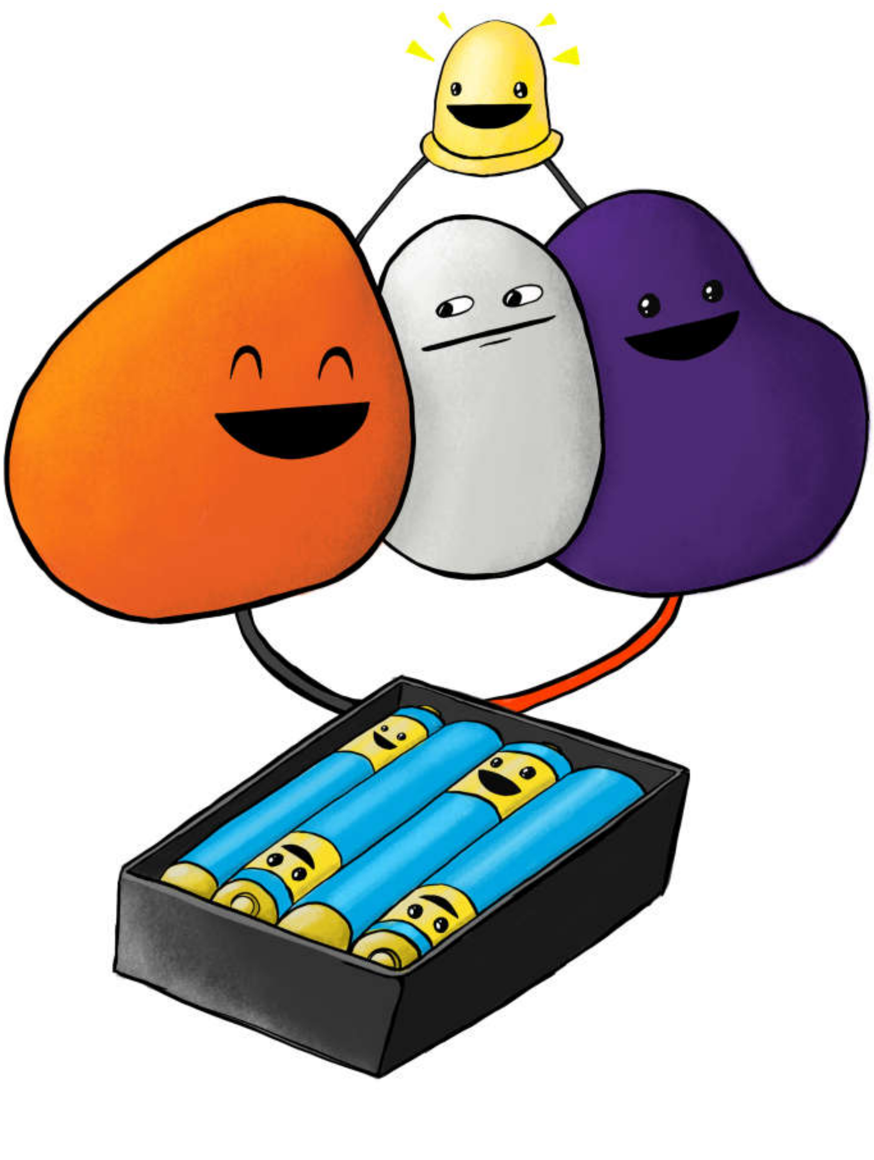
# NGSS Curricula and Educator's Guide



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**Photography: Small Batch Creative, LLC**

**Last revised June 2017**

**Comments, Questions, Concerns? Please reach out at: ContactUs@SquishyCircuits.com**

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# Introduction

## Why Squishy Circuits?

Squishy Circuits® were created in the Playful Learning Lab at the University of St. Thomas. Squishy Circuits are a design tool that allows everyone, from young children through adults, to create circuits and explore electronics using play dough. See the 2011 TED Talk, AnnMarie Thomas: Hands-on science with squishy circuits at http://squishycircuits.com/what-is-squishy-circuits/ to learn more about the creator's inspiration.


## Learning Objectives

1. Students will be able to explain how an electrical circuit works.
2. Students will explore the difference between conductive and insulating materials.
3. Students will design and build a circuit to accomplish a desired outcome.
4. Students will be able to identify various electrical circuit components and explain their function.

## Alignment to Next Generation Science Standards

***Standards:***

| Grade | Standard | Applicable Sub Strands | Related DCI (Disciplinary Core Idea) |
|---|---|---|---|
| 4 | 4-PS3 Energy | 4-PS3-4<br>4-PS3-2 | PS3.B<br>PS3.D |
| 3-5 | 3-5-ETS1 Engineering Design | 3-5-ETS1-1<br>3-5-ETS1-2<br>3-5-ETS1-3 | ETS1.A<br>ETS1.B<br>ETS1.C |

***Disciplinary Core Ideas:***

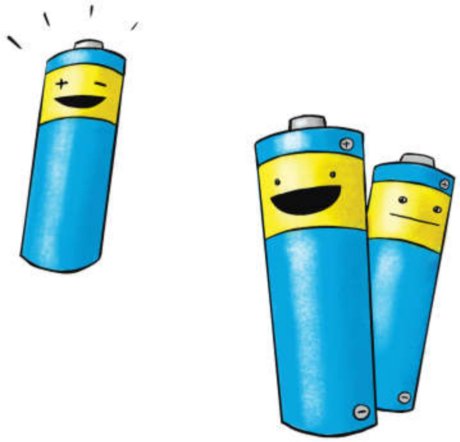
| DCI | Specific DCI | Grade Levels Applied | Related Standards |
|---|---|---|---|
| PS3 | PS3.B | 4,5 | 4-PS3-2,4 (Energy) |
| PS3 | PS3.D | 4,5 | 4-PS3-2,4 (Energy) |
| ETS | ETS1.A | 3-5 | 3-5-ETS1-1 (Engineering Design) |
| ETS | ETS1.B | 3-5 | 3-5-ETS1-2,3 (Engineering Design) |
| ETS | ETS1.C | 3-5 | 3-5-ETS1-3 (Engineering Design) |

***Crosscutting Concepts***

- ☑ **- Patterns**
- ☑ **- Cause and effect: Mechanism and explanation**
- ☑ **- Scale, proportion and quantity**
- ☑ **- Systems and system models**
- ☑ **- Energy and matter: Flows, cycles, and conservation**
- ☐ - Structure and function
- ☐ - Stability and change

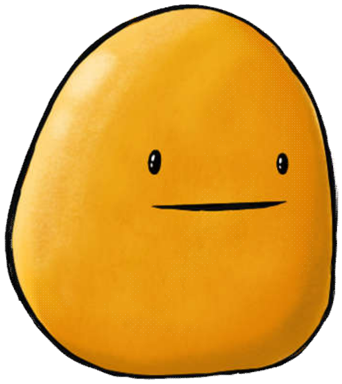
***Science and Engineering Practices***

- ☑ **- Asking questions and defining problems**
- ☑ **- Developing and using models**
- ☑ **- Planning and carrying out investigations**
- ☑ **- Analyzing and interpreting data**
- ☑ **- Using mathematics and computational thinking**
- ☑ **- Constructing explanations and design solutions**
- ☑ **- Engaging in argument from evidence**
- ☑ **- Obtaining, evaluating and communicating information**



## Educator Preparation Material

**Supplies needed for each student or group of students:**



- 4-AA Battery pack with leads
- Conductive dough
- Insulating dough
- 3+ LEDs

Optional, but recommended:

- Buzzer
- Motor
- Switch

These materials are all available on our web store at http://squishycircuits.com/store. We offer both kits and individual components.

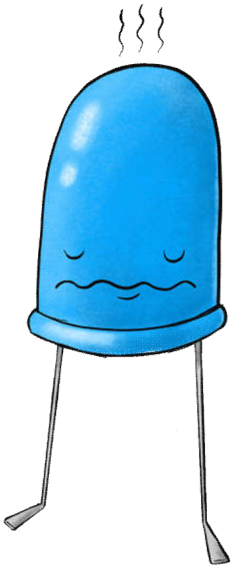
Squishy Circuits was created to be as accessible as possible. Therefore many readily-available, low current components will work. If you are using your own, be sure to add terminals to increase the surface area (we also recommend using aluminum terminals because it resists corrosion the best) and ensure the component operates at 6 volts with 30 or less milliamps of current.

## Safety

In general, Squishy Circuits is a very safe activity. However, some safety notes should be addressed:

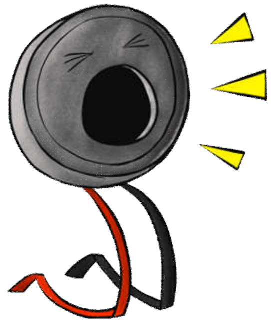
- The battery packs should never be shorted out (letting the wire/terminals touch each other directly). Our battery holders have safety features that prevent overheating, but with other battery holders they will quickly warm up and could cause burns if shorted. When doing any electrical project, batteries should never be shorted directly.

- LEDs should not be hooked directly to the battery packs. They will burn out and may pop. LEDs require a resistor to limit the amount of power flowing through them. With Squishy Circuits, the conductive dough acts as the wire and a resistor, so they're safe to use with the dough.



# Background Knowledge

## Vocabulary

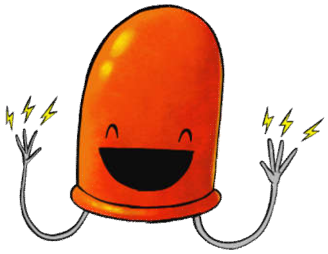


**Buzzers** - Buzzers can be added to your Squishy Circuits by matching the red lead from the buzzer to the red lead of the battery pack and the black lead from the buzzer to the black lead of the battery pack. If desired, place a piece of tap over the top of the buzzer to reduce the volume. There are two types – mechanical and piezo. Mechanical buzzers have a plastic reed that vibrates to produce a buzz. Piezoelectric buzzers vibrate a crystal and produce a higher-pitched buzz.

**Circuit** - Electricity flows in a loop called a circuit. A circuit starts and stops at the battery pack and flows through wires, conductive dough, and electrical components such as LEDs and motors. An **open circuit** is an incomplete circuit. A **closed circuit** is a completed one.

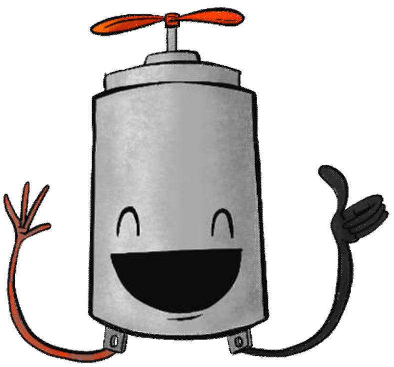
**Conductor** - Conductors are materials that allow electricity to flow through them. Most metals are good conductors. Squishy Circuits uses the colored conductive doughs are used. Users can make their own, purchase through our online store, or use most play doughs.

**Insulator** - Insulators are materials that do not allow electricity to flow through them. Air, plastic, rubber, and glass are good examples of insulators. In Squishy Circuits, the white insulating dough is used. Users can make their own, purchase through our online store, or use most modeling clays.



**LEDs (Light Emitting Diodes)** – LEDs produce light from electrical power. To work, the LED has to be oriented properly (this is called **polarity**). Usually, the two leads are different lengths. The longer lead goes to the positive (red) side of the battery pack. The short lead goes to the negative (black) side of the battery pack.

**Motors** - Motors can be used to bring motion to your Squishy Circuit creations. The motor has two leads, like the LED, but orientation, or polarity, is not necessary. However, the polarity does change the direction the motor spins.



**Parallel Circuits** - A parallel circuit allows multiple paths for electricity to flow through. LEDs or other electrical items are connected to the dough each in their own loop or circuit. Since electricity flows through each LED independently, if one is removed or burns out, the others will continue to shine brightly.

**Schematic** – A schematic is a way to draw electrical circuits on paper easily. Each component has a specialized symbol that is connected by lines (which represent wires) that complete the circuit.

**Series Circuits** - A series circuit only allows one path for the electricity to flow through. LEDs can be added however they will get dimmer because there is less electricity available to power them. If one of the LEDs is taken out, the entire circuit is broken and all of the lights will go out.

**Short Circuit** - Electricity is like water; it takes the path of least resistance. It is easier for the electricity to flow through the conductive dough than through the LED (or other component), so if there is a path where the electricity can skip the LED and instead run through play dough the entire way, the majority of the current will do that. When this happens, the LED will stay unlit. This is called a short circuit.

## Essential Questions

1. How can we create an electrical circuit using play dough?
2. What does it mean for a material to be conductive? Insulating?
3. When would it be beneficial to use a series vs. parallel circuit and vice versa?
4. How can we use schematics to show electrical circuits?

## Pre-/Post- Lesson Assessment

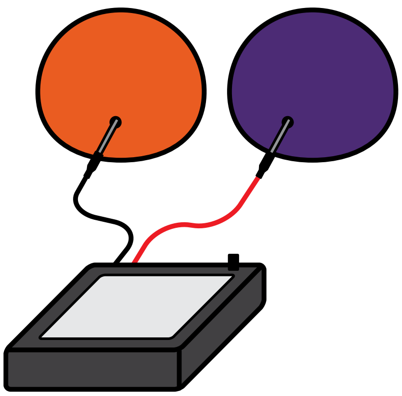
1. What is electricity?
2. What is a conductor?
3. What is an insulator?
4. Draw an electrical circuit with the following components: battery, wire, and Light Emitting Diode (LED)
5. What is a closed circuit?
6. What is an open circuit?
7. How can you tell that energy is moving (transferred) from the battery pack and through the play dough? **(PS3.B, 4-PS3-2, 4-PS3-4)**
8. When is there energy present in the circuit? **(PS3.B, 4-PS3-4)**
    a. How could you prove this?
9. What components (parts) are needed to make a circuit work? **(3-5-ETS1-1)**
10. What configurations of insulating and conductive dough work to construct a functioning circuit? **(3-5-ETS1-3, 3-5-ETS1-2)**

# Lesson 1: Sculpting Your First Circuit

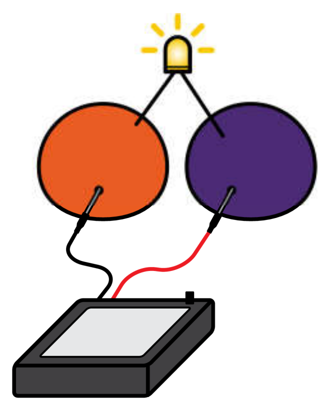
## Summary and Background Knowledge

In this lesson, students will create a functioning electrical circuit using a battery pack, LEDs, and conductive and insulating play dough. By completing student-led experiments, groups of two to three students will work together to attempt to light their LED up using the materials listed above.

At the most basic level, electricity is a stream of small bits of electrical charge, called electrons. These electrons flow through components and cause them to do work. For example, when they flow through a light bulb, they produce light. These electrons move through conductors. When building a Squishy Circuit, the play dough replaces the wires typically used in the circuit, making them more user-friendly and familiar to students.

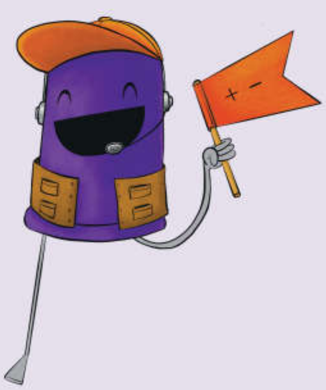


Let's investigate a simple circuit using Squishy Circuits. With the conductive dough, create two pieces of dough (they can be any size or shape). Insert one wire from each side of the battery terminal into each piece of dough.



Now, create a bridge across the two pieces of dough with an LED (separate the legs if necessary) so that the electrons can flow through the LED to the other side and back to the battery pack. Way to go! You have created your first Squishy Circuit!

The LED is lighting because the electrons are flowing from the battery pack, through the wire and into one piece of conductive dough, through the LED into the other piece of conductive dough, and finally back to the battery pack. It can be helpful to visualize the circuit as a circle of electrons. Since the electrons can flow in the circuit, it's called a closed circuit.

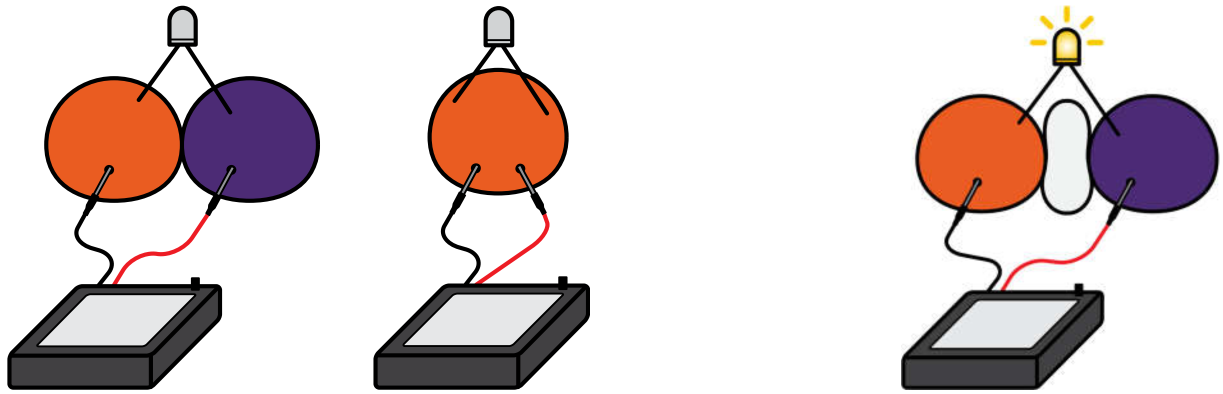


**Reminder –**

LEDs have polarity, which means they only operate if inserted correctly in the right direction. The longer leg should go into the dough with the red wire. You can just try switching the LED around if it's not working.

An open circuit means that there is not a path for the electrons to flow. Try taking out one leg of the LED and you'll notice that it turns off. This is because there is no conductor for the electrons to flow through to complete the circuit.

First time Squishy Circuit users often create short circuits when exploring. These are circuits in which the electrons can simply bypass the LED and go through the conductive dough to close the circuit. Since no electrons are flowing through the LED, it stays unlit. They can be fixed by separating the two pieces with air or the white insulating dough.



Now try getting more creative with your circuits and replacing the LED with a motor or buzzer. Does polarity matter with them also?

## Applicable Vocabulary:

- Closed Circuit
- Open Circuit
- Short Circuit
- Polarity
- Insulating material
- Conductive material

## Main Objective:

Upon completion of this activity, students will be able to construct a working ( input results in a desired output) closed circuit using the materials provided with a Squishy Circuit kit. Students will be able to demonstrate an understanding of a closed vs. open circuit as well as conductive and insulating materials by completing a variety of student-led, inquiry-based experiments. They will also be able to describe the basic flow of electricity and why there circuits are working.

## Materials:

- Insulating dough (roughly ¼ cup per pair of students)
- Conductive dough (roughly 2 cups per pair of students)
- 1 battery pack with four (4) AA batteries
- At least two light emitting diodes
- Optional: motors, fans, buzzers, and switches
- Student science journal or provided handout

## Time:

- Pair students and hand out materials: 5 minutes
- Discovery time (Steps 2-3): 10 minutes
- Sharing: 5 minutes
- Redesign, retest: 10 minutes
- Data recording: 5 minutes

**Total Time:** 35 minutes

## Instructor Procedure:

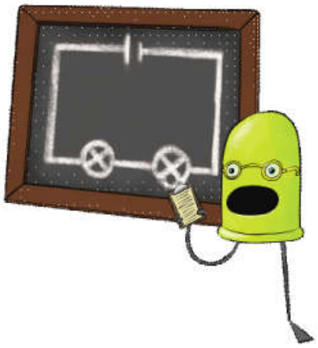
1. After students have been divided into pairs or trios, provide each student with the materials listed above
2. Provide students with the following directions:
    a. *With your partner, discuss different ways you think you could make the LED light up. (Use this time to investigate your materials, but don't hook anything up yet)*
    b. *Draw in your science journal how you will attempt to solve the challenge: "Make your LED light up using only the materials in front of you."*
    c. *Using the materials, work with your partner as a team to create working circuit.*
3. Spend time wandering the classroom to identify student misunderstandings, comprehension, and answer questions as well as ask questions. *Provide guidance as you see fit.*
4. When students have completed the challenge, ask pairs to share with neighboring groups. Allow students one minute to do this.
5. Bring the class together. Invite a few groups to share.
6. Provide students with another challenge: "*Using what you learned from the first challenge as well as hearing from your classmates, design a new way(s) to make your LED's light up."* Encourage students to plan and document in their journals or handout as a way of emphasizing the engineering design process.
   Optional: Allow groups to join together.

# Lesson 2: Series and Parallel Circuits

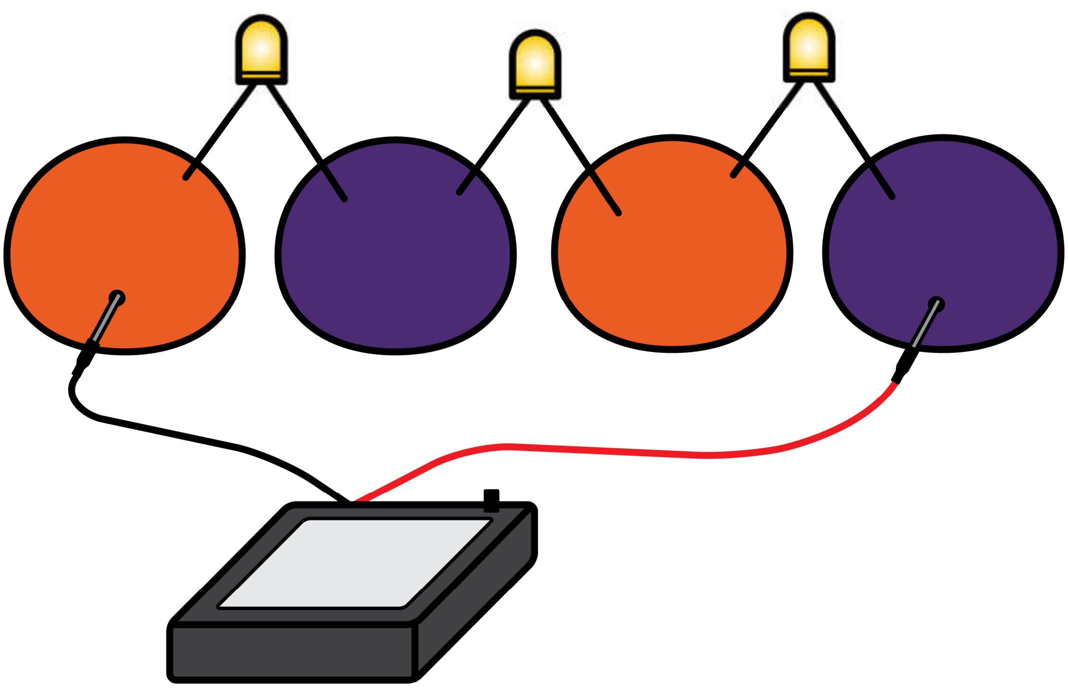
## Summary and Background Knowledge:

In this lesson, students will build on their existing knowledge regarding circuits by experimenting with Squishy Circuit materials to discover the differences between parallel and series circuits. The circuits students created in Lesson 1 were simple circuits, meaning that they comprised of a power source, a single energy output (LED or motor), and an optional switch.

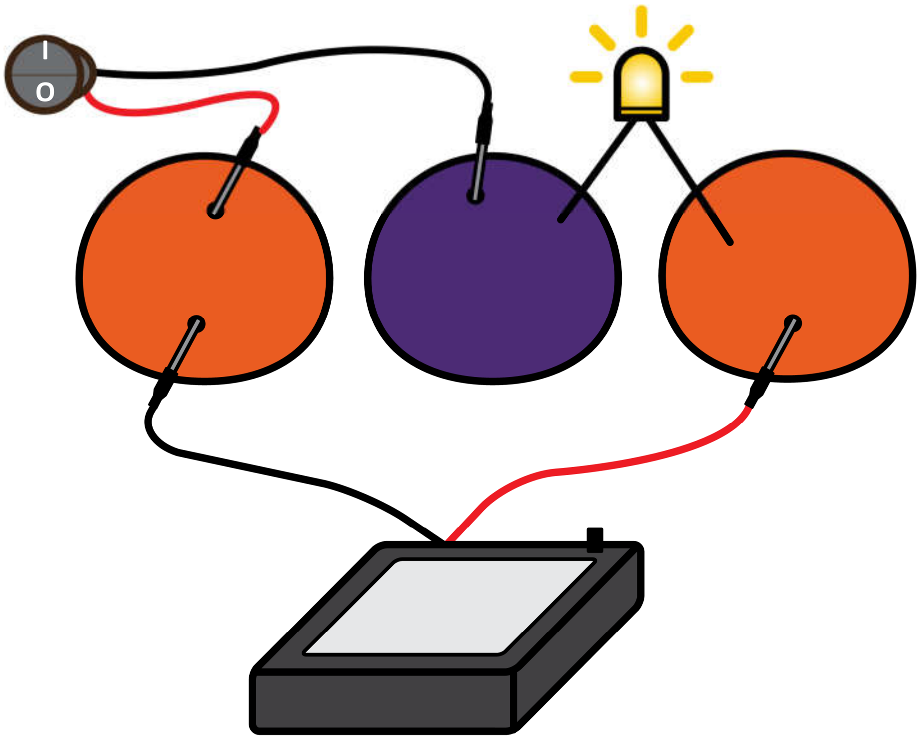
Series and parallel circuits are more intensive, and contain more than one output. If a circuit is connected in series, the electrical charge passes through each output (use LEDs of the same color) in a consecutive order.



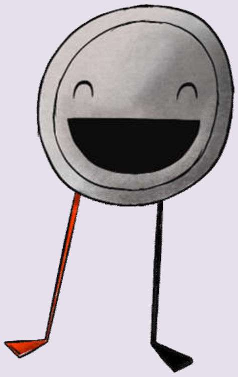
The circuit created in lesson was a **series circuit**. If one output is removed in the circuit, all future outputs will no longer turn on. This is because the circuit is no longer complete, and the electrical charge cannot reach those other LEDs. Users will notice that the LEDs are also dimmer. This is because the 6 volts from the batteries must be shared by all the LEDs. Each LED requires ~2.5v to turn on, so if you have three LED lights connected in **series,** they require more voltage than the batteries can provide and likely won't turn on at all!



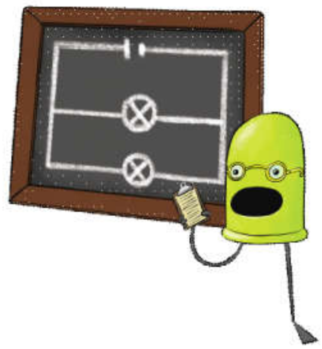
A more useable example of a series circuit is to use the switch. If you put the switch in series with the LED, then the circuit will either be open or closed depending on the switch!



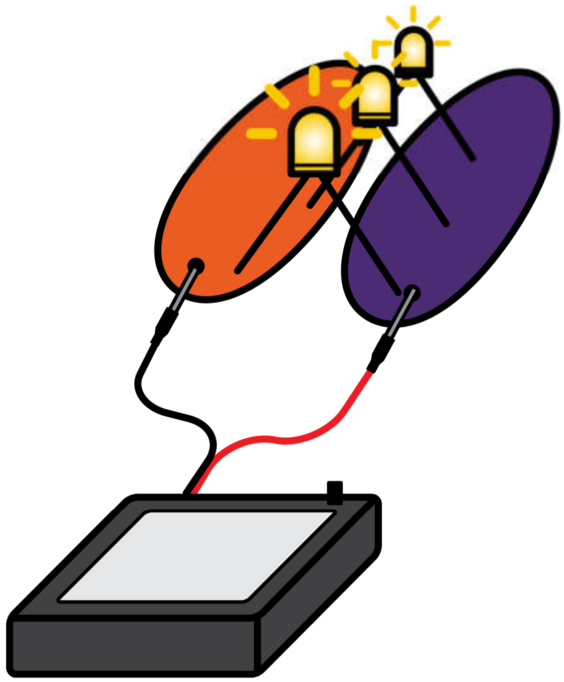

**Did You Know? –**
Many switches use ‘I’ and ‘O’ to indicate on and off. It is believed that these symbols originate from binary which uses 0 to represent off and 1 to represent on. Binary is a way to denote numbers with only 0 and 1s and is used for coding, data storage, and more.



If a circuit is organized in **parallel,** each output (LED etc.) is independent of the others. If one output is disconnected, all others will still function.



This is because they are connected on their own circuit and they all operate independently from each other.

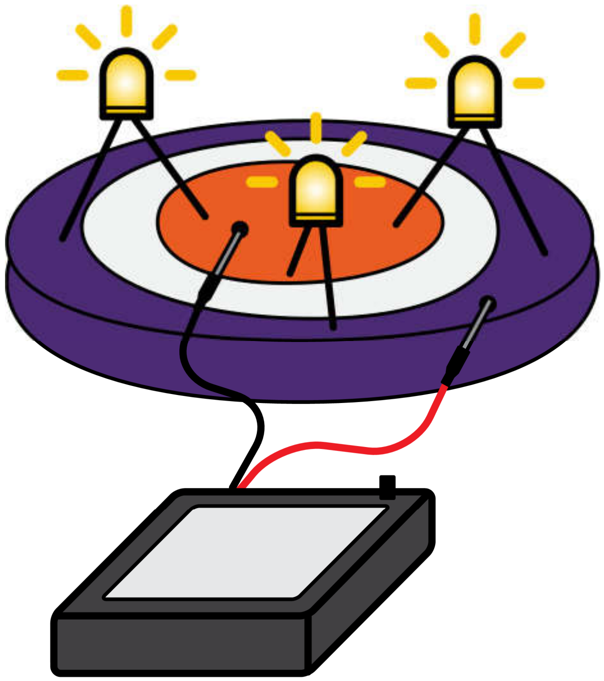


Try and think of different real-world applications for series and parallel circuits.

If you have many lights in a room, typically they are connected in **series** with the switch – that way one switch can control all of the lights at once.

Christmas lights are a good example of **parallel** circuits because if one bulb burns out, the rest continue to glow. Older sets of these lights actually were in series so if one burnt out, you had to try every single bulb to find the bad one and replace it to make the rest turn on!

Remember, the shape of the dough does not matter. This is another example of a parallel circuit with the two pieces of conductive dough separated with a layer of insulating dough.



## Applicable Vocabulary:

- Series circuit
- Parallel circuit

## Main Objective:

Upon completion of this lesson, students will be able to explain using models and verbal and/or written language the difference between series and parallel circuits, and demonstrate examples of a use for each.

## Materials:

- Insulating dough (roughly ¼ cup per pair of students)
- Conductive dough (roughly 2 cups per pair of students)
- 1 battery pack with four (4) AA batteries
- At least three light emitting diodes
- Optional: motors, switches,  fans, and buzzers
- Student science journal or provided handout

## Time:

- Pair students and hand out materials: 5 minutes
- Discovery time (Steps 2-3): 5 minutes
- Sharing: 5 minutes
- Instruction: 5 minutes
- Redesign, retest: 10 minutes
- Data recording: 5 minutes

**Total Time:** 35 minutes

## Instructor Procedure:

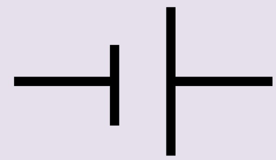
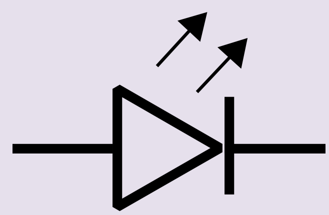
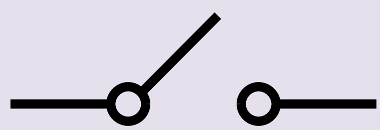
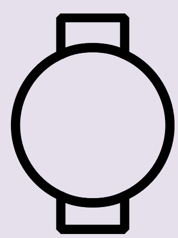
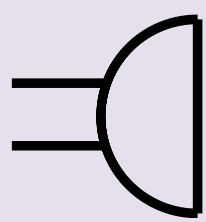
1. After students have been divided into pairs or trios, provide each student with the materials listed above
2. Provide students with the following directions:
    a. *With your partner, discuss different ways you think you could make the two LEDs to light up. (Use this time to investigate your materials, but don't hook anything up yet)*
    b. *Draw in your science journal how you will attempt to solve the challenge: "Make two LEDs light up using only the materials in front of you."*
    c. *Using the materials, work with your partner as a team to create working circuit.*
3. Spend time wandering the classroom to identify student misunderstandings, comprehension, and answer questions as well as ask questions. *Provide guidance as you see fit.*
4. When students have completed the challenge, ask pairs to share with neighboring groups. Allow students one minute to do this.
5. Bring the class together. Invite a few groups to share what they now know, and what they wonder about as a result of the activity.
6. Instruct class on two different types of series and parallel circuits' configurations. Brainstorm benefits of each together.
7. Provide students with another challenge: "*Can you design both series and parallel circuits? What are other examples of them in your life?"* Encourage students to plan and document in their journals or handout as a way of emphasizing the engineering design process.
    a. Optional: Allow groups to join together.

# Lesson 3: Challenge Time!

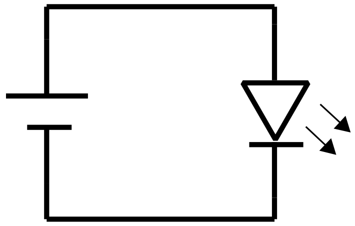
## Summary and Background Knowledge:

In this lesson, students will use their previously gained knowledge to construct more advanced circuits that utilize both series and parallel circuits. Then, they will transfer their circuits to paper using schematics.

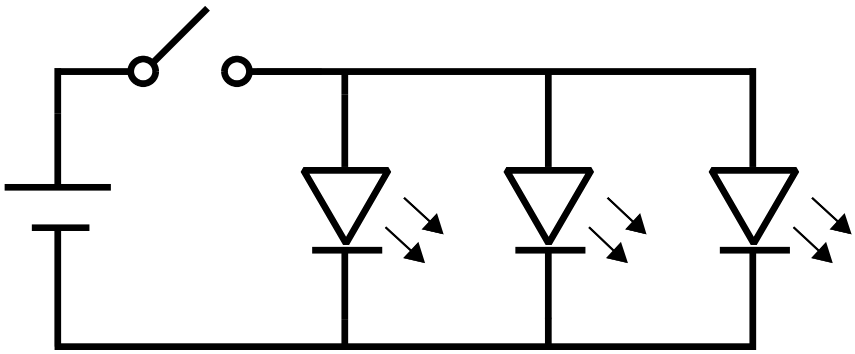
**Schematics** are a way to easily draw electrical circuits so that they can be analyzed, rebuilt, and shared. Every component has its own symbol, and they are joined together by lines (which represent wires, or with Squishy Circuits, play dough!)

| | |
|---|---|
| **Battery Pack** |  |
| **LED** |  |
| **Switch** |  |
| **Motor** |  |
| **Buzzer** |  |

When we built the simple circuit in Lesson 1 with a battery pack and LED, the schematic looked like this:

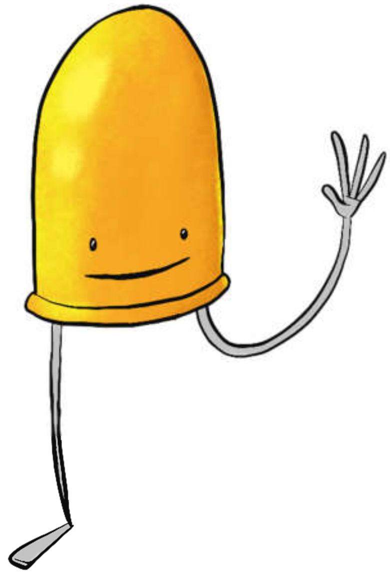


Challenge students to build a circuit that uses both a series and parallel circuit. This circuit has a switch in series with three different LEDs in parallel. If the switch is turned off, it breaks the circuit and all three lights turn off. But, if one of the LEDs is removed, the others will continue to shine brightly because there are separate paths for the electrons to take to complete the circuit.

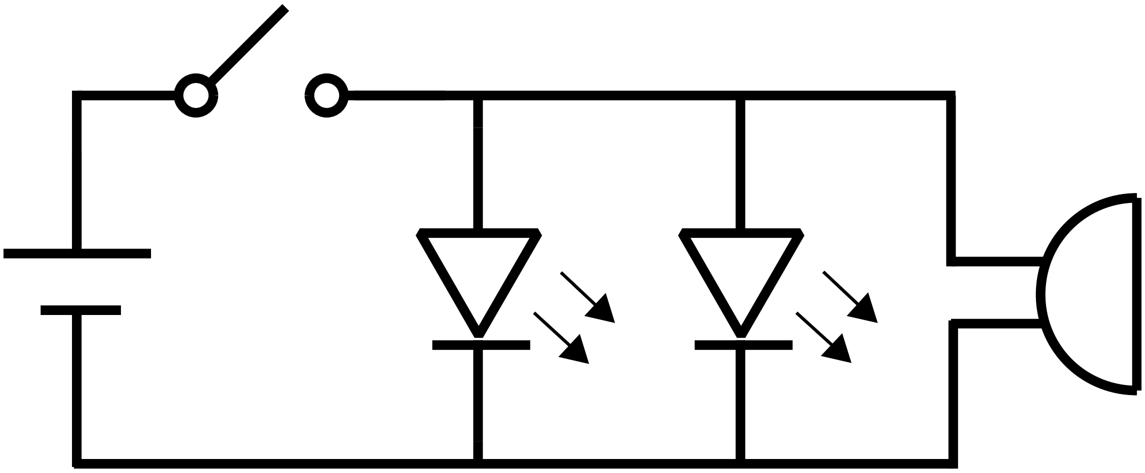


Often, it can be fun to think of a scene that the entire class can build and have each student or group build an object from that scene. For example, you could create a neighborhood – so groups could create a car, house, light pole, etc.

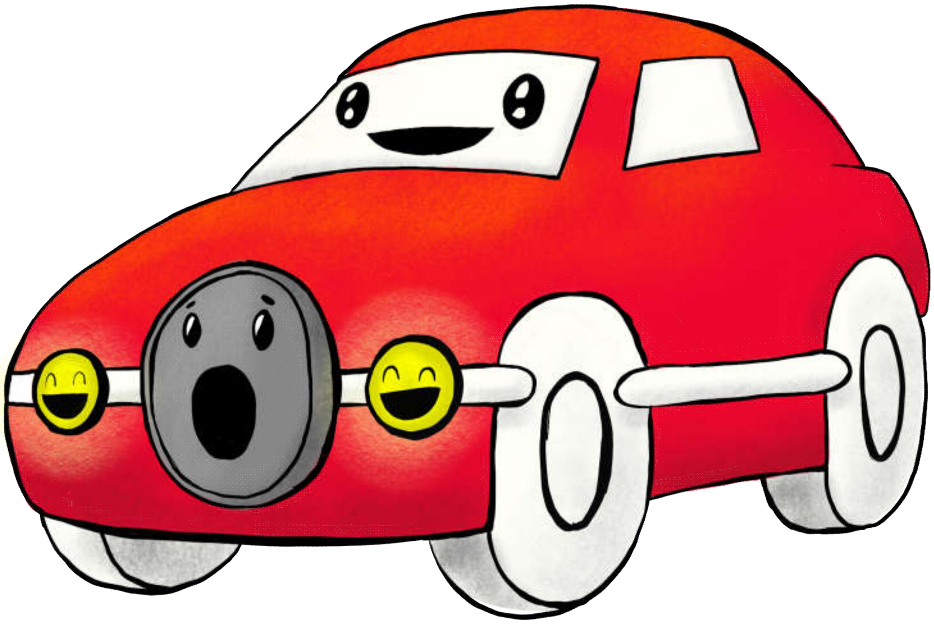
As you get more creative with your Squishy Circuits, it's important to remember to avoid short circuits!



What if you made a car with two LED headlights in parallel, and a horn buzzer – all controlled by the switch? Its schematic could look like this:



And could be made to look like this:



Remember, the schematic only illustrates what electrical components are used in the circuit, and in what configuration. It does not indicate the shape or distance between them and the dough (or wires) used.

## Applicable Vocabulary:

- Schematic

## Main Objective:

Upon completion of this lesson, students will be able to

1. Combine a series and a parallel circuit using a single battery pack
2. Create a schematic using component symbols that represent their circuits.

## Materials:

- Insulating dough (roughly 1 cup per pair of students)
- Conductive dough (roughly 2 cups per pair of students)
- 1 battery pack with four (4) AA batteries
- At least three light emitting diodes
- Optional: motors, switches, fans, and buzzers
- Student science journal or provided handout

## Time:

- Pair students and hand out materials: 5 minutes
- Instruction: 10 minutes
- Design: 15 minutes
- Data recording: 5 minutes

**Total Time:** 35 minutes

## Instructor Procedure:

1. After students have been divided into pairs or trios, provide each student with the materials listed above
2. Encourage students to participate in a class-wide conversation:
    a. *How could you write down your circuit to share with a classmate who hasn't seen it before?*
    b. *What if we used symbols for each component?*
    c. Explain each schematic symbol by drawing on the board.
3. Challenge students to create a circuit that uses a series and parallel circuit
4. Spend time wandering the classroom to identify student misunderstandings, comprehension, and answer questions as well as ask questions. *Provide guidance as you see fit.*
5. Bring the class together. Invite a few groups to share.
6. Instruct class to create a scene where each student is given an object to create. The objects can be assigned or open-ended. Challenge students to use multiple components arranged in both series and parallel. Have them capture the schematic in their journals.
7. Share with the class!

# Squishy Circuits Dough Recipes

Dough can be purchased from our online store or most purchased doughs work as conductive doughs and most modeling clays work as insulating dough. Or, recipes are below that use common household ingredients!

## Conductive Dough

Ingredients:

- 1½ Cup (355 mL) Flour
- 1 Cup (237 mL) Water
- ¼ Cup (59 mL) Salt
- 3 Tbsp. (44 mL) Cream of Tartar*
- 1 Tbsp. (15 mL) Vegetable Oil
- Optional: food coloring
  *9 Tbsp. (133 mL) of Lemon Juice may be substituted

**Step 1:**
Mix water, 1 cup of flour, salt, cream of tartar, vegetable oil and food coloring (if using) in a medium-sized saucepan.

A non-stick pan works best.

**Step 2:**
Cook over medium heat, stirring continuously. The mixture will thicken, and lumps will begin to form.

**Step 3:**
Continue heating and stirring until the mixture forms a ball and pulls away cleanly from the sides of the saucepan.

**Step 4:**
Turn the dough out onto a floured surface. Use caution, as it is very hot at this point.

**Step 5:**
Allow the dough to cool for a few minutes before kneading flour into it until the desired consistency is reached.

**Storage:**
Keep the dough in a sealed container or bag for several weeks. For longer periods, the dough can also be frozen.

While in storage, water from the dough may create condensation inside the container; this is normal. Knead the dough after removing it from the storage container to refresh its pliability.

## Insulating Dough

Ingredients

- 1½ Cup (355 mL) Flour
- ½ Cup (118 mL) Sugar
- 3 Tbsp. (44mL) Vegetable Oil
- ½ Cup (118 mL) Deionized Water
  (Note: distilled or regular tap water can be used, but the resistance of the dough will be lower)

**Step 1:**
Set aside ½ cup flour to be used later. Mix remaining flour, sugar, and oil in a pot or large bowl.

**Step 2:**
Mix in a small amount (about 1 Tbsp.) of deionized water, stirring until the water is absorbed.

Repeat this step until large, sandy lumps begin to form.

**Step 3:**
Turn the dough out onto a sheet tray or a floured countertop, gathering it into a single lump.

**Step 4:**
Add small increments of flour or water to yield a dough-like, pliable consistency.

**Storage:**
Keep the dough in a sealed container or bag for up to a week. For longer periods, the dough can be frozen.

While in storage, the oil may separate and the dough may lose its dough-like consistency. Simply add additional flour to remove the stickiness before using again.