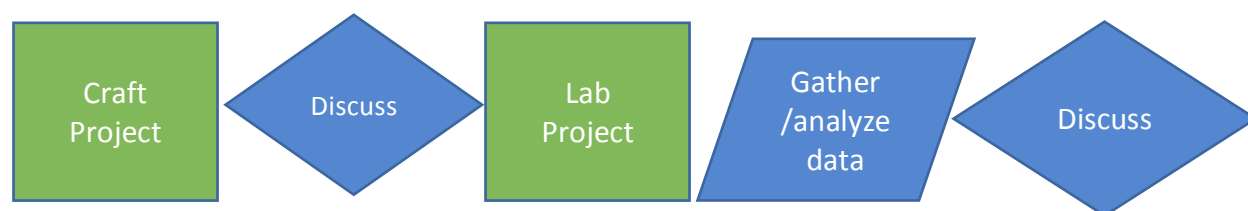


# Exploring Electronics through Making

This document describes a series of progressive lesson plans that teach core engineering and electronics concepts through student direct exploration and making.

The document is intended to be used as a framework to be modified by the instructor to match the pace, experience and maturity of the target students. The concepts covered map to many NGSS Engineering standards for students as young as 4<sup>th</sup> grade but also cover concepts taught in AP Physics.

The proposed curriculum sequence of each module is built on two projects as follows:



- Project 1: Craft Project – Open ended craft project to allow students to discover the core concepts through making
- Review and discuss core concepts
- Project 2: Lab Project – More structured project focused on scientific process and data gathering.
- Review data and discuss core concepts

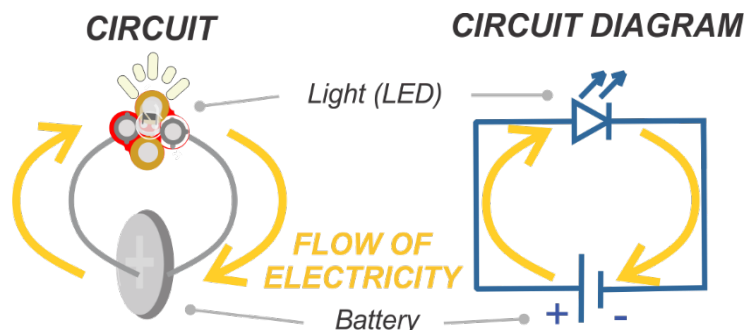
Each Module builds upon the previous module while reinforcing the original core concepts.

There are three major modules within that sequence:

1. Electricity Basics.
2. Resistance and conductivity
3. Measuring Change

# MODULE 1 – Electricity and Circuits

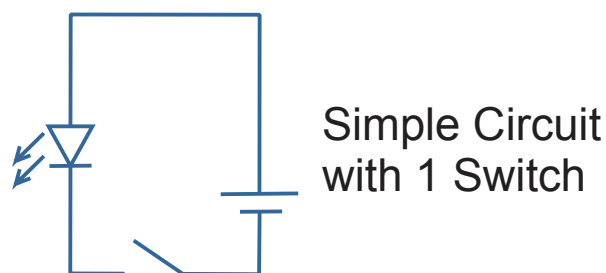
What is a circuit? A circuit is a closed path through which electric current flows.



The simplest circuit we can work with is a battery connected to a light. The light turns on when electricity flows from the battery, through the light and back to the battery. A common way of drawing circuits is called a circuit diagram. In a circuit diagram, a battery is shown as two parallel lines and an LED as a triangle and line with arrows representing the light.

In the above circuit, the light is always on until the battery runs out of energy. When we add a switch to the circuit, we can control when the light is on or off. In a circuit diagram, a switch is drawn as a door

Lectrify battery packs come with an on/off switch.



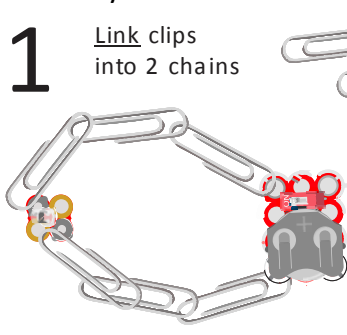
## Key Concepts:

- **LED** – LED stands for Light Emitting Diode and is a semiconductor diode that emits light when a current is applied to it. LEDs convert electricity directly into light through a process called **electroluminescence** which makes them much more energy efficient than incandescent bulbs which lose energy to heat.
- **Direction** - LEDs are diodes and conduct electricity in only one direction (forward) while blocking electricity in the other direction (reverse). This direction is indicated by the direction of the triangle in the circuit diagram and is from positive to negative. On Lectrify LEDs, the positive side is marked in **red** and the negative side is marked in **white**.
- **Conventional current/flow vs. electron flow** – When electricity was first discovered, it was believed that the electrical current flowed from positive to negative and this became the convention for circuit diagrams and is often described as **conventional flow** or **conventional current**. However, it is now known that electrons flow from negative to positive and that is described as **electron flow**. Many norms (like the direction of the Diode arrow) were designed using conventional flow.

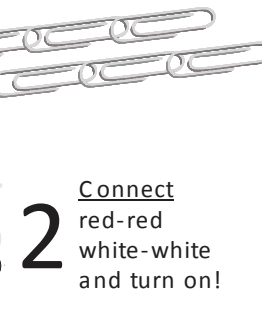
## Project 1: Circuit Crafts.

Now we are ready to build our first circuit. We recommend doing so using simple paper clips a, a battery and an LED.

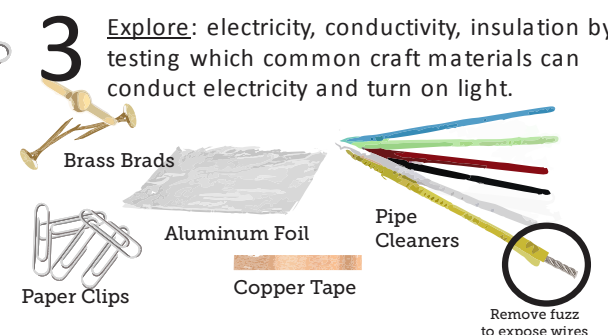
**1** Link clips into 2 chains

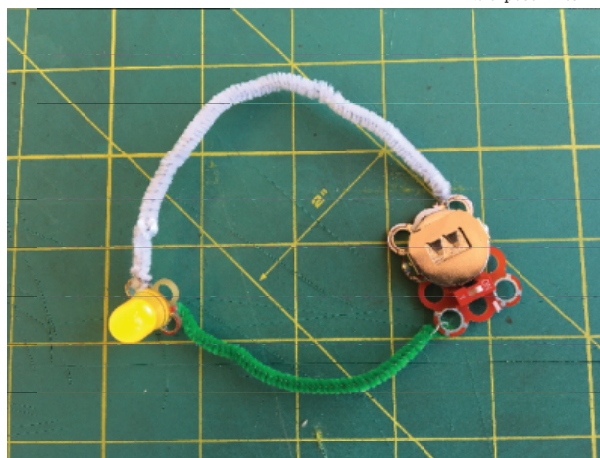
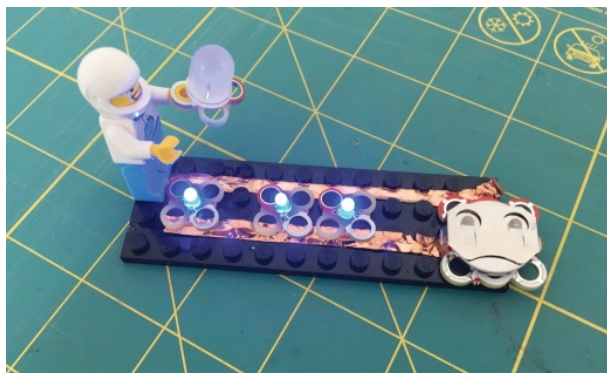


**2** Connect red-red white-white and turn on!



**3** Explore: electricity, conductivity, insulation by testing which common craft materials can conduct electricity and turn on light.





Once students have had an opportunity to explore through circuit crafts, now would be a good opportunity to engage them in a discussion about what they learned about conductivity and resistance.

### Teachable Moments/Vocabulary:

Conductive materials allow the flow of electricity. **Conductors** are usually made out of metal such as paper clips, copper tape, and aluminum foil. Have students explore to find other conductive materials to build their projects with. Discuss why pipe cleaners are conductive.

**Resistance** is the measure of how difficult it is for electrical current to flow through a material. Higher resistance means less current will flow through a circuit, and low resistance means more current will flow.

**Engineering Design** is the process of coming up with a solution to a problem. The steps include brainstorming, prototyping and testing your ideas. Students engage in this as they create their projects.

For additional information, visit our website [www.lectrify.it/educators](http://www.lectrify.it/educators)

## Project 2: Conductivity Probe Lab

The second project reinforces the lessons from the circuit crafts through the creation of a simple sensor: a conductivity probe. This conductivity probe can be made with plastic straws and copper tape.

### Make a Conductivity Probe

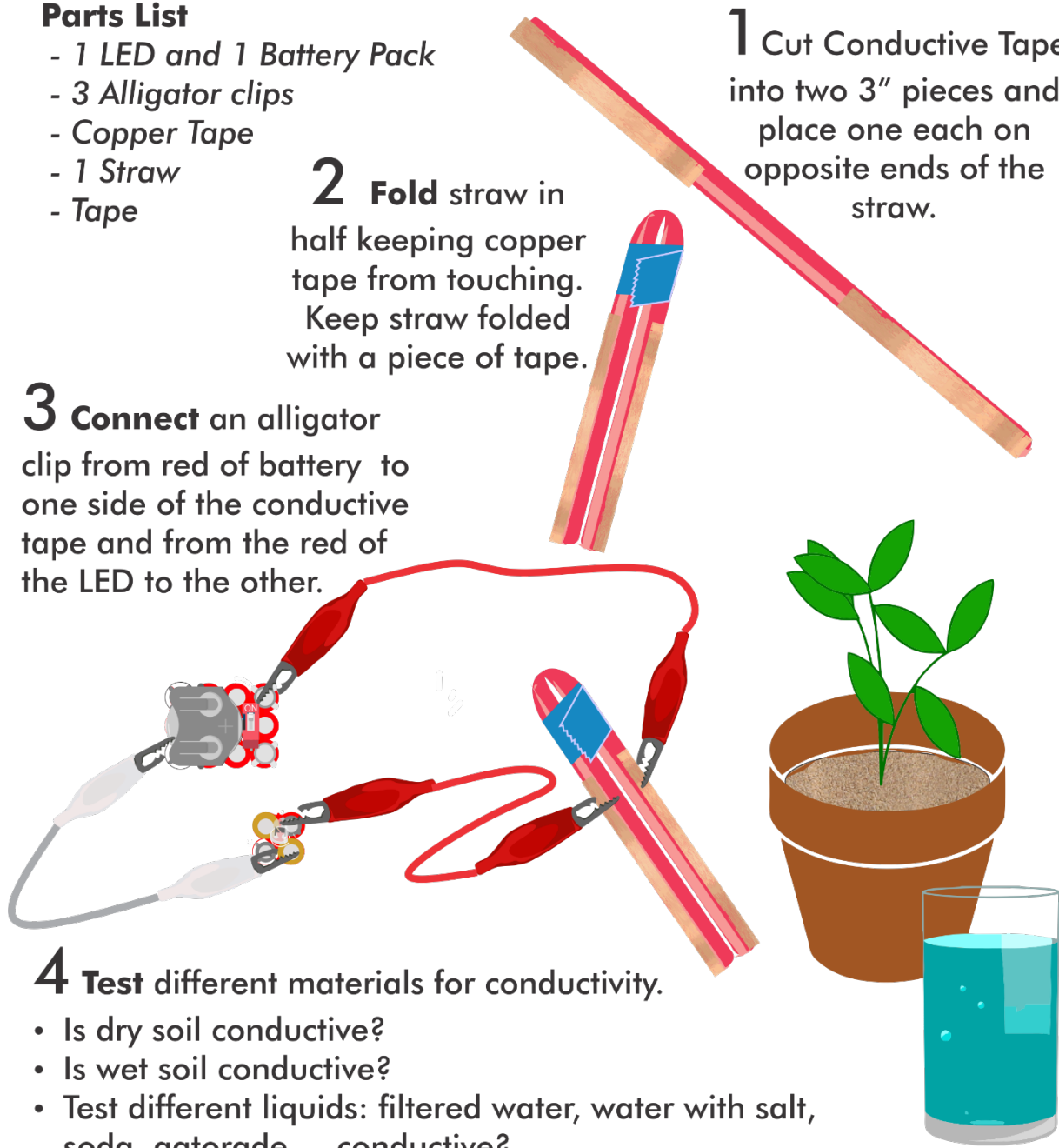
#### Parts List

- 1 LED and 1 Battery Pack
- 3 Alligator clips
- Copper Tape
- 1 Straw
- Tape

**1** Cut Conductive Tape into two 3" pieces and place one each on opposite ends of the straw.

**2** Fold straw in half keeping copper tape from touching. Keep straw folded with a piece of tape.

**3** Connect an alligator clip from red of battery to one side of the conductive tape and from the red of the LED to the other.



**4** Test different materials for conductivity.

- Is dry soil conductive?
- Is wet soil conductive?
- Test different liquids: filtered water, water with salt, soda, gatorade.... conductive?

With the conductivity probe built, we can now design a lab to explore conductivity in more depth.

It is suggested that the lab be designed around a theme. Suggested themes include:

- **Exploring food:** This works best with common beverages (juices, soda, water)
- **Food Science:** This lab would explore different liquid titrations: by adding salt or sugar, can they make the liquid conductive? How much.
- **Environmental Engineering** – Lets understand the differences in the water around us: Is tap water conductive, is pond water conductive, is bay water conductive? A common test for water quality is **dissolved solids** which measures conductivity. Can this probe be used to test for dissolved solids?
  - Soils can also be explored – is dry soil conductive, is wet soil?

It is important to emphasize the importance of documenting the students' hypothesis as well as their data gathered through experimentation.

Data can be gathered in a simple table as follows:

Name	Description	Conductive? Hypothesis (Y/N)	Conductive? Experiment (Y/N)

The data gathered will be revisited later in the 4<sup>th</sup> project.

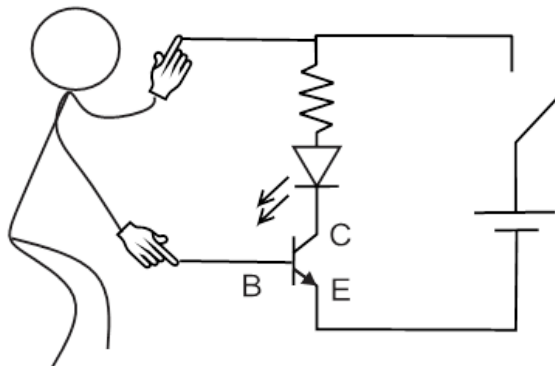
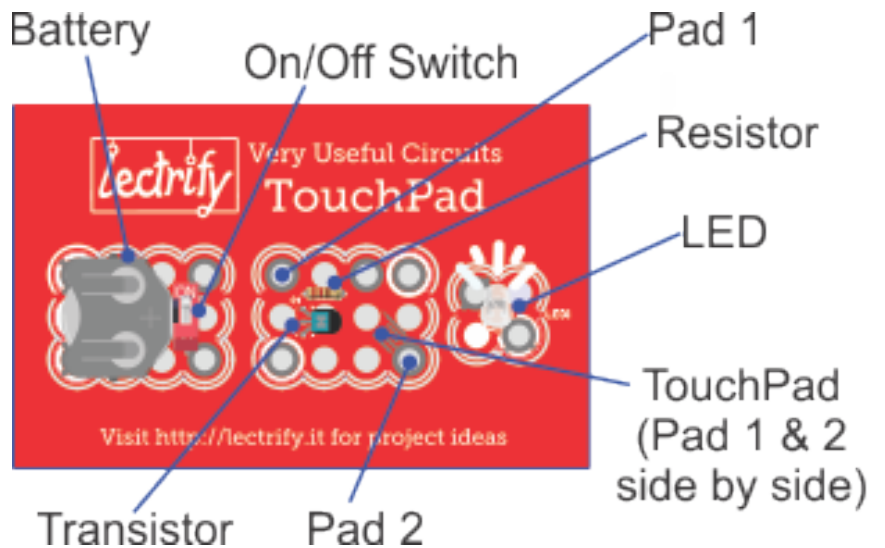
## MODULE 2: Resistance and Conductivity

This module requires the TouchPad board which is described below. The instructor can elect to explore the function of the circuit based on the level and interest of the students. The minimum discussion should be on the fact that this circuit works with a very small charge of electricity between the two pads.

### Tour of the Board

The TouchPad board consists of 5 components: battery, on/off switch, transistor (NPN), resistor (220K) and LED.

There are two pads on opposite corners of the center component we call the “control circuit.” These are the two pads that complete the circuit to activate the transistor as a switch.



#### HOW TOUCHPAD WORKS:

When the current at the Base is at 0 Volts, the transistor is in cutoff (OFF) mode.

When a very small current is applied to the transistor Base (B), it changes it from cutoff (OFF) to saturation (ON) mode allowing the LED to turn on.

The “TouchPad” area has both Pad 1 and Pad 2 side by side to enable closing the circuit with one finger.

The TouchPad requires only a small current to open the transistor switch allowing the LED to be controlled by a lower **threshold voltage** than required to turn it on directly. An LED requires a minimum **forward voltage** (voltage going through the circuit) before the light is visible. If the voltage is too low, no light is visible.

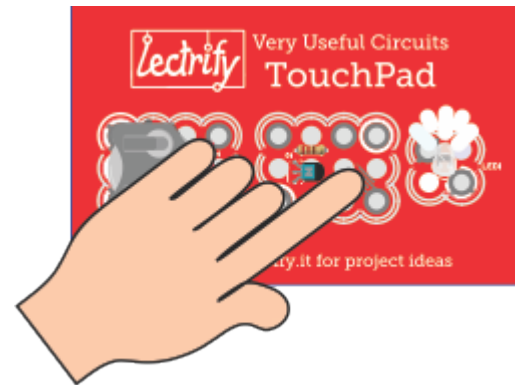


## Project 3 – Exploring Conductivity

By placing your finger on the TouchPad (side by side lines of Pads 1 & 2), you can turn on the LED because you will allow a small amount of current to go through your finger.

You can also connect an alligator clip (or put your finger) on

TouchPad 1 and TouchPad 2 and then connect the other end of those clips to something that is conductive.



### Make a Fruit Switch

#### Parts List

- TouchPad Board
- 2 Alligator clips
- Aluminum foil

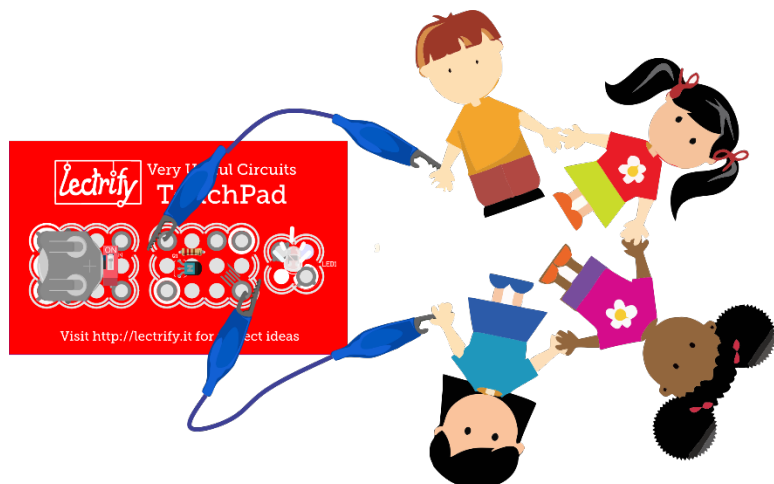


Use alligator clips to test conductivity of different materials



Clip each touchpad on board to aluminum foil and place side by side. Place fruit on foil touching both pieces of foil.

See if you can conduct electricity through people.  
How many people can you conduct electricity through?



## Project 4 – Revisit the Probe Lab using TouchPad

### Conductivity Probe with TouchPad

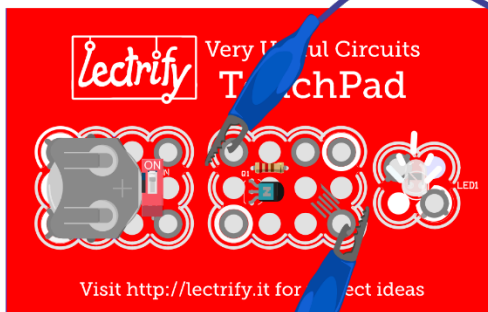
#### Parts List

- 1 TouchPad Board
- 2 Alligator clips
- Copper Tape
- 1 Straw
- Tape

**1** Cut Conductive Tape into two 3" pieces and place one each on opposite ends of the straw.

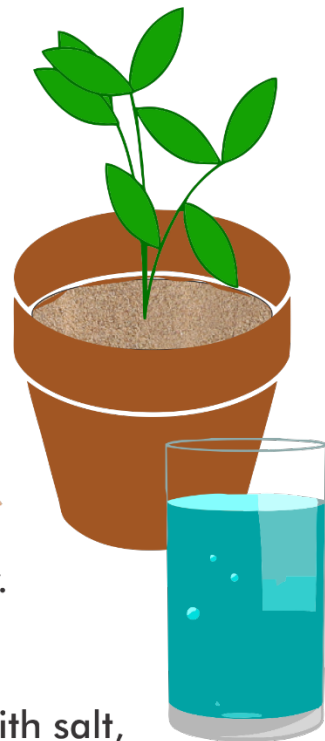
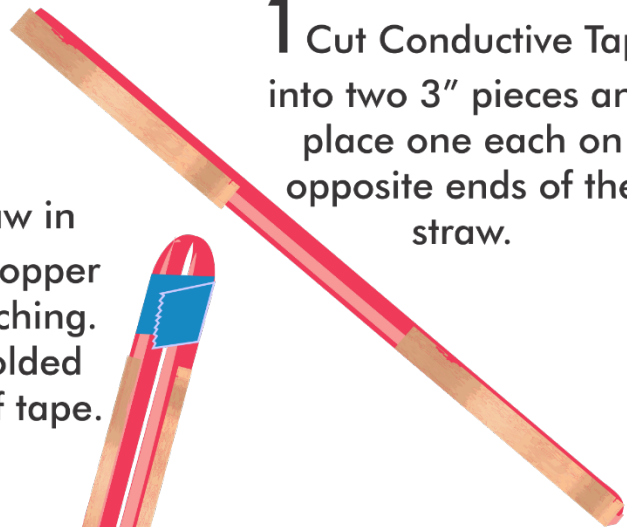
**2** Fold straw in half keeping copper tape from touching. Keep straw folded with a piece of tape.

**3** Connect an alligator clip from Pad 1 to one side of the conductive tape and from Pad 2 to the other.



**4** Re-Test different materials for conductivity.

- Is dry soil conductive?
- Is wet soil conductive?
- Test different liquids: filtered water, water with salt, soda, gatorade.... conductive?
- ARE any results different? Why?





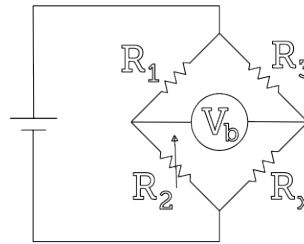
## MODULE 3: Measuring a change in resistance

This module requires the Sensor board which is described below. The instructor can elect to explore the function of the circuit based on the level and interest of the students.

### Sensor Board

The Sensor Board uses a circuit known as a Wheatstone Bridge. The properties of the Wheatstone bridge were first discovered in 1833<sup>1</sup> and it remains a relevant circuit to identify changes in resistance. Even today, many sensors work based on a measuring a small change of resistance (temperature, pressure, light, humidity, TDS...) and the **Sensor** circuit allows exploration of these sensors.

A Wheatstone bridge is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component<sup>2</sup> using the formula shown.



$$\text{When } V_b = 0 \\ \frac{R_2}{R_1} = \frac{R_x}{R_3}$$

In practice, resistors  $R_1$  and  $R_3$  are known values (often identical).  $R_x$  is an unknown resistance and  $R_2$  is some form of variable resistor that can be changed until  $V_b$  is zero.

In the Sensor Circuit,  $R_2$  is a potentiometer that is used to balance the circuit. The sensor also uses an Operational Amplifier (OpAmp) to amplify the change in voltage when the circuit is unbalanced. Because of the sensitivity of the circuit, it is impossible for  $V_b$  to reach zero (which would be indicated by both LEDs being off). Instead, the recommended use is to turn  $R_2$  to the point where a fraction of a turn flips between the two lights. In that mode, if LED1 on, when the resistance  $R_x$  becomes higher than  $R_2$ , the circuit flips and turns on LED2. Conversely, if LED2 is on and the resistance of  $R_x$  becomes lower than  $R_2$ , LED1 will turn on.

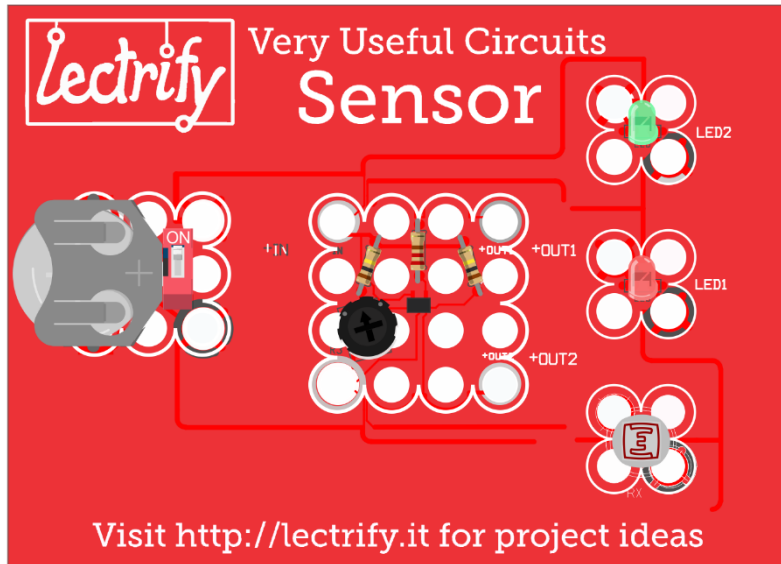
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<sup>1</sup> [https://en.wikipedia.org/wiki/Wheatstone\\_bridge](https://en.wikipedia.org/wiki/Wheatstone_bridge)

<sup>2</sup> ibid

## Project 5: Sensing light and dark.

The board comes with a photoresistor as Rx. A photoresistor is a light sensitive variable resistor where the resistance decreases as the light intensifies.



The behavior of this board is best understood by having the students create a “Truth Table” similar to the one filled in below. As discussed earlier, this circuit is too sensitive to reach a perfect “zero voltage” where both LEDs would be off. Therefore, the “Starting Point” is achieved by turning the potentiometer to the point where the LEDs flip back and forth (circuit is balanced) and then a fraction of a turn in a direction that gets the desired color.

Starting Point	Action	Outcome	Discussion
LED 2 ON (Green)	Darker (i.e. cover the photoresistor)	LED 2 ON (Green)	No change because LED 2 (Green) is lit when the resistance in the photoresistor increases from the starting point and resistance increases with darkness.
LED 2 ON (Green)	Lighter (i.e. shine a light on photoresistor)	LED 1 ON (RED)	The photoresistor resistance decreases below the starting point and the red LED turns on.
LED 1 ON (red)	Darker (i.e. cover the photoresistor)	LED 2 ON (green)	An increase in resistance turns on LED 2.
LED 1 ON (red)	Lighter (i.e. shine a light on the photoresistor)	LED 1 ON (red)	A decrease in resistance keeps LED 1 lit.

## Project 6: Revisiting the Probe Conductivity Probe with Sensor

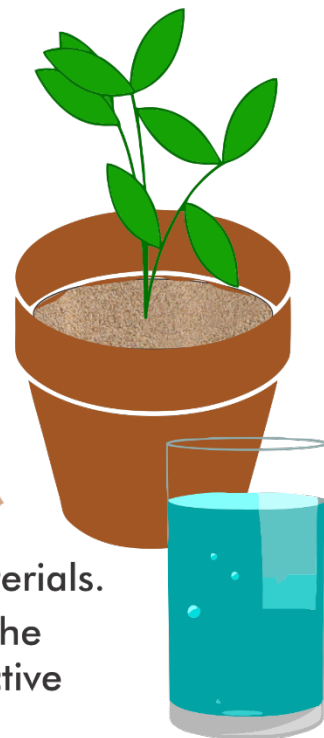
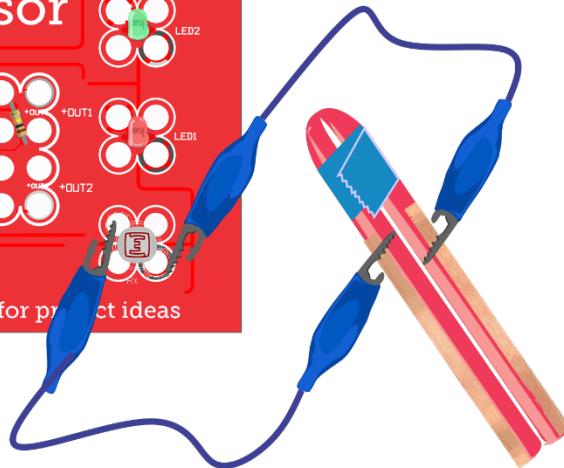
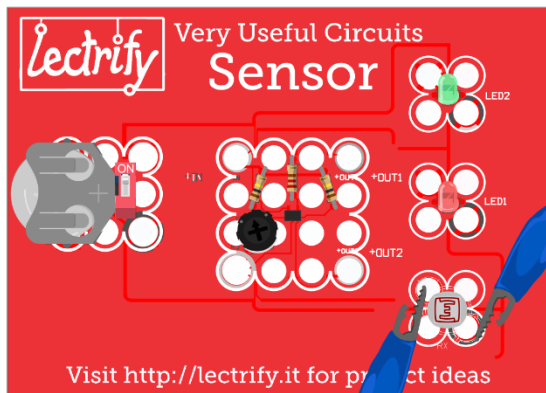
### Parts List

- 1 Sensor Board
- 2 Alligator clips
- Copper Tape
- 1 Straw
- Tape

**2 Fold** straw in half keeping copper tape from touching. Keep straw folded with a piece of tape.

**1** Cut Conductive Tape into two 3" pieces and place one each on opposite ends of the straw.

**3** Connect an alligator clip on either side of the Photoresistor.



**4** Compare the conductivity of different materials. Select one material as the baseline then use the Sensor to identify what is more or less conductive

Why are some materials more conductive than others?

Using the conductivity probe and the Sensor, can students rank the different objects they've previously tested based on conductivity?

If you have a multimeter, you can measure the objects to confirm the rankings.

Why do they believe the objects fell into this ranking?