be used in the kits.

   Note: Using an LED without any resistance will often burn out the LED since values are rarely exact, even if the forward voltage of the LED is the same voltage as the battery.
4. Before starting the construction of prototypes, assemble the supplies for each group's circuit construction. Check that none of the LEDs are burnt out, and make sure the resistors are all labeled with their values.
5. Before testing in Part 3, have the excel sheet loaded to compare efficiencies of the circuits from each group.

Part I

Engage (5-10 min): Explain the students are going to design their own prototypes for a flashlight, and they have to figure out how to make the brightest light they can.

Ask students how light bulbs work. Have each student write down their ideas on a whiteboard and then share their answers with their group. They can select the best answer(s) and share with the class. Explain how engineers have to design new lights for various purposes (lab testing for new lights to make sure they work for long enough, produce lights for soldiers that need long battery life and lightweight versus household use, etc).

Explain and explore (15 minutes): Describe a circuit, and a waterslide (as shown on slide 2, projected on the board).

Discuss the analogy between different components - the pump is like a battery, voltage is height of the slide, current is how fast the water goes and how much there is, steepness/length of slide is like resistance.

Review previous electrical knowledge: From the slide analogy, ask if any of the students can describe what a series or parallel circuit would look like, first as the slide, if they prefer, but making sure to review it as a circuit.

Have several students come up to be in charge of the LED, battery, and different resistors. Connect the components with the alligator clips.

When connecting the circuit, remember the LEDs have an anode (positive side) and cathode (negative side). To function correctly, the negative side (which will have a flat spot above the wire) must be connected towards the negative end of the battery and the positive side (which will have a slightly longer wire) should be connected towards the positive end of the battery. There may be resistors or other components between the battery and the LED, it's the orientation that is most important.

Connect the resistors to the LED and then to the battery, making sure the connections from the LED's positive connection goes towards the positive terminal on the battery. Ask them to connect resistors in series and parallel to change the circuit. Make sure the students walk around the room with their circuit so it's visible to everyone.

Reverse the LED so that the positive and negative ends are connected in the wrong order so the students see how it won't light up when connected backwards.
Note: Make sure the reverse or breakdown voltage of the LED (from the data sheet) is larger than the breakdown voltage. If in doubt, use the LED with the largest forward voltage and the 2 AA batteries for this demonstration.

Evaluate (Included with previous): During the demonstration, calculate the variables in V=IR equations for predetermined circuits on worksheet. Do the first problem together as a class, and have the students calculate the values for the second in their groups. Ask students what happened to the LED when the resistors values got larger or smaller.

Explain how in the engineering design cycle (shown on Slide 4), it's important to know how the materials they'll be using work, so they can properly define their problem. Introduce the design challenge to build a light as bright as possible with the components they saw today.

Teaching assessment: Ask students to write one sentence about something they think they really understand and one sentence about something that confuses them. Use this information to guide the discussion/review for the next section.

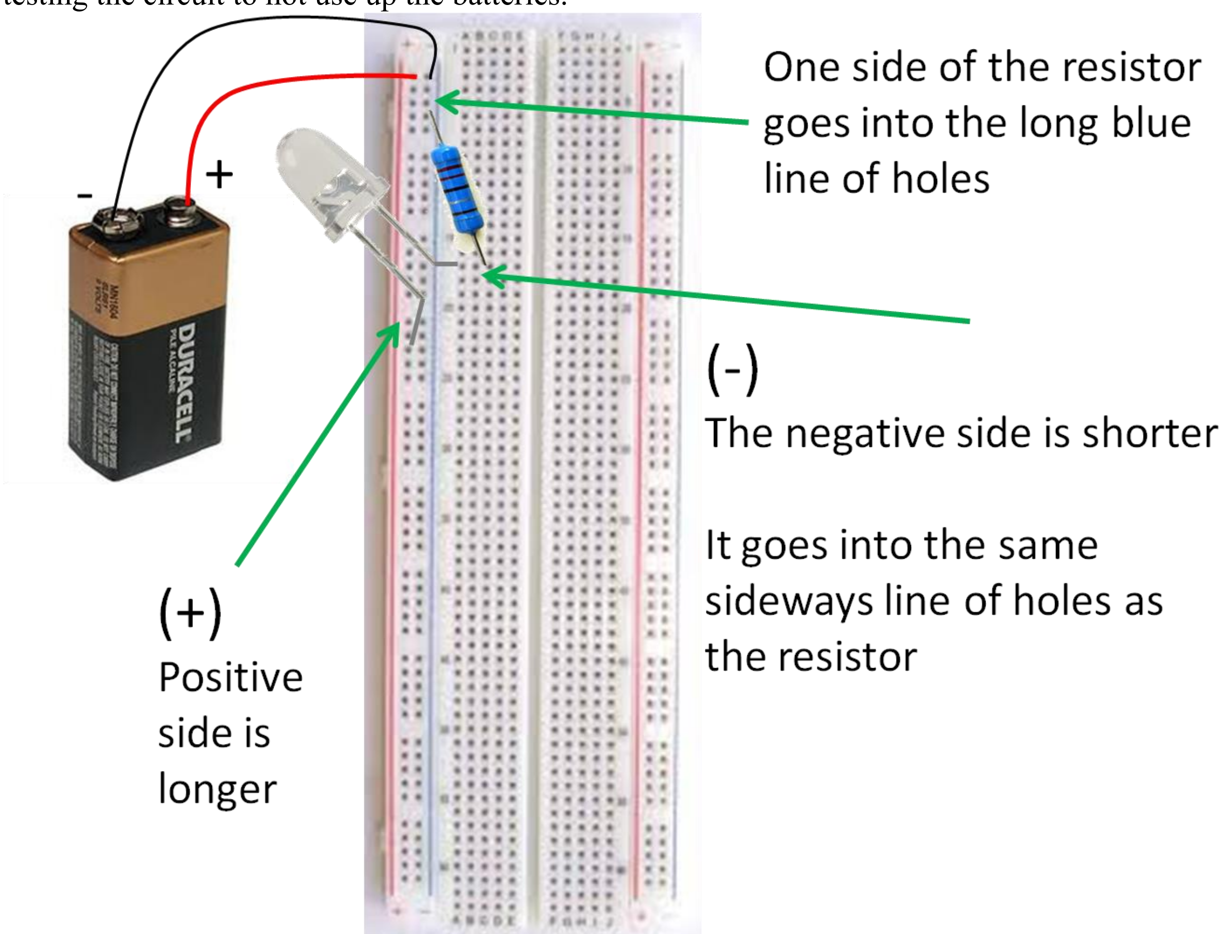
Part II
Engage (5 minutes): In groups, discuss all the places you might use a flashlight. What would make it a "good" flashlight for those places? Consider brightness, color, how big it is, how long the battery should last, etc. Write on whiteboards in groups to share with the class.

Note: Do NOT start this section without at least 30 minutes for students to learn how to use the prototyping board and start building their circuits.
Explain (10 minutes): Review the components from the last section and match them to their symbols in the circuit diagram, as on slide 5. Describe how a prototyping board replaces the

wires we used in the demonstration to connect the components together and show the diagram of how to connect everything on the prototyping board.

For simplicity, it's easiest for the students to assemble all the components on the prototyping board and only switch out the resistors they will be testing, then repeating with the next LED. Give the students explicit instructions, and a diagram to follow, as below.

Connect long end of the LED to the same node as the positive (red) wire from the battery. The other end of the LED must be in a separate node with one end of the resistor, and the last end of the resistor must be in the same node as the negative (black) wire from the battery. Use the diagram on slide 7 and below as guide. Ask the students to "unplug" the battery when they aren't testing the circuit to not use up the batteries.



Remind students about the design challenge to build a circuit with the brightest LED. Ask them to decide in their groups how they will pick the best color LED and resistor value for their circuit.

(20 minutes) Pass out components to groups and let them start building. On the worksheet, have them write down which resistor and LED combination they think was best of the ones they had time to try.

Optional extension: Have the students add a second LED in parallel or in series with the first. Have them discuss what effect this has on the brightness of the LEDs in the circuit.

Evaluate - In the last five minutes, have students pack up supplies and share what did and didn't work with a partner team. As a class, discuss how the resistors consume some of the power from the battery and that power doesn't go to the LEDs. This power is dissipated as heat, which decreases the overall efficiency of the circuit.

Teaching assessment: Have the students answer on their worksheets "What made the brightest LEDs?" and complete the 3-2-1 assessment.

Part III
(10-15 minutes) To do the brightness test, turn the room lights off and hold the illuminated circuit in front of a white sheet of paper. Have the students move a hand in between the two and show the shadow cast by the hand. The students with the paper and the circuit will move farther apart until they can't identify the hand shadow.

The greater the final distance between the two, the brighter the LED in the circuit. It helps to have all the students vote by putting a hand up at the beginning and dropping it when they can't see the shadow.

These distance values should be loaded into the spreadsheet under the 'Distance Column' for each group. The column will highlight values with brighter blue for longer distances.

(10 minutes): Input the values of the circuit components into the Excel worksheet to determine which circuit was the most efficient. The boxes in blue highlights all need to be filled in for the formulas to work correctly. If the voltage of the battery and the LED (the forward voltage) are the same, set the voltage of the battery at 0.1 higher (this is an arbitrary value, but avoids any division by zero errors in the worksheet). The resistor values also need to be input.

Note: As described in the Background Information, the power efficiency here is comparing the amount of power consumed by the resistor and the LED, rather than the efficiency of "useful power" that is strictly going towards producing visible light.

Values are calculated automatically using the following formulas:
Resistor voltage = Battery voltage-LED forward voltage
Current = Resistor value/Resistor voltage
Total Power = Battery voltage x Current
Resistor Power = Resistor value x Current squared (Here, the current multiplied by resistance were substituted for the voltage, using Ohm's Law where $V=I \times R$)

Power Consumed by the LED = Total Power – Power Consumed by the Resistor
Percent Efficient = Power Used by the LED/Total Power

As the power efficiencies are calculated, the highest efficiency (meaning the least power wasted as heat dissipated through the resistors) will be highlighted dark green. Lower efficiencies will be colored with lighter shades of green.

Compare brightness and power efficiency on each circuit - filling in the values on worksheets as described in the preparation section.

Optional extension: The current values generated by the worksheet will vary. An additional discussion point is how the different resistors on different batteries will result in different currents through the circuit. This also changes the power consumed by different components.

Explain how the larger batteries had more power for the LEDs, but also needed larger resistors to keep from burning out the LEDs. Resistors also need power, so the larger the resistor, the less energy efficient the circuit will be. Have the students fill these values in on the worksheet. Ask the students how they would manage the design tradeoff if they had to build a new circuit that needed to be bright but also energy efficient?

Wrap up: Review the engineering design cycle for this project. What were the things we measured? What kind of tradeoffs does this project have? Have student answers these questions in groups on their worksheets and then share with the class.

Depending on the time available, some additional discussion prompts:
- What was the problem?
- What were the limitations you had for your light?
- Generating ideas when we discussed the different uses for flashlights...
- Building a prototype – using a prototyping board as a way to practice the design and change it easily to make sure all the parts work properly.
- Testing – what was brightest? What was the most efficient?
- What would you change to make your light brighter next time? More efficient? What else would you have to do to make this a real flashlight?

Additional Information and Links:

Fundamentals of Electric Circuits, Charles K. Alexander, Matthew Sadiku
For an overview of electric circuit components and their function, see Chapter 1. Ohm's Law is thoroughly explained in Section 2.2.

http://physics.bu.edu/py106/notes/Circuits.html
Good introductory descriptions of series and parallel circuits.

http://www.youtube.com/watch?v=oiqNaSPTI7w
A video introduction on how to use a prototyping board, like the ones used for the circuit design in this project.

http://www.facstaff.bucknell.edu/kjh016/courses/common/Prototyping boardIntro.pdf
An online pdf reference describing the use of a prototyping board.

http://www.academia.edu/879577/Promises_and_Limitations_of_Light-Emitting_Diodes
This page provides additional detail as to the history and function of Light-Emitting Diodes (invented by an Illinois native during his time as a researcher at GE).

Appendix:

Images from the slides for other worksheets, etc.