

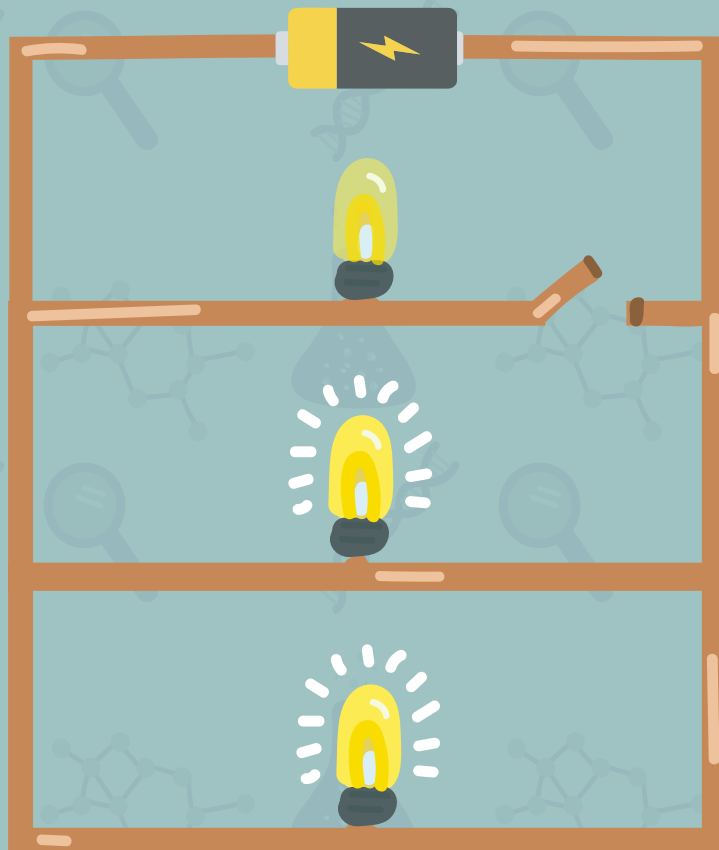
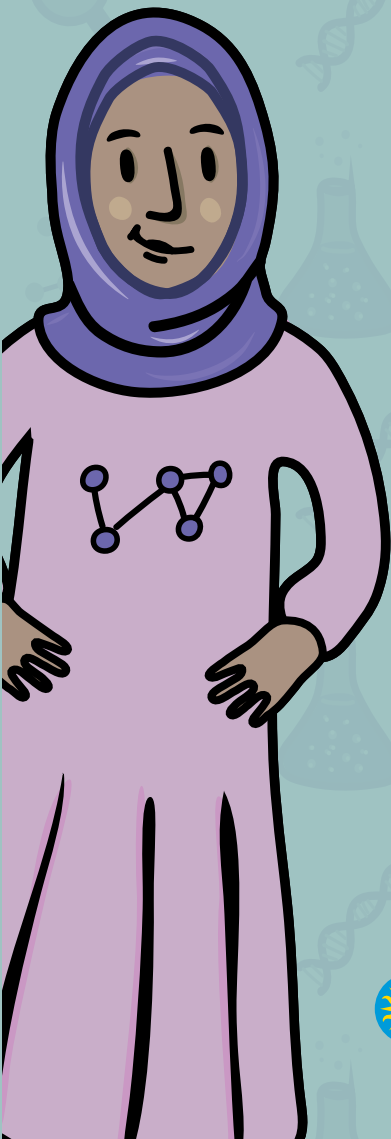
ENGINEERING CIRCUITS

STEM²D Topics:

Science, Technology, Electricity, Circuits, Design

Target Audience:

Students, ages 9-18



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ENGINEERING CIRCUITS is part of the STEM²D Student Activity Series. The content and layout were both developed by the Smithsonian Science Education Center as part of Johnson & Johnson's WiSTEM²D initiative (Women in Science, Technology, Engineering, Mathematics, Manufacturing, and Design), using a template provided by FHI 360 and JA Worldwide. This series includes a suite of interactive and fun, hands-on activities for girls (and boys), ages 5-18, globally.

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Design and illustrations by Sofia Elia

ENGINEERING CIRCUITS

STEM²D Topics: Science, Technology, Electricity, Circuits, Design

Target Audience: Students, ages 9-18

ACTIVITY DESCRIPTION

This activity introduces students to electric circuits through a number of hands-on activities utilizing copper tape, light-emitting diodes (LEDs), and other basic components. A number of concepts are introduced, including electrical flow, polarity, open and closed circuits, and series and parallel circuits. In doing these activities, students gain an understanding of how electricity can be manipulated in a circuit to do useful things while gaining perspective into the important role circuits play in our daily lives.



ESTIMATED TIME:

This session typically takes 60-90 minutes to complete.

STUDENT DISCOVERIES

Students will:

- Assemble a number of simple circuits consisting of batteries, LEDs, and switches
- Test the conductivity of various materials
- Learn about polarity and electrical flow
- Test and learn about series and parallel circuits
- Use new understanding to build a multicolor night lamp

GETTING READY

Materials:

- 1 Student Activity Guide per student
- 1 15 foot strip of adhesive copper tape per student
- 2 3V Button batteries (CR2032) per student
- 4 3V Light-emitting diodes (LEDs) (one each: red, green, blue, yellow) per student
- 5 Paper clips per student

- 1 strip of aluminum foil per student measuring 16 cm x 0.7 cm (6 inches x 0.25 inches)
- 1 Wood craft stick per student
- 1 Styrofoam cup per student
- Clear tape or masking tape
- Video projector and computer (to display PowerPoint illustrations)

FACILITATOR BACKGROUND

How to use this guide:

This guide will assist you in teaching the science behind the activity and provide you with helpful insight and verbatim phrasing to explain key concepts.

Activity Leader Preparation:

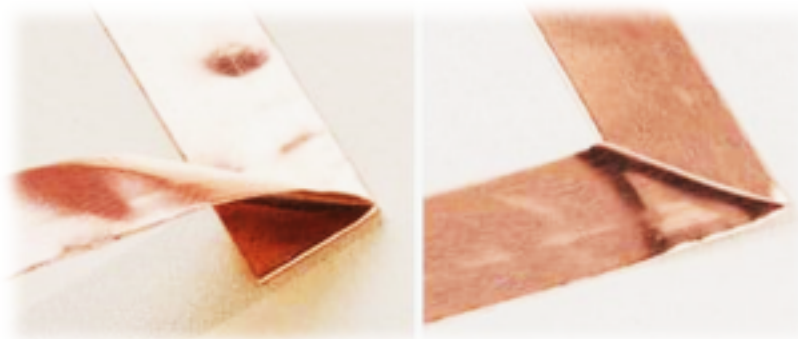
1. Read the Spark WiSTEM²D guide. This is essential reading for all volunteers interested in working with youth. It provides important background knowledge about STEM²D, strategies for engaging female students, and tips for working with groups of students. Download your copy at <http://www.STEM2D.org>.
2. Review this entire activity guide, which includes a complete lesson of prerequisite scientific concepts and step-by-step instructions for the hands-on activity.
3. Depending on the amount of time you will have with the students, select two or three activities for them to complete.

General Tips:

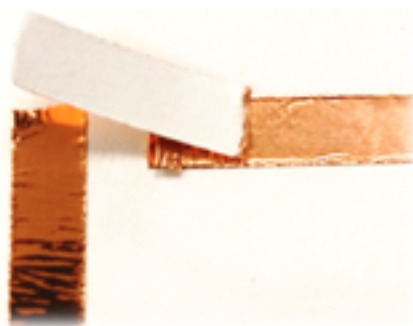
- Because of time constraints, it's recommended that materials be set up prior to students arriving in the classroom.
- Activity leaders should focus on building rapport with students, e.g., conveying their personal and professional stories. Share why you are excited about STEM²D and why you chose your profession. Additional guidance can be found in the Spark WiSTEM²D guide.
- Aim to introduce scientific concepts within 10 minutes to ensure there is adequate time for the hands-on activity and follow-up discussion.

Technical Tips:

- Aim to use copper tape in single, continuous pieces. Have students practice laying down corner turns as one long piece. This will help eliminate any waste of copper tape.



- One way to make a switch is by bending a piece of copper tape back on itself with most of its protective paper backing left in place. The exposed sticky portion can then be affixed to a lead piece of tape as shown here.



- The electrical connections achieved with copper tape are quite delicate. To ensure the best possible connection, LEDs should be taped over the top of the copper tape with an additional piece of copper tape.
- The LEDs used in this activity are unidirectional and feature long and short legs for positive and negative leads. If improperly placed in a circuit (backward), they will not illuminate. To remedy, simply flip the LED to ensure correct polarity.
- Each circuit diagram will indicate the colors of LEDs to be used. This is important because the voltage and resistance can vary with LED color, causing circuits to function in unforeseen ways. For example, red LEDs are rated at 2 volts (V), while green and blue LEDs are rated at 3V.

ACTIVITY AND INTRODUCTIONS

Pre-Activity Welcome and Introductions

- Greet the students.
- Tell the students your name and who you work for. Talk about your education and career. Use the Tell My Story form as the basis for your remarks. Be prepared to describe your job or a typical day and provide information about your background including:
 - Your education
 - Current work projects
 - Interests and hobbies
 - Why you love STEM²D and how your work is connected
- Ask the students or any volunteers helping today to introduce themselves.
- Ask questions to learn more about the students and their interests. The prime objective is to build rapport with the students with the aim of getting them curious about STEM²D and how it relates to them.

Activity Introduction

- Explain that understanding how circuits work is a great skill for anyone interested in computers, video games, and healthcare, such as surgical robotics that help doctors save lives. Convey that people with these technical skills are in high demand and can have rewarding careers. Relate this to your own story to the extent possible.
- Introduce the activity and solicit reaction from the students by asking, "Who is interested in electronics?" Tell students today we are going to learn about circuits and how they are used to make electricity do useful things. We will test what we learn by building some actual circuits, including a colorful night light.
- Refer students to PowerPoint slide 2. Introduce the take-home message that circuits are everywhere.
 - Circuits are in our toys, in our computers, and other everyday devices like a light bulb.
 - Have students point out objects in their classroom that they think contain some kind of circuitry.

Required Concepts – Circuits, Polarity, and Electrical Flow

- Establish a basic understanding of electricity:
Electricity is a form of **energy** or the ability to do things. It results from

the flow of **electrons** through a material. Electrons are extremely small particles that make up part of an atom. Approximately 1 billion atoms can fit on the head of a pin!

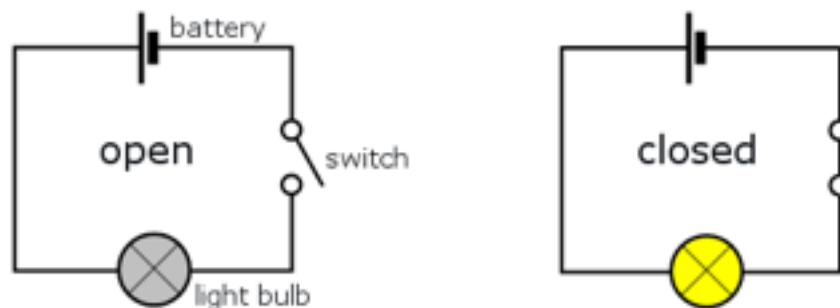
- Refer students to PowerPoint slides 5-7. Introduce the concept that circuits and electricity go hand-in-hand:

Electricity needs a path to travel. A **circuit** provides that path through a collection of wires and electrical parts that act much like pipes and allow electricity to flow. We can design circuits in ways that guide electricity's flow along different paths and through devices to do useful things like turn on a light, radio, toy, or other device.

- All circuits have:
 - An energy source, e.g., a battery, (slide 5)
 - An energy consumer, e.g., a light bulb (slide 6)
 - A way to connect the two, e.g., a wire or material capable of transporting electricity, which is called a **conductor** (slide 7)
- Refer students to PowerPoint slide 8. Introduce open and closed circuits:

Circuits can be open or closed. A **closed circuit** is one that has an unbroken path for electricity to follow. An **open circuit** is one that has a gap or break in the path, e.g., a disconnected part. Because of this gap, electricity cannot flow in an open circuit and our device remains unpowered or off.

Figure 1.

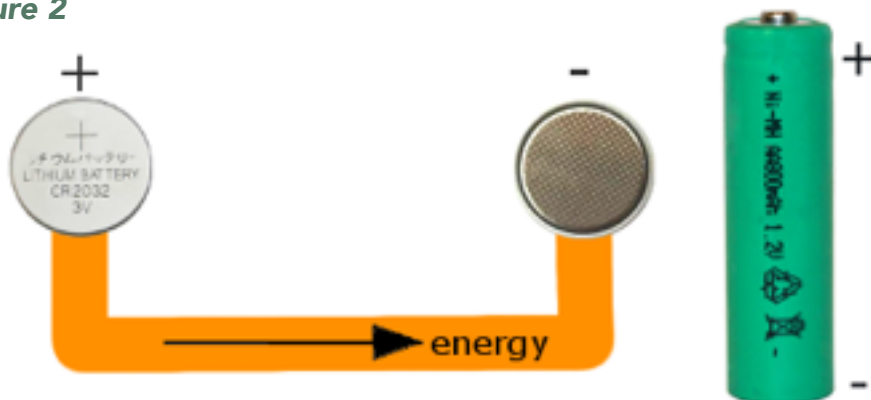


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- A device called a **switch** can be used to open or close circuits. Electrical devices use switches to control circuits, turning them on and off to cause intended results.
- Refer students to PowerPoint slide 9, Figure 2. Introduce batteries, polarity, and electrical flow:

We'll be using some small button-sized batteries in our activity. Like all batteries, these have two sides: a positive side indicated by a plus (+) and an unmarked negative side. Electricity flows between positive and negative parts of a circuit.

Figure 2



- Refer students to PowerPoint slide 10, Figure 3. Introduce the LED:
We will be using small colorful lights throughout our activity called **light-emitting diodes or LEDs**. Like batteries, they have a positive and negative side. We need to make sure to place them in a circuit correctly or they won't work. You can remember which side is positive by the length of a LEDs wires: long = positive, short = negative.

Figure 3



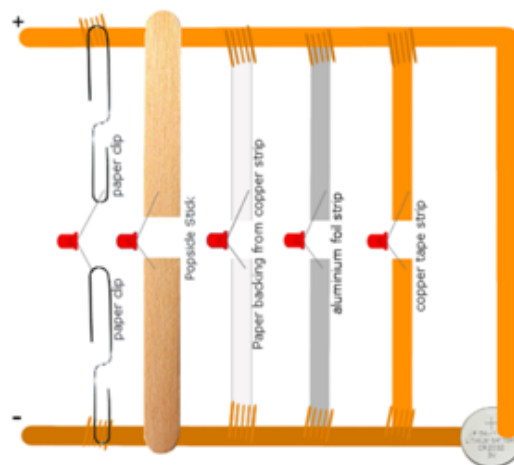
Activity – Material Conductivity

Which of these materials can conduct electricity? Which cannot?

Objectives: Students will build a basic circuit and observe that some materials conduct electricity while others do not.

Instructions:

1. Introduce students to the materials they will be working with, including the Student Guide.
2. Instruct students to build the circuit by placing copper tape down along the printed path, connecting one piece to the positive (+) battery terminal and the other to the negative (-) battery terminal exactly as shown.
 - a. Refer students to PowerPoint slide 11 for best practices when working with copper tape.
 - b. Younger students might benefit from placing additional clear or masking tape over the connected battery to better secure it to the paper.
3. Instruct students to prepare the test materials by tearing two pieces each of: copper tape, paper strip (the backing from copper tape), and aluminum foil. In addition, students will have a two ends of a wood craft stick and two paper clips which they should partially unfold as shown.
4. Have the students connect the various test materials across the two terminals using a small piece of copper tape, ensuring they leave a small (~1 cm) gap in the center.
5. Instruct the students to hold a LED across each of the test materials to complete a circuit (reverse the LED if it does not illuminate).
6. Ask the students, "Which types of materials conducted electricity?" Ask what these materials have in common (color, shape, material, etc.). Elicit responses that lead students to deduce that metals are good **conductors**. Convey that materials which do not conduct electricity are called **insulators**.



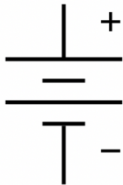


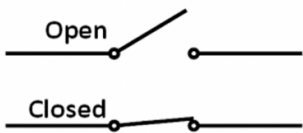

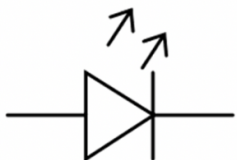
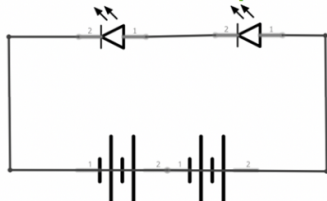
Introduction to Circuit Design

- Refer to PowerPoint slides 12-14. Introduce students to circuit diagrams and schematics:

Before building a circuit, engineers use special symbols to construct a **circuit diagram** either on paper or a computer. Indicate that many hundreds of these symbols exist, though we will be focusing on five for this lesson.

- Guide the students through each of the diagrams while noting the particulars of each.

These symbols include:

| | |
|---|---|
| <p>Batteries (and other DC power sources):</p>  <p>Includes indicators for positive and negative battery terminals (long horizontal line indicates +)</p> | <p>Wires Connected / Not connected:</p> <div style="display: flex; justify-content: space-around; align-items: center;"> <div style="text-align: center;"> <p>Connected</p>  </div> <div style="text-align: center;"> <p>Not connected</p>  </div> </div> <p>A solid dot indicates a connection and the up-and-over loop indicates no connection.</p> |
| <p>Switches (open / closed):</p>  <p>The switch diagram forms a near-continuous line when closed.</p> | <p>Resistors (also electricity consumers or loads):</p>  <p>This zig-zagging line indicates a load (device) or special purpose resistor designed to limit electricity (current) through a circuit.</p> |
| <p>Light-Emitting Diodes:</p>  <p>The triangle points away from the positive side of the DC power source. Two arrows indicate light.</p> | <p>Example schematic of a complete circuit:</p>  <p>A simple circuit consisting of two LEDs and two batteries wired in series</p> |

Activity – Series Circuits

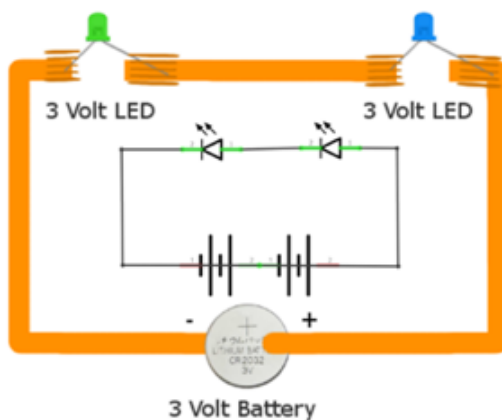
Batteries provide a limited amount of electricity. The **voltage** needs of devices in a circuit add up when connected to a battery one after another (in **series**). If the needed voltage is greater than the battery voltage, the devices will not function.

Objective: Students will investigate to address the following:

1. How many volts are needed to power the lights in this circuit?
2. How many batteries are needed?
3. Devise a way to illuminate two 3-volt LEDs.

Instructions:

1. Have the students build their circuit using one blue and one green LED (the LEDs long terminal must lead toward to the positive side of the battery). Secure the LEDs to the copper tape using additional pieces of copper tape. Reuse the battery from the last activity and connect it as shown. **The LEDs will NOT illuminate.**
2. Ask students to evaluate the circuit diagram and brainstorm what the problem might be. Walk them through the diagram as needed. Elicit student problem solving as needed by asking the students how many volts of electricity their LEDs draw (3V each) and how many their battery is able to output (3V). Guide the students to realize the diagram calls for two batteries.
3. Solution: Explain to the students that each of their LEDs requires 3V to function and because this is a **series circuit**, through which electricity travels along a single path, the two 3V LEDs require a 6V power source to function. However, just as two 3V LEDs in series add up to require 6V of electricity, two 3V batteries add up to provide 6V of electricity.
 - a. To complete the activity, students must disconnect the positive copper tape from the battery, place a second battery over the first battery (ensuring a negative-to-positive series arrangement) and reconnect the copper tape over the second battery's positive terminal. The LEDs will illuminate now that 6V of power are available.



Activity – Parallel Circuits

Scientists are constantly challenged to conserve energy by finding creative ways to power devices with fewer resources and materials. In the previous activity, you learned that volts add up as devices are connected one after another. However, if these devices are connected in **parallel**, where each device has its own electrical path to and from a battery, the voltages do not add up. They remain constant. Your next task is to devise a way to illuminate three LEDs using only one battery.

Objective: Students will design and test parallel circuits to light multiple LED bulbs.

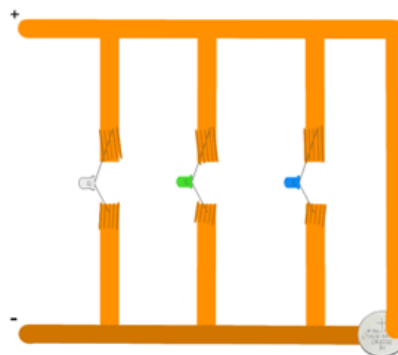
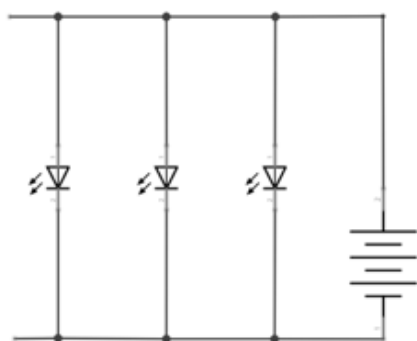
Instructions:

1. Convey that scientists are always being challenged to do more with less resources to meet the growing demand on our energy resources. Explain that a clever scientist can get one battery to power not one, not two, but all three LEDs. Explain that while volts add up in a series circuit, they don't add up in **parallel circuits**—where each device is on its own electrical path to and from a power source.
2. Instruct students to work with their classmates and use the schematic diagrams introduced earlier to design a circuit that can illuminate three LEDs using only one battery and providing each LED with its own electrical path. Instruct them to draw this circuit on their worksheets.
3. Inform students they are free to use any combination of materials available to them to build and test their circuit design. Students may then build their circuit atop of their schematic.

TEACHING TIP:

For older students, you might discuss how the parallel circuit arrangement comes at a cost: the battery will only last 1/3 as long.

Note: Based on the previous activity, students may insist they need three batteries for a total of 9 volts. Be sure to emphasize the difference between a series circuit in which all LEDs are placed on a single path vs. a parallel circuit where each LED has its own path to/from the battery.



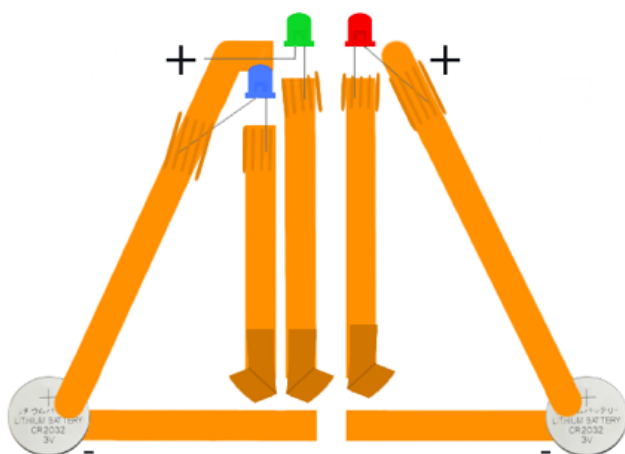
Examples of a circuit schematic (left) and built circuit (right) for this activity. (Wikipedia)

Activity – Multicolor Night Light

Objective: Students use what they have learned to build a multicolor night light. Using switches, students can activate a combination of LEDs to create light in all of the colors. The switches may be clamped on by using paper clips.

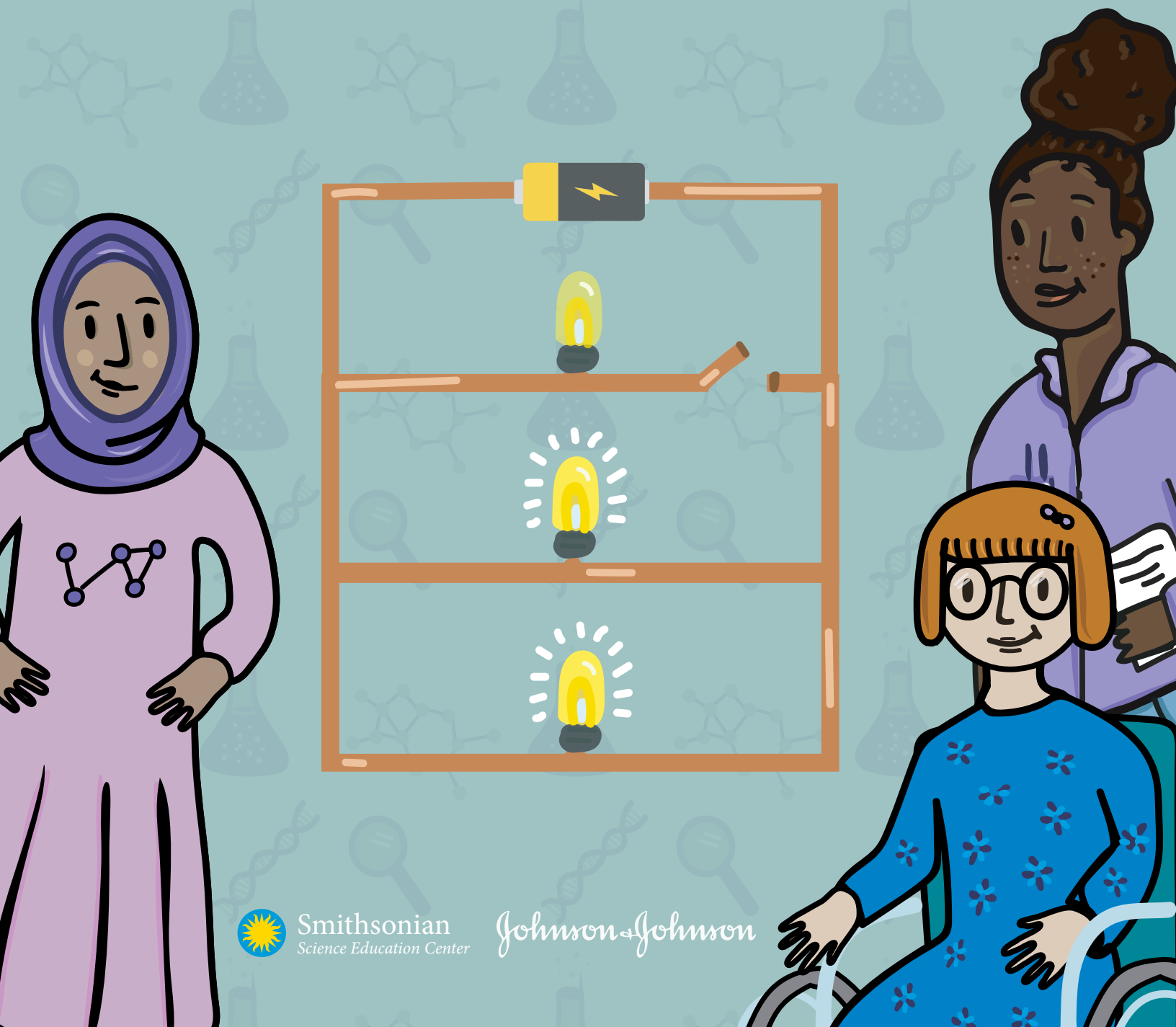
Instructions:

1. Refer to PowerPoint slide 11 and briefly reintroduce the switch and how to construct one by folding a piece of copper tape back on itself with a portion of its paper backing left on (see figure).
2. Instruct students that they will now build their multicolor night light circuit. Instruct them to follow the template below and what they've learned in class to accomplish the task. The lamp will include:
 - a. Two batteries and various lengths of copper tape
 - b. One series (red LED) and one parallel circuit (blue & green LEDs)
 - c. Three switches to control the color LEDs
 - i. *Students will use the switches to experiment with producing light of various color: blue + red = purple; green + red = orange; red + green + blue = white*
 - d. A Styrofoam cup placed over the LEDs to diffuse the light and act as a lamp shade
3. Bonus: If time permits, have the students draw a circuit diagram for their night lamp.



ENGINEERING CIRCUITS

STUDENT ACTIVITY GUIDE



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YOUR ENGINEERING TASK...

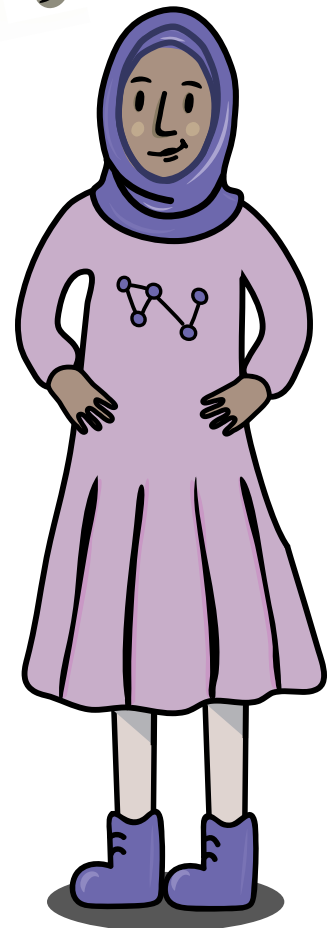
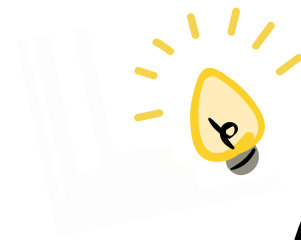
Circuits allow us to use electricity in useful ways. We find them everywhere, and they are an important part of our daily lives. Circuits are in our toys, computers, televisions, telephones, and even the lights in our homes. In this activity, you will learn about the different kinds of circuits by building and testing each type. You will then use what you have learned to build a multicolor night light.

Criteria (goals):

- You must be able to control the night light.
- The night light must change color.

Constraints (limits)

- You can use only the materials provided by the teacher to make your night light.

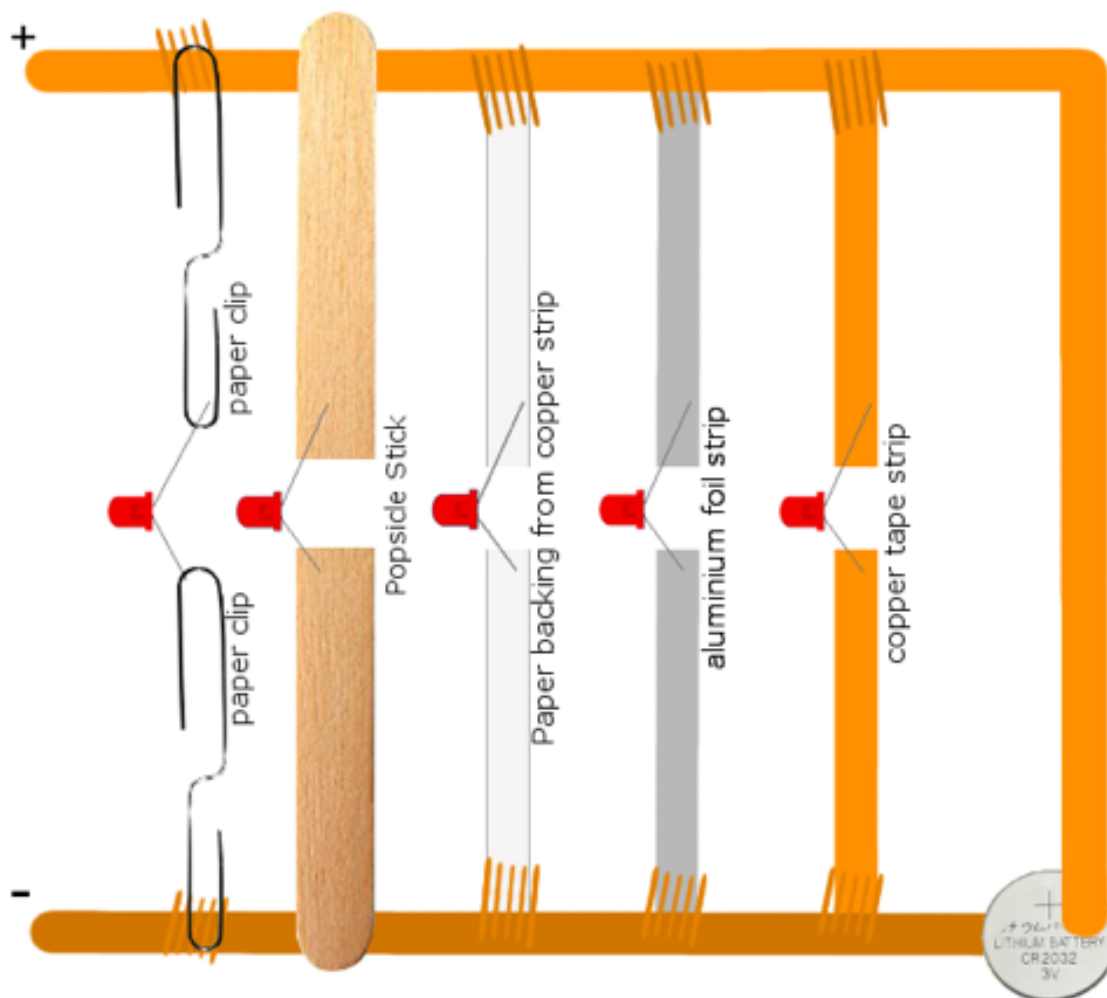


Activity – Material Conductivity

Some materials conduct electricity and some do not. We call these materials **conductors** and **insulators**. Can you predict which materials are conductors?

Instructions:

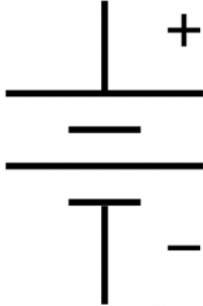





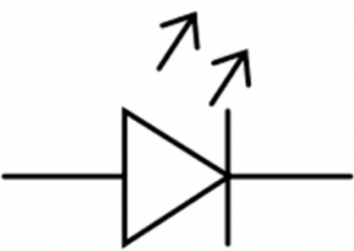
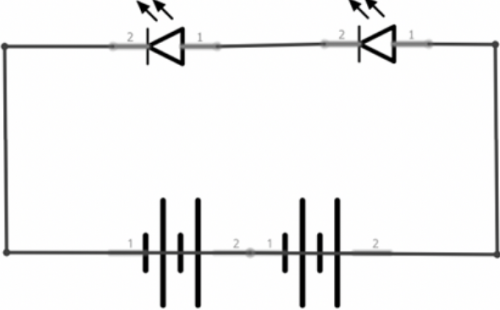
1. Peel the paper back from the copper tape and stick the copper tape along the orange path shown here. Connect one piece of the tape to the battery's positive (+) side (called a terminal) and the other to the battery's negative (-) terminal. Place additional clear tape over the battery to better secure it to the paper.
2. Unfold two paper clips and cut the remaining test materials (Wood craft stick, paper strip, aluminum foil, copper tape) into two sections and tape them down along the top and bottom sides of the path using copper tape. Leave a small (1 cm) gap in the center.
3. Hold a colored light across each of the test materials (long leg pointing upward) to test which materials can conduct electricity. Try flipping the light over if it does not light up.
4. How do you know if the materials conduct electricity?



Introduction to Circuit Design

Before building a circuit, engineers use special symbols to make a **circuit diagram** either on paper or a computer.

These symbols include:

| | |
|---|---|
| Batteries (and other DC power sources):  | Wires Connected / Not connected: <div>Connected </div> <div>Not connected </div> |
| Switches (open / closed): <div>Open </div> <div>Closed </div> | Resistors (also electricity consumers or "loads"):  |
| Light Emitting Diodes (LEDs):  | Example of complete circuit:  |

Activity – Series Circuits

Batteries provide a limited amount of electricity. The **voltage** needs of devices in a circuit add up when connected to a battery one after another (in **series**). If the devices need more voltage than the battery has, the devices will not work.

Objective: Investigate to address the following:

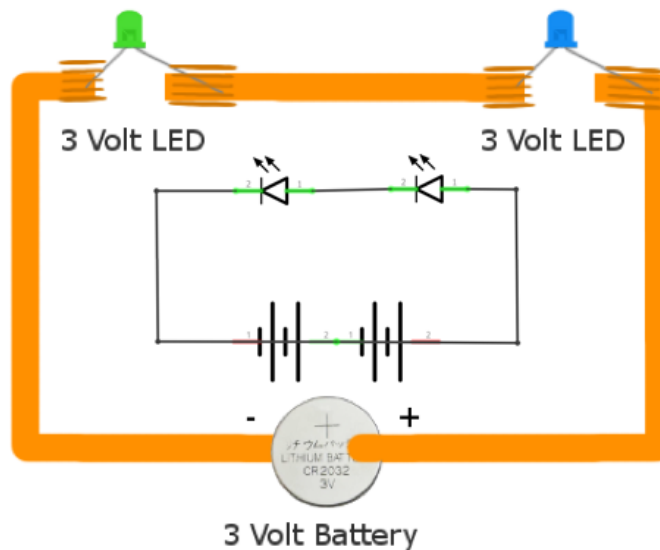
1. How many volts are needed to power the lights in this circuit?
2. How many batteries are needed?
3. Find a way to illuminate two different colored 3V lights.

Instructions:

1. Build the circuit:
 - a. Peel the paper back from the copper tape and stick the copper tape along the orange path.
 - b. Leave two small gaps at the top of the path as shown.
 - c. Connect one piece of copper tape to the positive (+) battery terminal and the other to the negative (-) battery terminal.
 - d. Place additional clear tape over the battery to better secure it to the paper.
2. Place one blue and one green light across the gaps with their long legs pointing to the right (toward the positive terminal). Secure the lights in place with copper tape.

Question: Does anything light up? Why or why not?

3. Use the circuit diagram to help you troubleshoot the problem and devise a way to illuminate both lights using the materials available to you: extra batteries and copper tape.

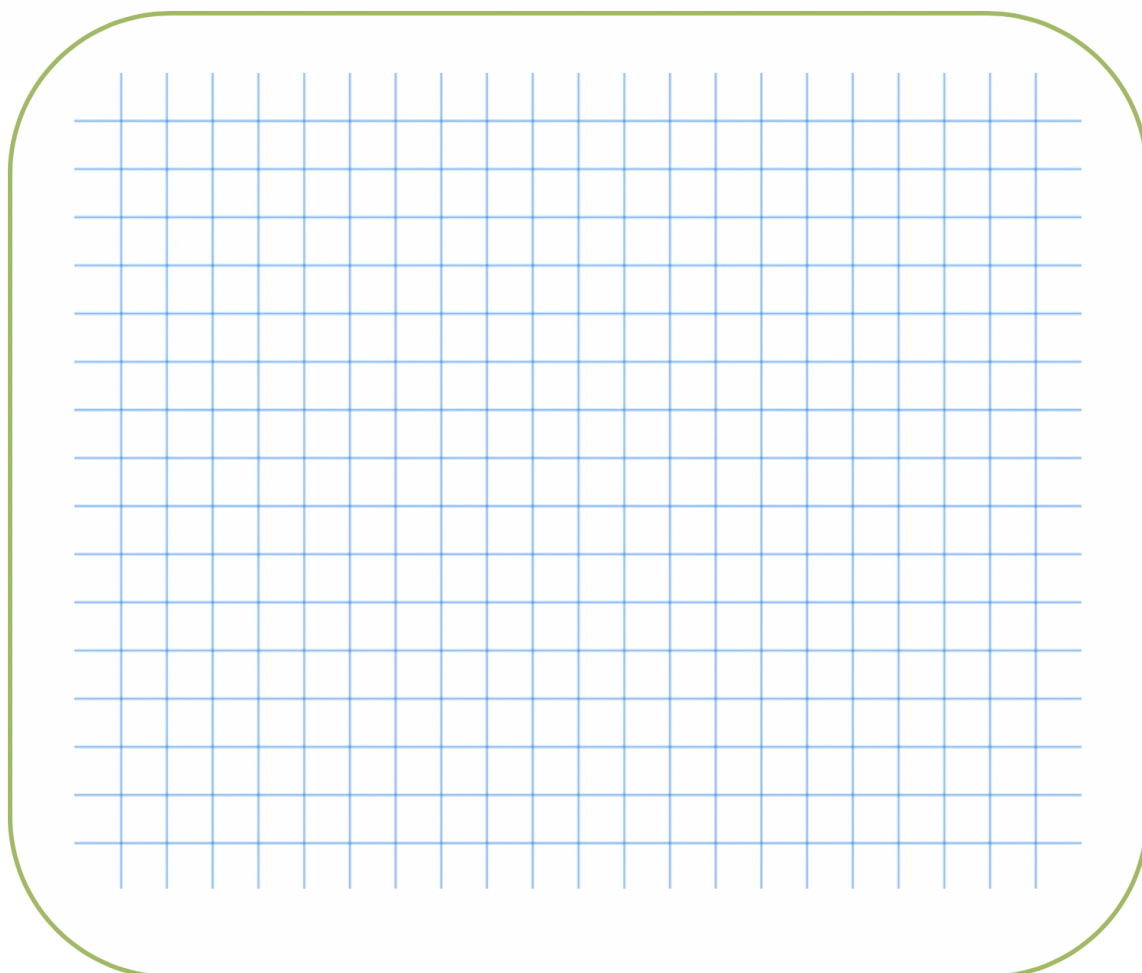


Activity – Parallel Circuits

Scientists are always challenged to conserve energy by finding creative ways to power devices with fewer resources and materials. In the previous activity, you learned that volts add up as devices are connected one after another. However, if these devices are connected in **parallel**, where each device has its own electrical path to and from the battery, the voltages do not add up. Each stays the same. Your next task is to devise a way to illuminate three colored lights using only one battery.

Instructions:

1. Together with your classmates, use the circuit diagrams from Page 18 to design a circuit that can illuminate three colored lights using only one battery. Draw this circuit in the space provided.
2. Use any combination of materials to build and test the circuit you designed in Step 1. Build the circuit over your drawing.

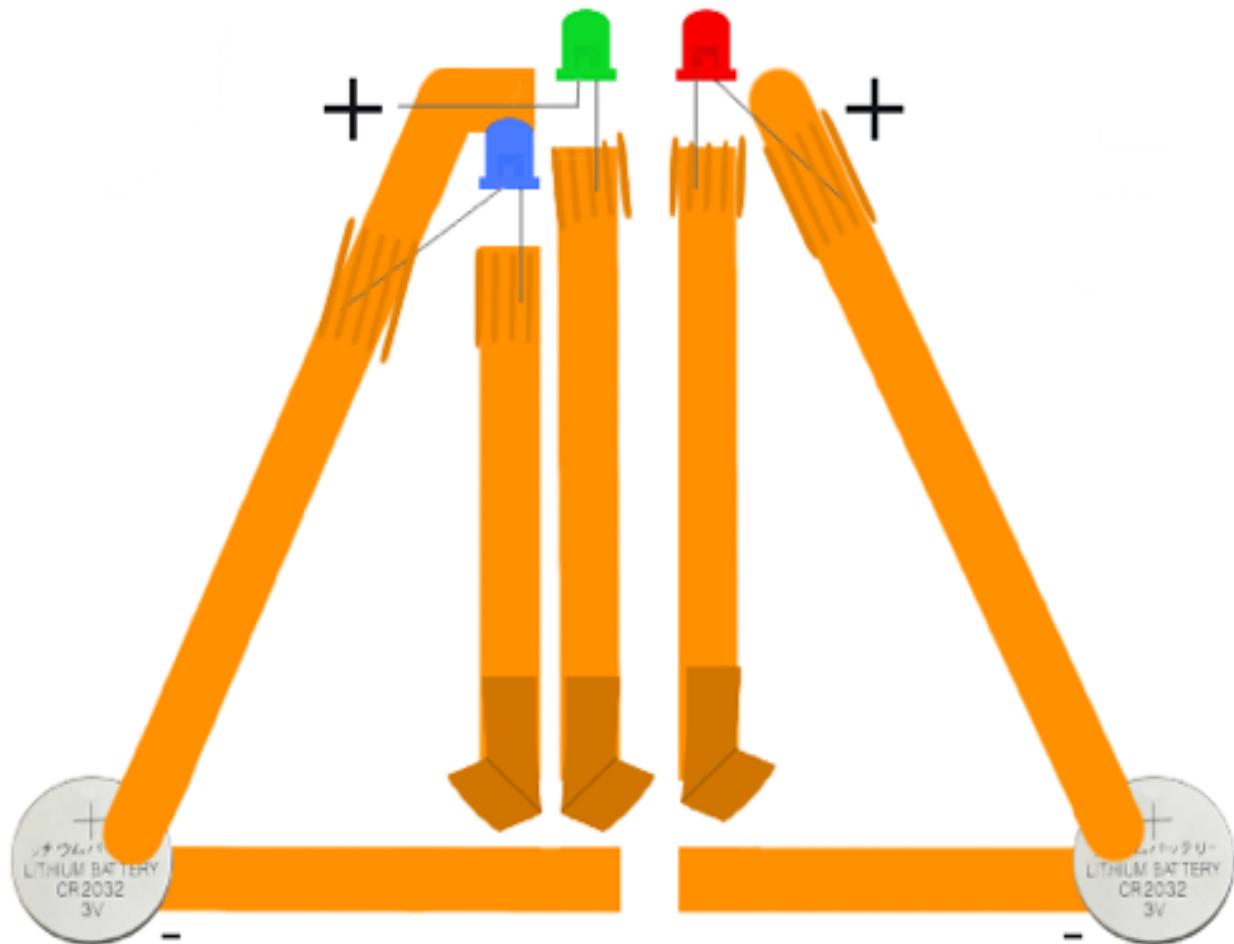


Activity – MultiColor Night Light

Congratulations, you’ve made it this far and you now understand the basics of how circuits work. Now let’s use what we’ve learned to make something useful and fun—a multicolor night light!

Instructions:

1. Build your multicolor night light circuit using the design below and what you’ve learned in class. Include **switches** to control which color light turns on and off.
2. Use a Styrofoam cup as a lamp shade and place it over the lights.
3. Experiment with the different switches to produce any color light you choose. For example: blue + red = purple; green + red = orange; red + green + blue = white
4. Bonus: Draw a circuit diagram for your night light.



ACTIVITY LEADER CHECKLIST:

DID YOU . . .

- ☐ Read Spark WiSTEM²D? This is essential reading for all volunteers interested in working with youth. It defines the STEM²D principles and philosophy and provides research-based strategies and tips for engaging and interacting with female students. Download at www.STEM2D.org.
- ☐ Visit the implementation site and observe the young people? (optional) If visiting, take note of the following:
 - ☐ How does the site encourage orderly participation? For example, do the young people raise their hands when responding to questions or during discussions? How are interruptions handled? Do you see any potential problems with managing the class of young people?
 - ☐ What does the site do to make each student feel important and at ease?
 - ☐ How is the room arranged? Will you need to move desks or chairs for any part of your presentation?
 - ☐ How can you engage the site representative in your presentation?
- ☐ Meet with and finalize the logistics with the Site Representative?
 - ☐ Confirm the date, time, and location of the activity?
 - ☐ Confirm the number of students attending? Knowing this will help you decide how to group the students into teams, as well as the appropriate materials to purchase.
- ☐ Recruit additional volunteers, if needed?
- ☐ Prepare for the activity:
 - ☐ Read the entire activity text prior to implementation?
 - ☐ Customize the activity, if desired, to reflect your background and experiences, as well as the cultural norms and language of the students in your community?
 - ☐ Complete the Tell My Story Form, which will prepare you to talk about your educational and career path with the students?
 - ☐ If teams are needed for this activity, please ask the teacher in advance to organize the students into teams.
- ☐ Practice your presentation, including the hands-on, minds-on activity? Be sure to:
 - ☐ Do the activity; make sure you can explain the concepts to students, if needed, and that you know the correct answers.
- ☐ Obtain the required materials (see the Materials and Estimated Materials Costs sections) and, if asked for in the Getting Ready section, photocopy the Student Handouts and Materials Testing Sheets. In addition:
 - ☐ Organize the materials to ensure each team has everything listed in the Materials section—keep in mind some materials are shared among the teams.
- ☐ Prepare the space? Specifically:
 - ☐ Make sure tables and chairs are arranged to accommodate teams of students.
 - ☐ Bring a camera, if desired, to take photographs.
- ☐ Obtain and collect permission slips and photo release forms for conducting the activity if applicable?
- ☐ Have fun!

Tell My Story Form

This form will help volunteers serving as activity leaders prepare to talk about their **STEM²D** interests, education, and career path.

ABOUT YOU

Name: _____

Job Title: _____

Company: _____

When/Why did you become interested in STEM²D? _____

What do you hope young people, especially females, will get out of this activity? _____

FUN FACT

Share a little about your background. Ideas:

- Share a memory from childhood where you first had your spark or interest in STEM.
- Detail your journey; highlight what you have tried, what you learned, steps to success, etc.
- Failures or set backs are also great to talk about—difficulties, and/or challenges and how you overcame them.

EDUCATION AND CAREER PATH

What classes/courses did you take in secondary school and in college that helped or interested you most?

How did you know you wanted to pursue a STEM²D career?

What was your postsecondary path, including the institution you attended and your degree? *If you switched disciplines, make sure you explain why to the students.*

What your current position entails. *Be sure to include how you use STEM²D on a typical work day.*



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