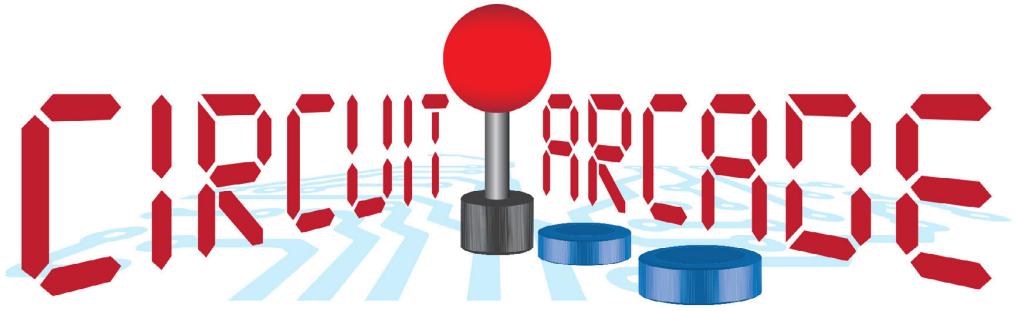


What's a circuit?

A flashlight. An electric toothbrush. A TV remote control.

All of these devices run on electricity. In order to power them, electricity needs to travel from one side of a power source and return to the opposite side along an unbroken path. This path, or circle of electricity, is called a **circuit**. In the case of a battery, electricity travels from the negative (-) end and returns to the positive (+) end.

Even as electrical systems have become increasingly complex over the years, the basic building blocks of a circuit have stayed consistent:

Power	Input	Output

Circuit kits — connectable tiles that teach the basics of circuitry — have been in schools for decades. This guide will help you create a DIY circuit kit that allows you to create some of the basic tiles found in many of these commercially available circuit kits:

- **Power tiles** contain **batteries**. *Do not plug into a wall outlet!*
- **Input tiles** contain **switches or sensors**.
- **Output tiles** contain **lights, speakers, or motors**.

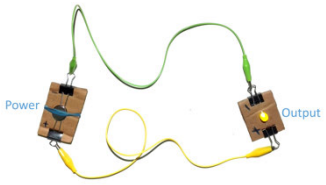
This Guide will help you learn and teach the basics of circuitry. Through a series of challenges, you will connect tiles to make your first circuit, build new tiles, and then dive deeper into creating more complex circuits, games, and eventually integrate these tools into diverse classroom projects. While this guide is designed for teachers to learn about circuits at Edcamps and during other professional development opportunities, many of these challenges can be offered directly to students.

As you make your cardboard circuits, share your work with the hashtag #MakerPromise.

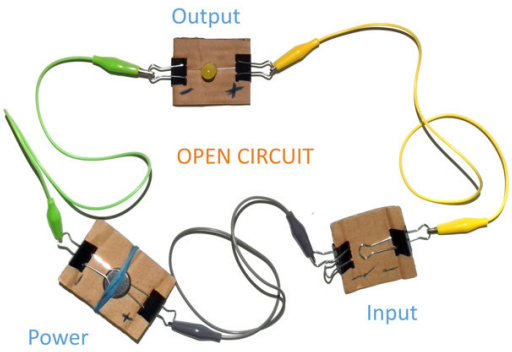
Challenge #1: Connect pre-built tiles to create a circuit

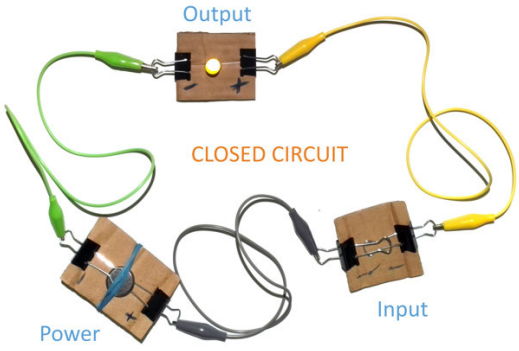
Use alligator clip wires to connect circuit tiles that others have made. How many different ways can you get a light to turn on?

A few things to keep in mind:



- The basic building blocks: power, input, output. You can even make a very simple circuit with just two tiles: power and output.
- Electricity flows in one direction. Always connect positive (+) terminals to other positive terminals and negative (-) terminals to other negative terminals. If the tiles you are working with aren't labelled you may need to try flipping the polarity (that is, the direction) of some of your tiles until it works.
- A circuit must be closed to work. A closed circuit makes a complete circle. The electricity must exit one end of the power tile and return to the other end. If it doesn't complete the loop it won't work — *that's why it's called a circuit*!





Start by making a light you can turn on and off with a switch using a battery tile (power), a switch tile (input), and an LED tile (output)

When your switch is "open," the path of the circuit is broken and the light will not turn on. When the switch is "closed," the circuit is completed and the light turns on. This is the same as how a light switch works in a building.

What other discoveries are you making about circuits and different electrical components?

What other working circuits can you make with the tiles available to you?

After you finish, take your circuits apart so others can use the tiles and materials.

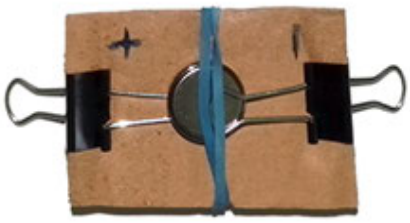
Challenge #2: Make your own circuit tiles

Now it's your turn to make the tiles! Use the materials on the table to create your own power, input, and output tiles.

Make a power tile with a coin cell battery

1. Attach a binder clip to each side of a cardboard tile. Fold down one handle and label that side "+." Label the opposite side "-.".

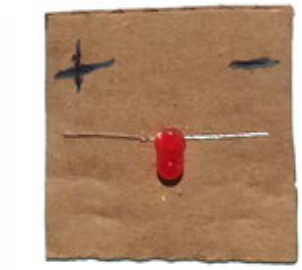
2. Place a battery over the folded handle of the binder clip. The positive side of the battery touching the handle (the positive side is flatter and should be marked with a "+").



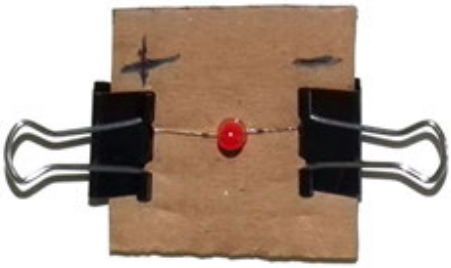
3. Close the handle of the second binder clip over the top of the battery. Use a rubber band to secure your clips over the battery. Leave the handles on the back side of the binder clips open.

Make an output tile with an LED

1. Label each end of your tile with "+" and "-." Align the leads of the LED. **The positive lead is the longer of the two.**

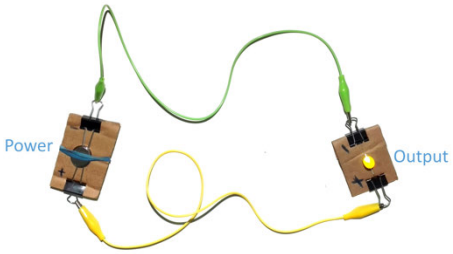


2. Bend the leads of the LED carefully. Place the LED on your tile with the longer lead on the positive side.



3 Clip binder clips over the two leads. Do not close the rear handles of the binder clips or you will create a "short circuit."

Make a simple circuit to test your tiles



Connect the power and output tiles to turn on the LED. Make sure you are connecting positive terminal to positive terminal and negative terminal to negative terminal. Make sure your connections are firm between alligator clip wires and binder clips, and wherever binder clips touch batteries and the leads of LEDs.

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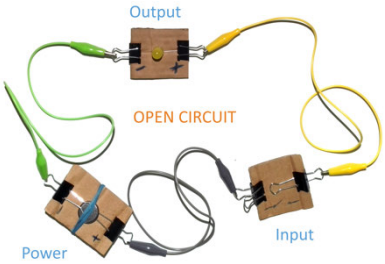
Make an input tile with a switch

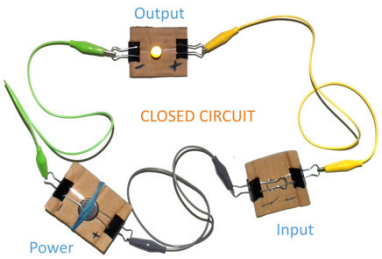
1. Attach a binder clip to each side of your tile. Flip the handle of one side down. Leave the handles on the back side of the binder clips open.

2. To close switch (that is, turn on the circuit), flip the handle of the other binder clip. To open the switch (turn off the circuit) flip one of the binder clips so they are not touching.

Add the switch tile to your circuit

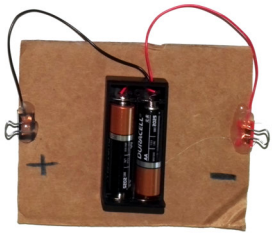


When your switch is "open," the path of the circuit is broken and the light will not turn on. When the switch is "closed," the circuit is completed and the light turns on. This is the same as how a light switch works in a building. See more tips on page 2 of this guide.

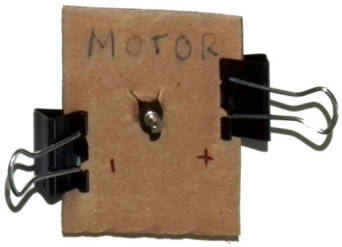


What other tiles can you make?

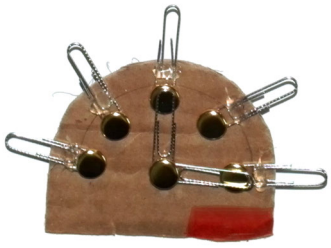
Here are a few examples of other circuit tiles people have made. Can you recreate one of these or design a new tile using materials you have available? Test your new tile by replacing the comparable (input, output, or power) tile in your circuit.



A power tile using AA batteries. *Research reasons why you would use different batteries for different projects.*



An output tile using a small motor. *What could you attach to the rotor to make a helicopter tile?*



An input tile with a five-way switch. *How might you use this tile to illustrate a circuitry concept to students?*

An input tile with a potentiometer. *Move on to Challenge #3 to see an idea for how you might use this tile.*

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Challenge #3: Design more complex circuits

What other circuits can you make using tiles available or by creating new tiles? Try making the circuit examples shown in this challenge or design your own. It's okay if it doesn't work right away. Troubleshooting a circuit is a great way to build problem-solving skills by testing each component and connection one at a time.

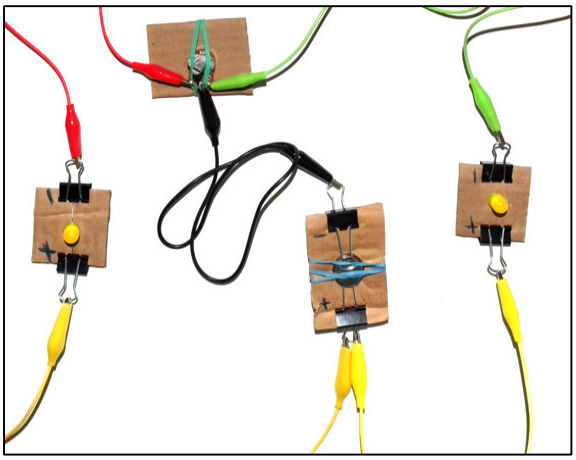
Example 1: Make a two-way switch by changing resistance

How it works:

- This is really TWO circuits in one. The potentiometer in the middle changes the **resistance** of both circuits at the same time.
- Resistance lowers (resists) the flow of electricity in a circuit. When the dial is turned all the way in one direction, the resistance in that part of the circuit is lower, causing one LED to have more current and glow more brightly while causing the other LED to have less current and dim.

You will need:

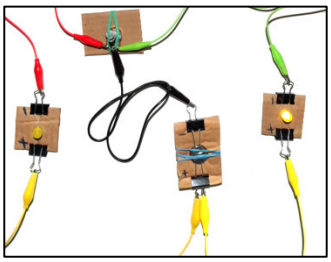
- 1 coin cell battery power tile
- 2 LED light output tiles
- 1 potentiometer input tile (or just a potentiometer, it will work fine without a cardboard tile)
- 5 alligator clip wires

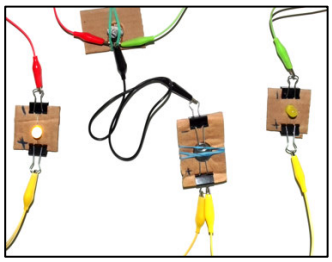


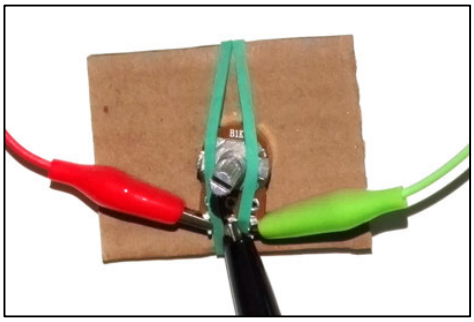
Fully connected circuit

Build the circuit:

1. Connect the left and right terminals of the potentiometer to the negative ends of both LED tiles.
2. Connect the MIDDLE terminal of the potentiometer to the negative end of the power tile.
3. Using two alligator clip wires, connect the positive end of the power tile to the positive end of both LED tiles.
4. Rotate the dial of the potentiometer to change the current between the two LEDs, as seen below:







Potentiometer hookup detail view

Extend the activity:

1. Disconnect one of the LEDs. What happens to the other LED? Why?
2. Instead of a potentiometer, can you make a two-way switch tile using only binder clips?
3. Can you draw how electricity is flowing in both halves of the circuit?
4. What else could you use a potentiometer for?

Example 2: Make a circuit game to test your dexterity

How to play

- Play the game by trying to maneuver the game wand around a bent paper clip without touching it. If they touch, the motor will vibrate the game tile to let you know you lost the game!

How it works

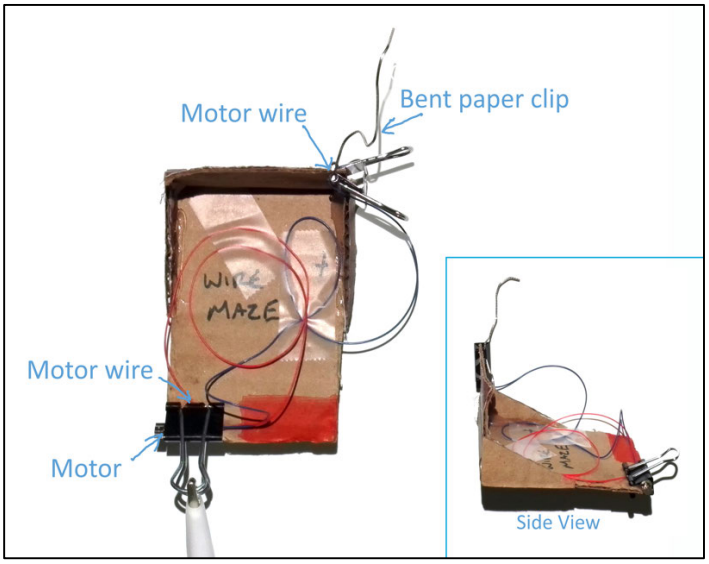
- The two pieces of wire (the game wand and the bent paper clip) act like a switch. When they touch, they close the circuit and the game tile vibrates. The game is to keep the circuit open. *What classic game works just like this?*

You will need:

- 1 power tile and alligator clip wire
- 1 game tile, made with scrap cardboard, 2 binder clips, a paper clip, a small motor, and tape or glue
- 1 game wand, made with an alligator clip wire and metal ring handle from a binder clip

Build the game tile:

1. Make an "L" shaped game tile by folding, or cutting and gluing cardboard scraps. Consider adding triangle brackets for stability (see "Side View" photo).
2. Squeeze open a binder clip and slide the motor into it, then attach to the horizontal base of the game tile. Make sure the rotor part of the motor can move freely outside the binder clip.
3. Loosely unbend the paper clip and attach to the tile's vertical surface using a binder clip.
4. Connect one wire lead from the motor underneath each binder clip. Ensure the connections are firm. For this project, it does not matter which lead connects to which clip, although reversing the leads will change the direction that the motor spins.

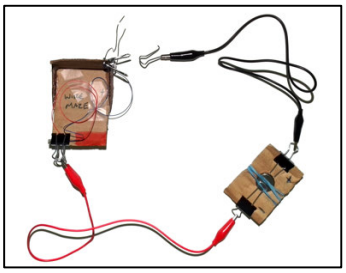


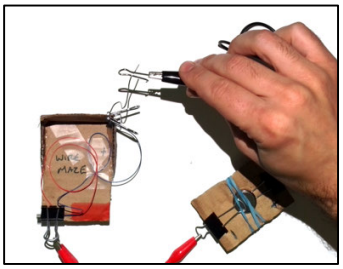
Build the game wand:

1. Detach a handle from one of the binder clips. Squeeze the sides of the handle to remove it from the clip. (You can use the rear handle from one of the clips on your game tile.)
2. Clip the handle to one end of an alligator clip wire.

Connect your tiles and play the game:

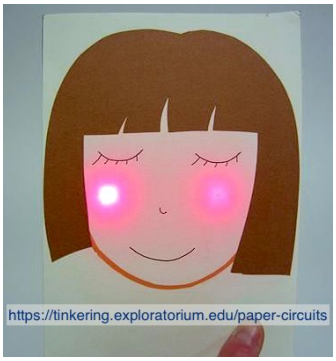
1. Connect one end of the power tile to the game wand; connect the other end of the power tile to the clip holding the motor on your game tile.
2. Play the game by trying to maneuver the loop of the game wand over the paper clip without touching. If you close the circuit, the motor will vibrate the game tile to let you know!

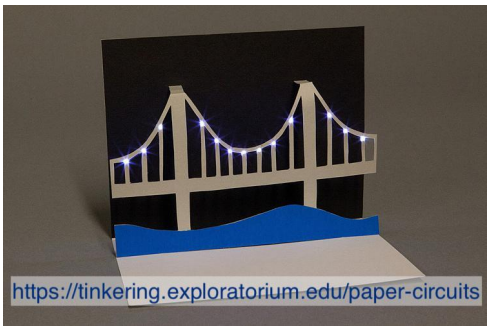


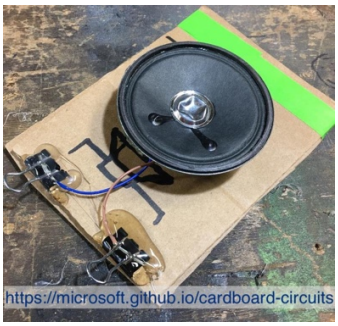


Challenge #4: Make something new

Using these and other inexpensive materials, you can create light up sculptures, cardboard robots, and simple machines. You can even carefully harvest parts from older electronics to make new circuits. *What will you make next?*







Challenge #5: Bring cardboard circuits to your students

We've started with a few projects that other teachers have used. Now add your own ideas!

- I would have students add a light-up element to their tri-fold project displays.
- I would have students make a cardboard replica of an important invention.
- I would have students create a light up quiz show board for learning vocabulary.
- I would...

- I would...

- I would...

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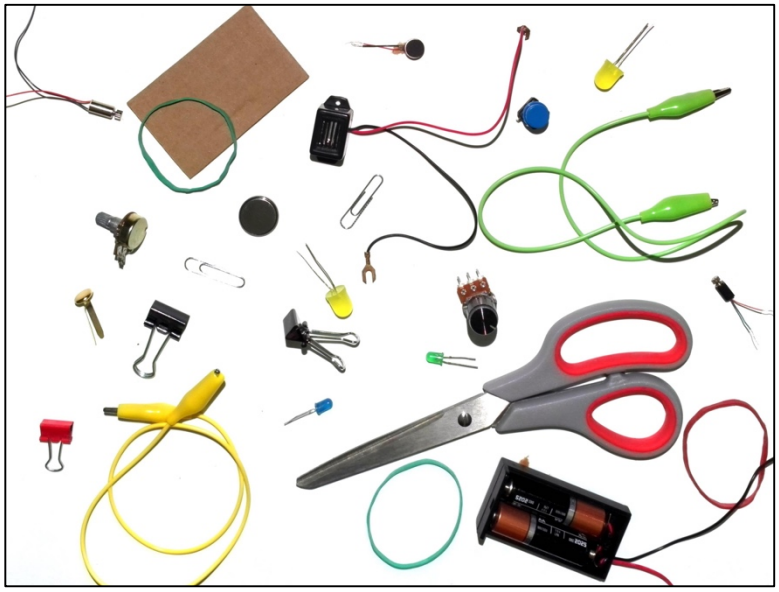
Materials List



Office/General Supplies

*Cardboard
*Metal binder clips
*Paper clips
Brads (paper fasteners)
*Rubber bands
*Scissors
*Tape
Glue

Specialty/Electronics Supplies

*LEDs (3mm, 5mm, or 10mm)
*Coin cell batteries (CR2032 type)
Battery packs (for AA or AAA batteries)
*Potentiometers
Switches
Buttons ("momentary switches")
Buzzers (look for "piezo" speakers)
*Small Motors (look for "vibration motors")
*Alligator clip wires (double ended)

*****Required to complete one of the challenges in this guide

Where can I get this stuff?

While many of the materials you will need for these activities are readily available at office supply stores, a few of the electronics components you will likely need to order online. Specialty electronics suppliers like Sparkfun.com and Adafruit.com offer educator discounts. You can usually also find everything you will need at Amazon.com. If you are buying a large quantity of supplies to run this activity several times or to stock a makerspace, consider looking at Ebay.com or Aliexpress.com for steeper discounts with bulk purchases.

How can I make sure the components will have enough power to work?

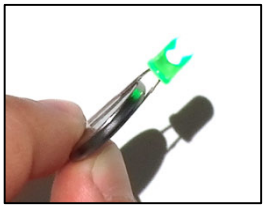
CR2032 batteries generate 3v of electricity. All outputs including LEDs, motors, and buzzers need to be able to run with 3v or less. Specific recommendations of components that will work with these batteries are in parentheses above.

AA and AAA batteries are less powerful than coin cells but they last longer. They only generate 1.5v of electricity. Using a battery holder that uses two batteries will generate more voltage. You can also pair coin cell batteries by stacking them if you need to power a component requiring more than 3v.

Facilitator Guide

Whether you are looking for an activity for your students, for a professional learning workshop, or even something to do with your kids at home, cardboard circuits are a fun and low-cost activity for anyone! Here are a few tips, tricks and ideas to consider when setting up your cardboard circuit arcade:

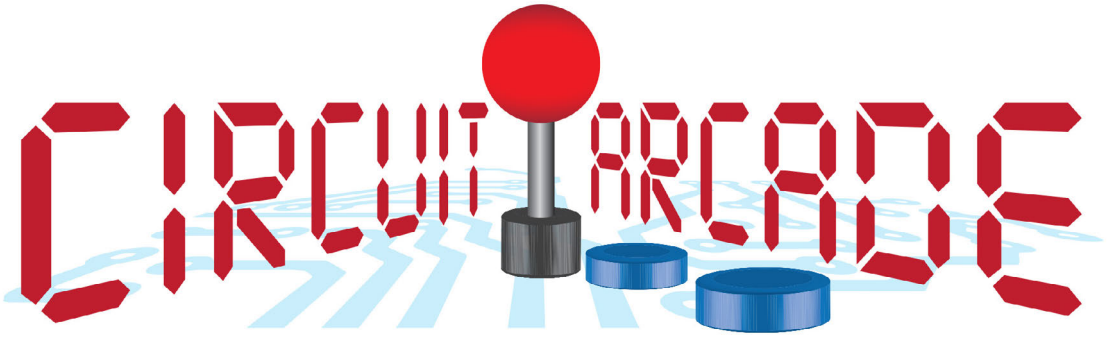
- Make a few power, input, and output tiles for participants to use before you start the activity.
- Consider setting up two or more work stations. One might be dedicated to assembling new tiles while the other has completed tiles for connecting into circuits. A third station might be used for getting started, which would have just the pre-made tiles for making the simple circuit described in "Challenge #1" in this guide.
- Allow participants to jump in to the challenge where they are comfortable. If they struggle with a challenge that is too difficult, they can always try a previous different prompt to refresh their understanding of some concepts.
- Test your batteries! If you are reusing batteries, make sure they all work before you begin, and don't forget to re-check them if a circuit doesn't work. A quick way to test a coin cell battery is to make an LED "throwie" by sandwiching the LED leads around the battery (long lead touching the positive side of the battery).



- If supplies are limited, encourage participants to take apart some of their tiles after they are finished making circuits with them. Alternately have participants construct their complete circuits in groups with each group member responsible for creating one of the tiles.
- Provide paper, sticky notes, or a shared document for participants to record their learnings and questions. Consider seeding this with some guiding questions or concepts to investigate.
- If you plan to save the tiles for future activities, consider color-coding them or labelling by type: power, input, and output.
- Take your circuit arcade to the next level by creating a take-apart station for old electronic toys and gadgets. You can harvest switches, rechargeable batteries or battery holders, and sometimes sensors, lights, or other input and output devices. Make sure you provide appropriate tools and safety guidelines!

Get more ideas from these resources that helped to inspire us as we created this guide:

- Cardboard Circuits, from Microsoft: http://microsoft.github.io/cardboard-circuits/
- Circuit Boards, from The Tinkering Studio: https://tinkering.exploratorium.edu/circuit-boards
- Paper Circuits, from Sparkfun: https://learn.sparkfun.com/tutorials/tags/paper-circuits
- Build a Simple Circuit from a Pizza Box, from Instructables user matt.e.jenkins: http://www.instructables.com/id/Build-a-Simple-Circuit-from-a-Pizza-Box-No-Solder/



DOWNLOAD THE PROJECT GUIDE

www.makerpromise.org/circuit-arcade

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