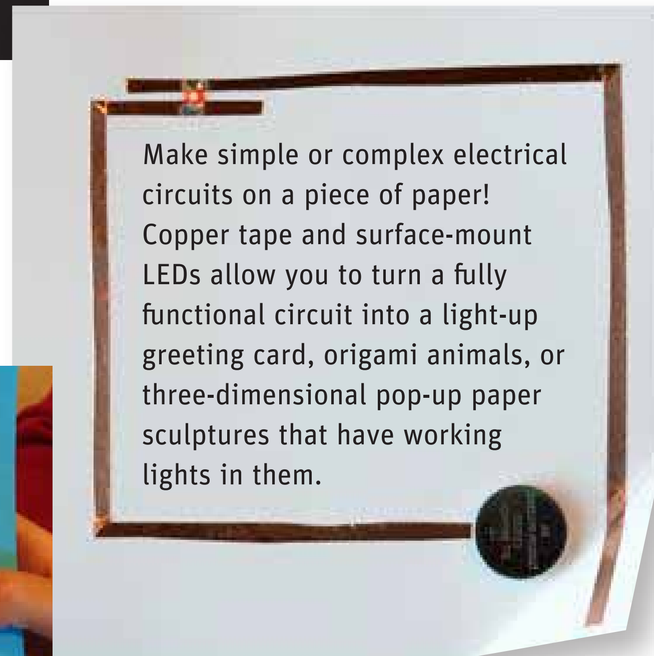
PAPER CIRCUITS



Make simple or complex electrical circuits on a piece of paper! Copper tape and surface-mount LEDs allow you to turn a fully functional circuit into a light-up greeting card, origami animals, or three-dimensional pop-up paper sculptures that have working lights in them.

BUILD IT!

Collect these things:

[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.]

the tinkering studio

exploratorium®

Other Helpful Materials:

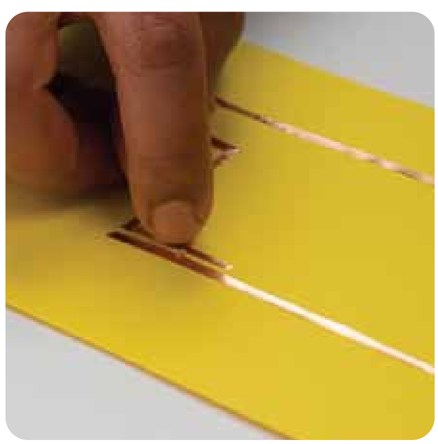
Fabric glue
(optional)

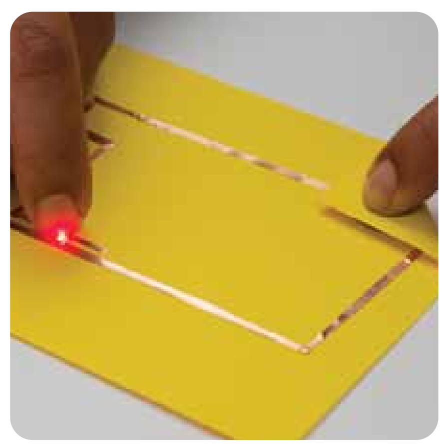
TRY IT!

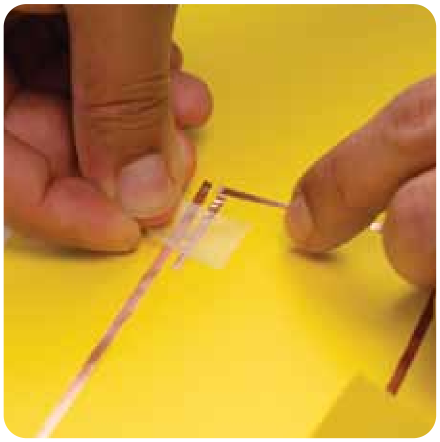
Getting started:

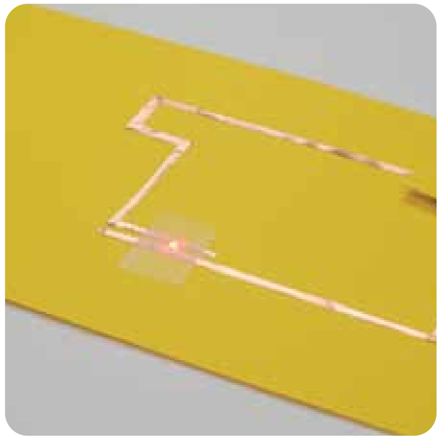
Start simple – fold over one corner of the paper and trace the battery on either side of the fold. Try taping down two strips of copper tape with each piece starting from one of the circles and ending about 1 mm apart (don't worry about how it looks for now).

Place a surface mount LED in the gap. Fold the battery in the tab you created earlier and see what happens. Does the light turn on? If not, try flipping the battery or gently pushing down on the light.



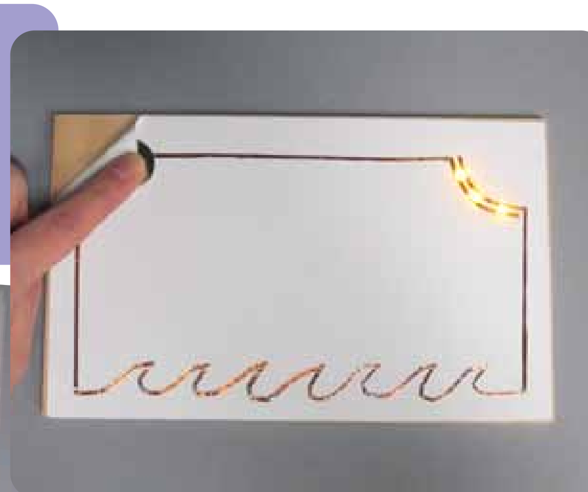






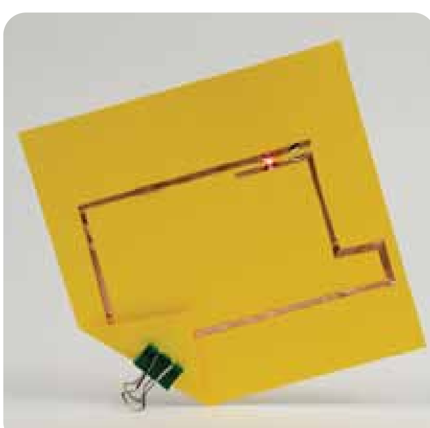
You can lay a piece of Scotch tape over your LED to secure it to the copper tape or solder the LED to the copper tape using a soldering iron. (See helpful techniques below for tips on soldering the lights.)

With these starting steps, the possibilities for creating your paper circuits are endless. You can **fold the copper tape into different designs** or make a collage that is lit by a hidden circuit on another piece of paper underneath.



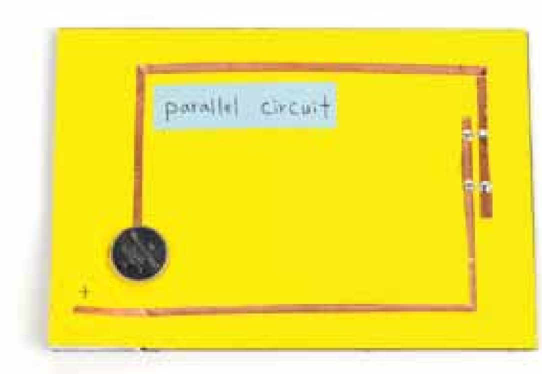
Could you make a battery holder somewhere else on the paper besides the corner? Or a switch that turns your lights on and off when pushed?

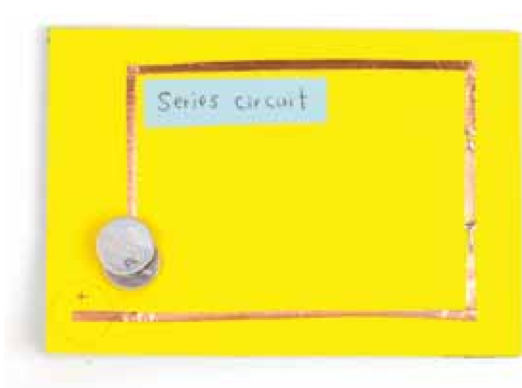
Binder clips are a great tool for holding the battery in place to keep the light turned on when displaying your circuit.



Look closely at your LED (a magnifying lens might help here). You'll notice one or two green markings on one side. These dots indicate the negative side of the LED. Being able to tell the positive from negative sides will come in handy later on, especially if you're using more than one light.

You can make cards with one light or many lights. When using multiple lights it's helpful to make a parallel circuit. It's possible to make series circuits, but you'll need an additional battery for each light.



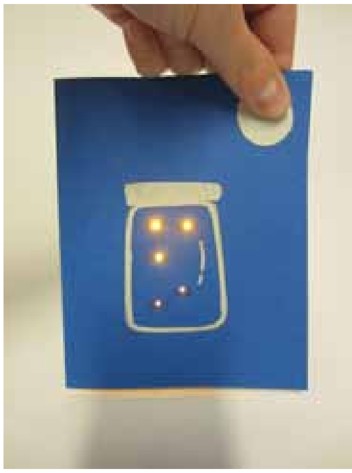


When making a parallel circuit, we like to **think of it as creating two copper tape pathways** that come very, very close together but don't touch. Your surface mount LEDs will have to bridge the gap between them, so we've found that placing them about 1 mm or less apart is ideal.

Make sure your LEDs are all oriented in the same direction, with all the positive leads touching the positive path, and vice versa. *(TIP: Many times if a light isn't working, it's oriented backwards.)*

When overlapping pieces of copper tape, **sometimes the adhesive acts like an insulator, blocking the electricity from flowing**. You can make a tiny solder "bridge" to fix the connection or fold a piece of copper back on itself (sticky side to sticky side) then Scotch tape that over the seam as a different type of "bridge."

Depending on the LEDs you buy, you might find that some colors work together and other colors don't (for us, red, yellow, and green work together, as do blue and white). This could become a feature of your circuit where by pushing a switch the lights change colors. You could also experiment with resistors to make incompatible colors (like blue and green) work at the same time.



The LEDs make diffuse circles when shined through thin, light-colored paper. Cardstock can block the light, so poking holes in it with an X-acto knife or small hole punch will let the light shine through.

Helpful tape folding techniques:

Making a sharp corner: Fold the copper tape back on itself and make a sharp crease. While holding down the crease, turn the tape the direction you would like it to go. Flatten the tape with a bone folder or Popsicle stick.

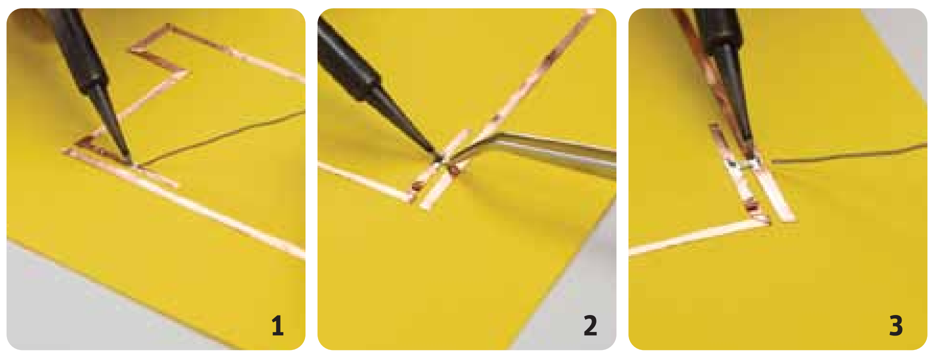
Making a curve: This works better with thinner tape. With one hand guide the tape along with curve you'd like to make. With the other hand, push down the tape to secure it to the paper. You might notice tiny puckers in the tape; you can smooth those out with a bone folder or Popsicle stick.

Soldering an LED:

1) Place a dot of solder on one side of your copper tape where you would like the LED to be.

2) Pick up one of the LEDs with the tweezers and hold it right next to the blob of solder. With your other hand, melt the solder and stick the LED into the liquid metal. Hold the LED in place while the solder cools.

3) Now you should be able to solder the other side onto the other piece of copper tape. Make sure both the leg of the LED and the copper tape get hot enough for the solder to flow and connect to them.



Test your design! And remember, working with a soldering iron takes time and practice, so don't be too frustrated if you don't get it perfect on the first try.

TAKING IT FURTHER

Origami and pop-ups: make your paper circuits three-dimensional by incorporating them into origami animals or pop up scenes.

Incorporate microcontrollers: You can program an ATTiny chip to make your lights blink, flicker, or even respond to sensors. Try making a circuit that responds to applause or changes in light.

EDUCATOR ADDENDUM

A note on our philosophy:
The Tinkering Studio is based on a constructivist theory of learning, which asserts that knowledge is not simply transmitted from teacher to learner but actively constructed by the mind of the learner. Constructionism suggests that learners are morelikely to make new ideas while actively engaged in making an external artifact. The Tinkering Studio supports the construction of knowledge within the context of building personally meaningful artifacts. We design opportunities for people to "think with their hands" in order to construct meaning and understanding.

Activity Design (decisions and designs that support a tinkering experience)

Tinkering Studio activities and investigations are designed to encourage learners to complexify their thinking over time. The variety of materials and variables available for experimentation allows learners to enter at a point where they are comfortable starting, and then alter and refine their designs as they develop new ideas. Tinkering activities are often fun, whimsical, inspired, and surprising.

Building a paper circuit is a playful platform for the learner to investigate concepts at the intersection of art, science, and technology. The circuit and collage created are as significant as the process of testing, questioning, and occasionally failing. Here are a few principles that exemplify the design goals of this activity:

- Materials and phenomena are evocative and invite inquiry

Paper, scotch tape, and batteries are all familiar materials. When combined with LEDs and copper tape, they take on new complexities. This juxtaposition of familiar and unfamiliar materials with high and low tech crafting techniques invites learners to dive in and explore their ideas.

- Activities and investigations encourage learners to complexify their thinking over time

Paper circuits start out simple, but often grow in complexity with circuit understanding and aesthetic choices. This activity also encourages iteration to make many versions of circuits as confidence grows with the tools, materials, and techniques.

- Activity station and design enables cross-talk and invites collaboration

Paper circuits are built at communal table that allows for participants to see and hear what others are working on. Solutions to similar problems are shared and iterated upon from one builder to the next.

Environment (the elements of the space that support tinkering)

In the Tinkering Studio there are many things that we keep in mind when setting up an environment for a successful tinkering activity.

Since learners often work with us for an extended period of time, so we try to create a warm and welcoming workspace with comfortable seating, sturdy worktables, and good lighting. We often display exhibits, or examples from past projects and current activities throughout the space to seed ideas and provide an introduction to what is happening that day. Materials are easily accessible and in close proximity to the tinkerers, and we often work at large, communal activity stations to enable cross-talk and invite collaboration between participants, allowing them to look to each other for answers and solutions.

We start with plenty of examples that show introductory techniques of circuit building (like a single LED, multiple LEDs in parallel, and simple switches) as well as inspirational examples to show aesthetic possibilities (like collages that lights shine through or a simple scene created by folding copper tape). If you're planning to solder with your group, we've found that it's helpful to set up the irons away from the main worktable at a separate station. This allows you to introduce soldering to individuals, away from the main workshop participants. You may want to have an extra light and magnifying lens on hand because the tiny LEDs can be hard to see when soldering.

Facilitation (the things we say and do to support learning through tinkering)

Facilitation is a way of teaching where you support the learner's own investigations, questions, and ideas within the framework of an activity. In the Tinkering Studio, we strive to practice a kind of facilitation that respects the individual path of the learner. As facilitators, we watch and wait until the precise moment to jump in and offer a hint, a material, or a new way of looking at a problem. As educators, we allow learners to feel frustration and encounter moments of failure as they work with real materials to try to solve their own challenges.

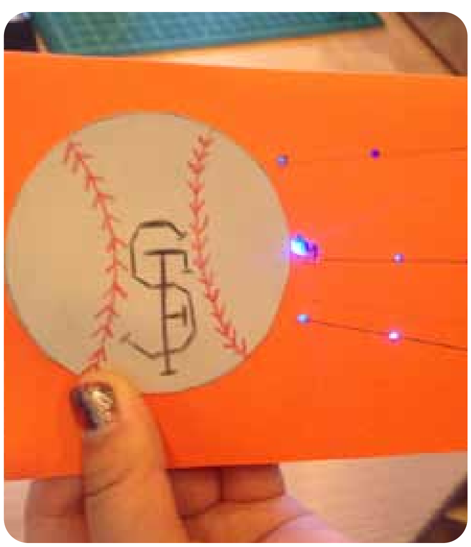
There are many ways that the facilitator can influence the interactions with participants in an activity. We help people get started with the activity by giving a quick sense of the goals. We invite them into the space and introduce the materials and tools they might use. We spark interest and sustain learner's engagement by asking questions about their work and responding to their answers. We support multiple outcomes of the activity and are open to the possibility of new ideas, different solutions, and changing goals of the individual learners. We try to practice a style of facilitation where we are not teachers who transmit knowledge to passive learners, but rather are guides and co-learners on a path to understanding.

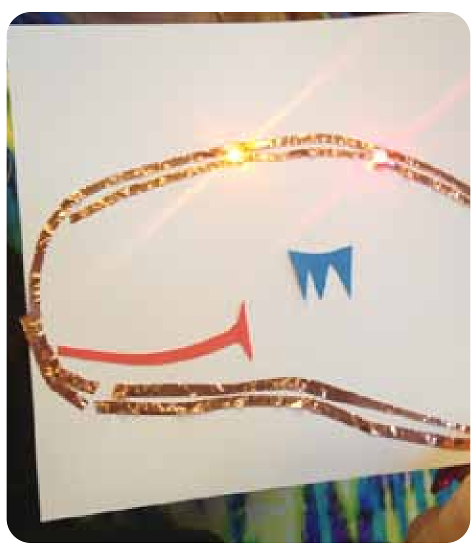
For paper circuits there are a few things to keep in mind as a facilitator. To start, you may want to show a few different examples to the learner and examine the components together. The first challenge you can help a learner start with is getting a single LED to turn on. This allows the learner to practice basic techniques like folding or curving copper tape and exploring LED polarity.

We often have learners draw their designs and circuit pathways with pencils, so we can review their plans together and make adjustments before laying down the tape and LEDs.

It helps to encourage participants to make several iterations, so that the first attempt is low-stakes. You can also ask what the learner is thinking about making next or what other ideas she has so that when she finishes the simple circuit, she's ready to utilize those skills to make something more personalized or complicated. Building a paper circuit can be frustrating; as a facilitator you can keep an eye out for challenges the learner is facing and be ready to step in with a suggestion or tool (like a multimeter) to help diagnose a problem.

A soldering iron is a useful tool for making paper circuits, and it can be used safely when facilitated in the right environment. We often start by asking learners if they've ever soldered before. Even if they have, it helps to reiterate a few safety basics: always wear safety glasses, only hold the insulated handle, don't touch any metal parts below the handle, and always return the iron to its holder when done. We like to introduce soldering as a skill to learners one-on-one to ensure good communication and their safety. We'll work with them on the first few solder points until we're confident that they can continue on their own. Soldering can be intimidating; for more hesitant learners, stay with them as long as needed to help them build confidence in their soldering skills.





RELATED TINKERING ACTIVITIES

Circuit boards: Tinker with electricity using common objects: batteries, lights, buzzers, motors, switches, and more. This activity provides an introduction to exploring circuits before making a paper circuit or an opportunity to continue testing ideas that arose after building a paper circuit.

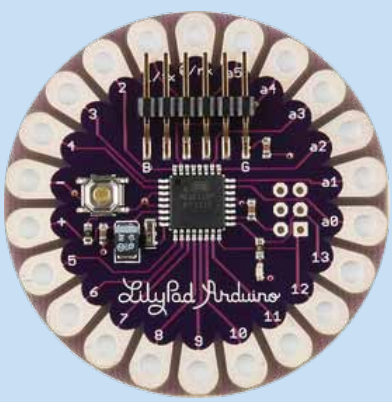
http://tinkering.exploratorium.edu/circuit-boards

Sewn Circuits: Explore a variety of circuits by experimenting with conductive thread, sew-on battery packs, and LEDs. Creating a unique soft electronic patch or wearable object is a great way to build on the basic understanding of electricity that you can develop with circuit boards. Additionally, circuit boards can be used to troubleshoot or plan out ideas while experimenting with these new materials.

http://tinkering.exploratorium.edu/sewn-circuits

ARTIST CONNECTIONS

(inspiring connections to the Paper Circuits activity)



Leah Buechley is a well-known expert in the field of electronic textiles (e-textiles). Her work in this area includes developing a method for creating cloth-printed circuit boards (fabric PCBs) and designing the commercially available LilyPad Arduino toolkit. Her research was the recipient of the best paper award at the 2006 International Symposium on Wearable Computers and has been featured in numerous articles in the popular press including the New York Times, Boston Globe, CRAFT Magazine, Denver Post, and Taipei Times. Leah received PhD and MS degrees in computer science from the University of Colorado at Boulder and a BA in physics from Skidmore College.

Leah came to the Learning Studio for two weeks as part of an NEA Artist in Residence grant. While in residence, she designed and built a large-scale interactive painting, inspired by craftsman-style wallpaper.

http://leahbuechley.org

Jie Qi loves to make things that blend paper craft and personal expression with programming and electronics—like pop-up books.

She is currently a graduate researcher in the High-Low Tech group at the MIT Media Lab and holds a BS in Mechanical Engineering from Columbia University. She previously worked in electronics design and fabrication at Eyebeam Art and Technology center.

http://technolojie.com