3rd Biannual NGSS STEM Conference
INFUSING ART INTO STEM
crafting a STEAM curriculum
November 22, 2014 | Pier 15, San Francisco, CA

Drawing with Circuits (Based on *Paper Circuits* from The Exploratorium's Tinkering Studio)

Recommended Grade Level:
4th -12th grades

NGSS Science & Engineering Practices:
- Asking Questions and Defining Problems
- Planning and Carrying Out Investigations
- Analyzing and Interpreting Data
- Obtaining, Evaluating and Communication Information

Time:
- Two or more class periods

Materials Needed

[TIP: You can get 5 mm copper tape, ready for use, from sparkfun.com (part #PRT-1-561). It is also often sold in hardware stores under the name of Slug Tape–it is taped to the lip of planters to prevent slugs and snails from climbing in. If you use slug tape, you might want to cut it into thinner strips before using it on your paper circuit.]

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Other Helpful Materials

Background Information:

Though science and engineering are often framed as activities whose purpose is to solve a specific problem and understand phenomena, artistic expression can also be a powerful way to engage in science and engineering. In this activity, students will use art as an entry into understanding circuits. As the complexity of the design increases, so will students' scientific comprehension.

The key to the activity is allowing students to iterate their designs. Starting with scratch paper and Scotch tape rather than card stock and soldering can make the initial designs feel "low stakes" for the students, permitting them to explore the design and the science behind the circuit. Having alternate materials around such as circuit boards and multi-meters can also enhance the feel of an experimental environment and let students apply the knowledge they gather to the final art piece.

To help students embrace this process of science discovery and problem solving through artistic expression, it is necessary that you, as the teacher, try it first, to understand how your students might engage in the process. Give yourself permission to try it out and work through challenges before reading the sections on troubleshooting. One of the most interesting things about this activity is that the more "mistakes" you make along the way, the more you will learn. The same is true for your students. This is the power of making in the classroom. Encourage wonder, creativity and wild ideas.

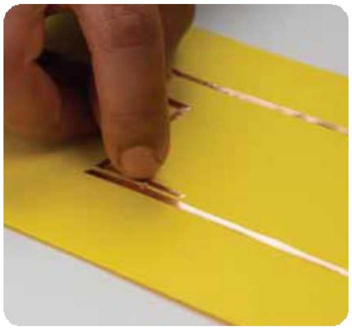
You can bring students into the activity by showing them examples of art pieces created by others.

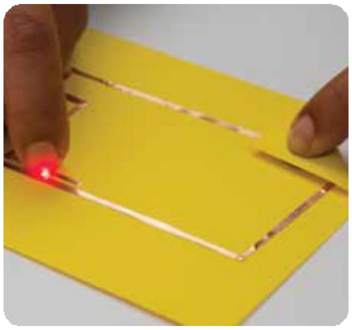
To Do and Notice:

For the first few steps of the activity, it is helpful to set a few guidelines in order to give students some success with constructing a circuit. From there, students will learn about circuit function through discovery as it serves their designs.

1. Fold over one corner of the paper and trace a battery on either side of the fold.

2. Tape down to strips of copper tape, with each piece starting from the middle of one of the circles and ending about 1 mm apart (don't worry about what it looks like for now).





3. Place a gumdrop LED in the gap. Fold the battery in the tab you created earlier and see what happens. You can use a binder clip to hold it in place. Did it light up? If not, what changes can you make to get it to light up?

4. Place Scotch tape on the LED (surface mount LED) or on the leads (gumdrop LED) to hold the light in place. You can also solder the LED in place.

From here, the possibilities for student art pieces are endless. For many students, the art itself will be impetus for discovery and learning will occur as it serves the design. Other students might require more specific challenges as they learn to flex their creative muscles.
Some challenges might include posing questions like:
- Can you create a switch?
- Can you incorporate different colors of bulbs?
- Can you use the copper tape as part of the artwork itself?
- Can you make a place for the battery holder someplace other than the corner?
- Can you create a hidden circuit?

Student Learning as Shared Knowledge:
As students construct their circuits, individuals and groups will make a variety of discoveries regarding both effective artistic strategies and how a circuit functions. Creating a public space for students to record their discoveries—either on a white board or on poster paper—affords them the opportunity to take ownership of their learning and to share ideas with their classmates. As you circulate through the room, notice the challenges students are met with and the solutions they discover. Encourage them to add to the class understanding.

As the teacher, you may decide to take time to pause during the activity to have students share their discoveries with their peers. As learning develops, you may choose to add academic vocabulary to the students' observations to develop common scientific terminology. It is important, however, to allow them to construct the concepts first.

As a class, students will learn many or all of the following:
- The circuit must be connected fully from the negative end to the positive end for an LED to light
- The negative ends of the light must be oriented toward the negative end of the battery
- Blue lights may not work with lights of other colors
- Adhesive, paper, and air do not effectively conduct electricity
- Different arrangements of LED's can cause the brightness to vary

Trouble Shooting:
Students will run into several solvable problems as they create their artwork. As much as possible, allow students to feel frustration and design solutions. When appropriate, use student discoveries to teach other students. That being said, as a teacher, it may be helpful to understand some potential causes of a non-functioning circuit as you steer students toward solutions. This will allow you pose the appropriate challenging questions to students when they are stuck without providing answers.

Battery not connected –during the design-process it is easy for the battery flap to become disconnected. If you notice this, you might challenge them to check for circuit completeness once they have established that this is necessary for the light to glow.

Short circuit – Electrons will follow the path of least resistance. If there is a path that avoids the light bulb, they will take it. Pose questions that challenge students to make sure that the electrons must pass through the light on the path from one side of the battery to the other.

Battery/light bulb orientation – Students may notice that light bulbs work in one direction but not the other. While this is not true in most light bulbs, it is true with LEDs (see *What's Going On* section below for an explanation as to why). The negative side of the battery must connect to the negative lead of the light bulb. In the case of the gumdrop LED, this is the shorter end. In the case of the surface mount LEDs, this is the side with the green markings (you may need a magnifying glass to help you see). This tends to be particularly challenging when students are using multiple bulbs on a single circuit. When students discover this, challenge them to build in strategies for keeping these clear as they build.

Copper tape joints – Paper is not conductive. Neither is the adhesive on the back of the copper tape. If the electrons' path is interrupted by either of these the current will stop and the LEDs will not light. Two common challenges for students are gaps in the tape and connecting joints by placing the sticky side of one piece of tape on the copper side of another. Challenge students to look at their joints. One solution that students often discover is folding the tape so the joint is copper-to-copper, avoiding the adhesive block.

Using different colored LEDs together **–** Because of the different voltage requirements for different colors of lights (lights on the blue end of the spectrum require more voltage than lights on the red end of the spectrum), placing two different colors on the same circuit may cause the one requiring more voltage not to light, as most electrons will flow through the light requiring less voltage. If their design requires those colors in concert, challenge students to find a solution to this problem.

Tips and Tricks:

Tips for soldering

1. Place a dot of solder on one side of your copper tape where you would like the LED to be.
2. If you are using a surface mount LED, pick it up with the tweezers. If you are using a gumdrop LED, place it on the copper tape.
3. With your other hand, melt the solder and stick the LED into the liquid metal. Hold the LED in place while the solder cools.
4. Now you should be able to solder the other side of the LED onto the other piece of copper tape. Make sure that both the leg of the LED and the copper tape get hot enough for the solder to flow and connect them.

Tips for working with copper tape

1. Cutting the tape lengthwise allows for more flexibility in design. Use it for curves and fine lines.
2. Smooth kinks in tape with a bone folder or Popsicle stick.
3. To make a sharp corner, fold the copper tape back on itself and make a sharp crease. While holding down the crease, turn the tape in the direction you would like it to go. Flatten the tape with a bone folder or popsicle stick.

Tips for placing lights

Because the leads on the gumdrop LED's are not rigid, they can be tricky to punch through the paper without bending or breaking the leads. Try punching a hole with a pushpin first and slipping the leads through.

What's Going On?

Batteries are devices that convert chemical energy into electrical energy. When a conductive material (copper tape in this case) creates a loop from one side of the battery to the other, electrons move from one surface of the battery to the other making an electric current. This is what we refer to as a complete circuit. When an LED (light emitting diode) is placed in the current's path, the electrons moving from one diode of the semi-conductive material to the other lose their energy, some of which generates light. Because different colored LEDs are made materials requiring different voltages to generate light, the energy released is also different creating a different color.

With these materials and the starting instructions, most students will construct a parallel circuit. This allows electrons to travel through multiple paths through the lights. A series circuit has all of the lights in a single row requiring the current to flow through one light in order to reach the next.

Going Further:

Pop-up art

Take your artwork to the next level by adding three dimensions to your design.

Hack your notebook

Light up your writing by adding paper circuitry to a notebook or journal. As you choose what aspects of your writing to *illuminate,* you are able to create and add meaning in bright new ways. (Image from *21st Century Notebooking*)

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Using other materials
Though lights were used in this case, a variety of different devices can be included in the circuit including buzzers and sensors. There are also inks, stickers, and fabrics that conduct adding a variety of material choices to your artwork.

Electronic textiles
Though this activity focused on paper art using conductive copper tape, there are conductive inks and threads that allow for a variety of artistic creations. Arduino's such as LilyPads can use simple programming tools to create art that flashes in patterns.

References

The Tinkering Studio – The Exploratorium
Photos and many descriptions are from the "Paper Circuits" activity developed by the Tinkering Studio.
tinkering.exploratorium.edu

Inspiration

Jie Qi's Pu Gong Ying Tu (Dandelion Painting)—(scroll down to the Vimeo video)
http://technolojie.com/category/featured-projects/

21st Century Notebooking
http://www.nexmap.org/21c-notebooking-io/
dmlcentral –

Digital Media + Learning: The Power of Participation
http://dmlcentral.net/blog/mia-c-zamora/paper-circuitry-illuminates-'writing-making'

Resources

SparkFun Electronics – products, blogs, classes and more hacking and Making with electronics.
sparkfun.com

Adafruit Industries – created by a woman artist and engineer, this site has weekly product blogs, featured e-textiles, products for design and more!
adafruit.com

Textile Messages by Leah Beuchly –interested in learning more about e-textiles? This inspiring book describes projects that combine art, engineering, science and computing in the most beautiful ways and it highlights projects used in a variety of settings.

The Tinkering Studio at the Exploratorium – fantastic activities, strategies, and the like for all things tinkery.
tinkering.exploratorium.edu