chibitronics®

Paper Circuits STEAM Educator's Guide

-Edition 1-

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Welcome to this Guide!

Dear Teacher,

We write to you as the mentor to young learners that you are... as well as a creative learner yourself! Thanks for joining us to explore and share the magical world of STEAM (Science, Technology, Engineering, and Math, blended with Art) through paper circuits.

Paper circuits use friendly art activities and familiar craft materials to introduce new and challenging (but powerful!) concepts like circuits and code.

We believe that the most effective way to learn and teach paper circuits is to put yourself in your students' shoes, play around and make circuit art of your own. On this journey you will encounter both "aha" moments and "huh?" moments, and it will take courage to dive into the unknown. But we assure you it's worth it!

Here's a secret: this journey isn't really about electronics or code, or even papercraft. **It's about creativity, curiosity, self-expression, and being willing to make mistakes along the way** to your own light bulb moments:

> *"I love the light bulb moment for students or teachers in workshops, especially when they are or were like me — intimidated and then empowered. It makes me feel smart and powerful and accomplished and successful when I make the light light up. In fact, that is my FAVORITE part of every workshop – when people exclaim 'Oh! I did it!' I think doing this work is very empowering for girls and those not as confident about science."*
>
> -Molly Adams, high school English teacher

Welcome to this adventure and happy making!

-The Chibitronics Team

How to Use this Guide

This guide begins with an overview and history of paper circuits, as well as an introduction to materials and techniques, suggested learning standards, and elaboration upon the *why* behind teaching with paper circuitry.

Next, Part 1 (*Circuit Sticker Sketchbook*) and Part 2 (*Love to Code*) present lesson sequences for use in the classroom. Be sure to also check out the featured artists, educators, and projects sprinkled throughout the guide!

Finally, templates, assessment tools, and additional resources are in the appendices.

Each lesson includes a teacher preparation section, which comes with the recommendation to craft the circuits yourself. The circuits you build will give you insights about how to support your students' paper circuit explorations, while serving as class demos that you can reuse in future lessons.

In order to help you make decisions about setup, materials, and pacing that will support all of your students, we recommend trying at least one circuit in each of the units you plan to teach as part of your preparation; you know your students and context best. We've provided guidelines to help you get started, but you can feel free to color outside the lines!

Welcome to Paper Circuits

What are Paper Circuits?

Paper circuits are the blend of paper craft with circuits and programming. Instead of using traditional tools like wires and breadboards to build electronics, with paper circuits we use craft materials like conductive tapes with flat, paper-friendly electronic components.

Paper circuits combine the simplicity and expressive flexibility of paper with the interactive and computational possibilities of electronics and code. Each circuit building activity is coupled with a drawing or crafting activity to show that the circuit alone is incomplete. Rather, it's when we transform the circuit with a story or scene that the technology comes to life with purpose and meaning.

By using familiar and friendly paper crafting techniques as an on-ramp to creating technology, paper circuits make electrical engineering and coding more approachable, especially to those who might otherwise find it intimidating. The expressive aspect of paper circuits helps make building electronics interesting to others who might otherwise find circuits and coding too abstract or removed from their everyday experiences.

High school AP art class and student artworks by Joy Schultz (left and lower center), student artwork and fourth graders from Novi School District by RJ Webber (upper center and right)

Or as professor Mitch Resnick put it, the goal is to build wide walls, in addition to low floors and high ceilings. "When [learners] work on projects they care about, they're willing to work longer and harder, persist in the face of challenges, and make deeper connections to the ideas they encounter" (Resnick, 2016).

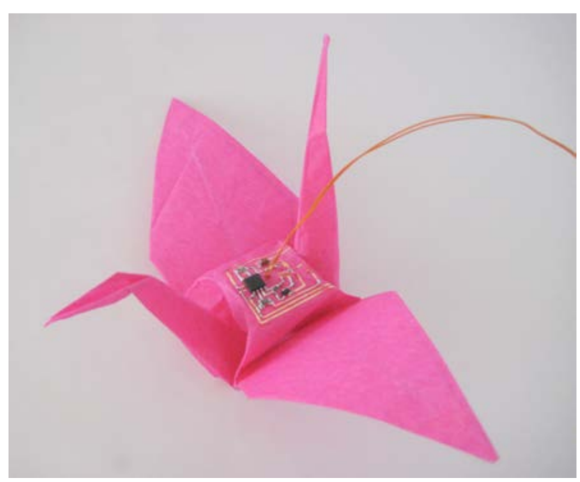
Starting with Wonder

At the heart of paper circuits is creating a sense of **wonder**, the energizing feeling of surprise and engagement at encountering something new amongst the familiar — for example, a scientific phenomenon, captivating artwork, or in our case seeing a plain piece of paper come to life with electricity!

Wonder snaps us out of our routine, sharpens our senses and captures our attention, giving us a sense of exciting possibility that there is more to the world than meets the eye (Bennett, 2001).

From wonder springs **curiosity**, which leads us to investigate and try to understand the new encounter. If we manage to explore and successfully explain the new phenomenon, the joy and empowerment of discovery helps fuel further curiosity and learning (Csikszentmihalyi, 1996).

However, if our solo attempts to explain the new repeatedly fail, or we come to associate the unknown with the threat of failure instead of increased discovery, we experience fear instead of wonder. Fear shuts down our senses and draws us away from the unknown back to safety.



So in order to cultivate wonder and curiosity, we must create spaces where learners can feel confident enough to leap into the unknown, ask each other questions and make sense of what they find. Confidence doesn't mean, "I know I'm right," but rather, "I'm willing to try" (Duckworth, 2006).

With paper circuits, the friendliness of the paper medium enables learners to build upon their existing knowledge, providing a safe and familiar space from which to explore the unfamiliar world of electronics and code. The open nature of paper circuits — components and connections are openly exposed — also make it great for learning debugging skills, both individually and collaboratively.

What we mean by STEAM

The term STEAM adds "Art" to STEM (Science, Technology, Engineering, and Math). But what exactly does this mean? For many, the term refers to cross-disciplinary teaching that blends multiple, varied subjects.

For us, STEAM is about using STEM as a medium to ask and explore big questions in ways only possible through the arts, questions like "Who are you?" and "What do you care about?" and "What is your relationship to the world?" It's an integrated experience with art at the core: finding meaning and connection through creating.

Situating STEM within the freedom of open-ended art activities also helps remove the pressure and limitations of "getting the right answer," because in the arts — as in life — there is often no correct answer. Sometimes there may not even be a question! Instead, students are empowered to lead their own explorations, decide for themselves what is meaningful and have trust in themselves to choose what success looks like.

STEAM is not about particular techniques or combinations of subjects, but rather it's about nurturing new forms of creativity so that students expand their imaginations and ask their own questions, maybe even questions that have never been asked before. The goal is not just to make, but to make believe!

Stretching Time and Creating Space

While it's easy to get excited about boundless open exploration, we also understand that in many classrooms it may feel impossible to achieve due to time-crunched classes and limited resources. You are not alone!

We've found that one of the most effective ways to stretch time and resources in the classroom is through **collaboration**: students teaching students as well as sharing tools and materials. Collaboration not only helps to stretch limited resources, it also helps move the classroom teacher from "sage on the stage" to "guide on the side," giving students the opportunity to practice communication skills, negotiate being out in the world, and ultimately connect with one another.

Check out our Collaboration and Troubleshooting sections for ideas on collaborating with paper circuits.

Equity in the Classroom

A core mission of Chibitronics is to broaden participation in technology and provide high quality learning experiences for *all* students. The following are some pedagogical approaches we recommend for using paper circuits to support equity in your classroom:

Celebrate Difference
Provide multiple paths to ideas and multiple ways to demonstrate learning; celebrate different kinds of projects and make space for divergent interests, approaches, and perspectives.

"Guide on the Side" rather than "Sage on the Stage"
Position students as scientists, makers, and artists, and as resources for each other to collaborate and solve problems.

Connect with Cultures and Communities
Create opportunities to make meaningful connections to topics that are relevant to student identities, communities, cultures, and futures. This includes the everyday lived experiences of students and the different places and languages (family, community, school) that they move through on a daily basis, as well as larger social and historical contexts that impact them. Meaningful projects could connect to events that impact students and their communities, create space to discuss their needs and thoughts as people, and/or help them build empathy for others. (Madkins et al., 2020, Vossoughi et al., 2016)

Diverse Role Models and Approaches
Address bias and stereotypes in the world of technology, and make sure that students see diverse examples of artists, scientists, and makers, as well as a diversity of approaches to technological making.

Start with Creative Agency
Treat creative agency for all students as something that does not need to be earned through good behavior or academic success (Adair & Colgrove, 2021), but rather as a starting point to spark interest and curiosity. In our work with thousands of young learners, we have seen many struggling students find their "spark" when given the opportunity to make their own paper circuits creation, often going beyond the assignment.

The Story of Chibitronics

Paper circuits began as an art and research project by Jie Qi, cofounder of Chibitronics, while she was a student at the MIT Media Lab under the advisorship of Leah Buechley, in the High Low Tech Group.

What started as an assignment from Leah to make examples of DIY paper sensors and switches eventually resulted in this electronic pop-up book:

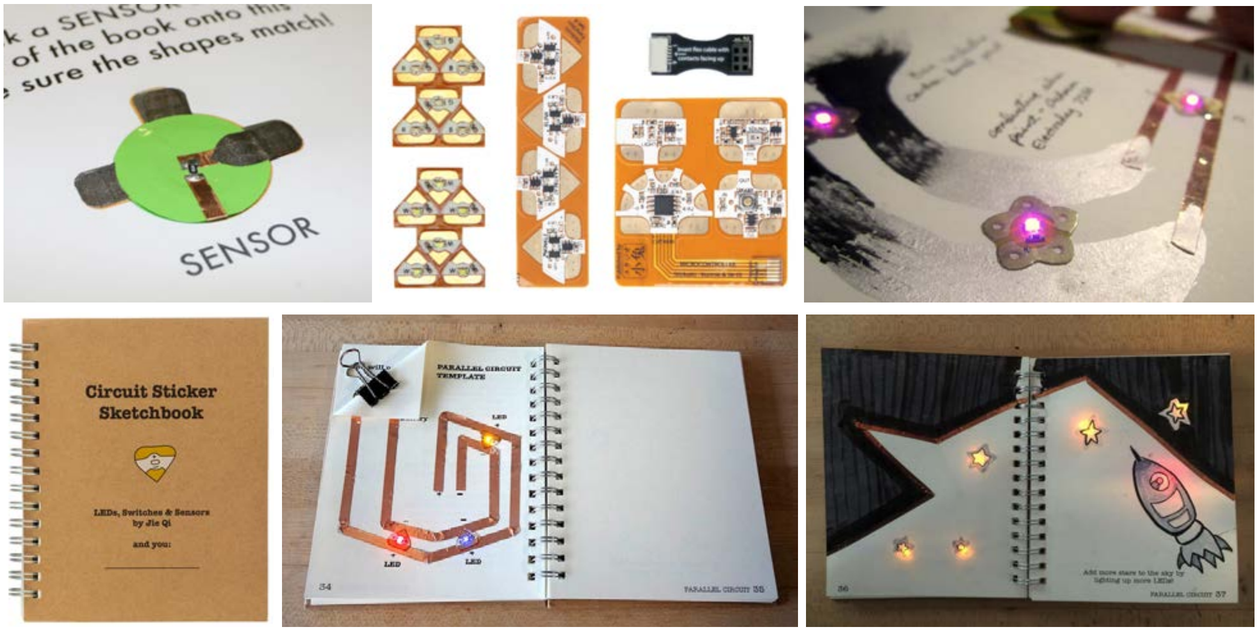
Images by Leah Buechley

At first Jie made paper buttons and knobs that were squares and circles, like the ones we encounter on our everyday electronic devices. But because paper was so easy to customize, she soon started making sensors that looked like flowers and fish and stars. It was empowering to create technology that didn't look and feel at all like what we typically see, that was entirely her own. Jie fell in love with how sprinkling in circuits and code opened whole new worlds of possibility for the paper medium.

Pu Gong Ying Tu (Dandelion Painting) left; Animating Cranes (center), Novel Architecture (right). Image by Brian Mayton

She soon found that many others wanted to learn paper circuits: artists wanted to incorporate technology into their work, engineers wanted to create art, and many others of all ages and backgrounds. The materials sparked curiosity in many who didn't previously have an interest in electronics, particularly women and girls.

However, the off-the-shelf electronic components Jie used were challenging for beginners and younger learners, such as LEDs that were smaller than a grain of rice! So she and Natalie Freed, also a student at the MIT Media Lab, began prototyping their own tools. From these experiments came circuit stickers, which are flexible printed circuit boards that look and feel like regular stickers but also function as electronic modules.



Circuit Sticker prototyping iterations (top) and Circuit Sticker Sketchbook, a friendly hands-on guided introduction to paper circuits, released with the launch of circuit stickers (bottom). Sketchbook drawing by Asli Demir.

With the goal of making paper circuits accessible to a wider audience outside the lab, Jie teamed up with Andrew "bunnie" Huang, an open source hardware engineer and manufacturing expert, to create the company Chibitronics. "Chibitronics" comes from the Japanese word "chibi" which means little and cute and "-tronics" is from electronics. Rather than intimidating and inaccessible, their vision was to make technology small, friendly, and even cute!

Since Chibitronics first launched in 2014, thousands of creators and K12 educators in all 50 states and over 50 countries throughout the world have used our tools to create paper circuits. Teachers and learners from virtually all subject areas have integrated paper circuits into their lessons, from light up poetry to interactive history maps, from animated scientific diagrams to electronic murals. You can explore what the educator community is up to on our Twitter (@chibitronics) or get inspired by some gorgeous creations from the art and craft community on our Instagram (@chibitronics).

What makes us most excited is seeing more and more people embracing the idea that art, design, engineering, and storytelling do not need to be split—that technology can be expressive, emotional and accessible. Learning and creating with STEAM doesn't require expertise or an engineering degree to participate, and inspiring applications of technology can come from creators of all backgrounds, ages and interests!

Star card by Tiffany Au, light-up fans by Eiko Uchida, pop-up house card by JooYeong Lee, and haunted house by Maya Isaksson.

Teacher Testimonials

Ideas, inspiration, and words of wisdom from the Chibitronics Educator Ambassadors

Shoshanna Cohen, K-5 STEAM Specialist at a Title One school in Seattle, WA
"The best advice I could give teachers just starting with paper circuits is: Just dive in. Jump in knowing that you will make mistakes and things will go wrong. The lights will work one minute and then not even flicker the next. You lined up the copper tape just right and yet your LED just won't reach. But the more and more that you learn from these challenges and keep moving forward, the quicker you can identify a problem and troubleshoot before you even test your project out." Check out Shoshanna's paper circuits intro lesson slides here!

Holly "Manzie" Manswell, Special Education teacher in an Early College Initiative school grades 6-12 in the "South Bronx" NYC
"Chibitronics has allowed me to take a difficult subject like physics and make it accessible to special needs students in a way they understood. When the students started learning about the different kinds of circuits, the *Circuit Sticker Sketchbook* helped the students have a real-world experience in designing and seeing how each circuit works. Because of this, the students were able to explain and design projects utilizing the lessons learned with Chibitronics. In ELA, the students are making interactive stories, allowing them to think deeply about details as they write."

Darshell Silva, Librarian, Nathanael Greene Middle School (grades 6-8) in Providence, RI.
"Paper circuits are a fun and engaging activity for school libraries, makerspaces, and classrooms. They can be used in so many different ways. You can use them for simple creative projects, posters, complex visualizations, models, interactive designs, or just about anything else that you can think of! I love seeing the imaginative ways my students think up to use them. Don't be afraid to get in there and learn with your students! I have as much fun thinking of new ways I can use paper circuits in my library as I do teaching my students to use them!"

Holly Pierce, STEAM SmartLab Facilitator at Colorado SKIES Academy Middle School (grades 6-8) in Englewood, CO. An aerospace focused PBL school.
"One thing I do to start out my lessons is to give learners a battery and an LED light. I don't tell them anything, but tell them to explore. This shows them my expectations for the entire year, that they will take materials and explore to see what works and why they work. Then once they get the LED to light up, we discuss how it works so they learn which side is positive and negative. We refer back to that many times throughout the future lessons. After teaching a few basics, learners made their own version of a larger project (some chose an airplane, airport, ping pong game, haunted house, and even a roller coaster.)"

Evonne Hackett, STEAM Lab Teacher, Lakeview Middle School (grades 6-8) in Rossville, GA
"Students love having opportunities to show learning in a way other than through text or taking a test. Our paper circuits unit was a great way to pull in students that say they are not interested in technology. One student was excited to explain how completing a paper circuit was similar to using jumper cables on a car. Teaching is so rewarding when students can overlap subjects and carry over concepts to everyday learning and activities."

Suggested Standards

Topic	Relevant Standards	In Practice with Paper Circuits STEAM Projects
Media Arts & Visual Arts National Core Arts Standards: - Media Arts - Visual Arts	MA:Cr1.1 MA:Cr2.1 MA:Cr3.1 MA:Pr4.1 MA:Pr5.1 MA:Pr6.1 MA:Re7.1 MA:Re8.1 MA:Cn10.1 MA:Cn10.1 MA:Cn11.1 VA:Cr1.1 VA:Cr2.1 VA:Cr3.1 VA:Re8.1 VA:Cn10.1	→ Individually and collaboratively, develop ideas for paper circuit artwork through creative processes such as brainstorming, sketching, experimenting, and prototyping → Develop and present a project plan considering artistic intent, available resources, and audience → Integrate multiple content areas and media into a unified production (interdisciplinary artwork incorporating paper-based media and electronics) → Develop proficiency and craftsmanship in use of papercraft and paper circuits tools and techniques → Apply internal and external knowledge (such as interests, experiences, research, and cultural understanding) to inform the creation of artwork → Connect artistic work with societal, cultural, and historical context
Social and Emotional Learning	CASEL Self Awareness	→ Express and reflect on identities through art → Identify and express emotions through art → Experience self-efficacy; cultivate a growth mindset → Develop interests and a sense of purpose
Collaboration	MA:Pr5.1. VA:Cr1.1.5a VA:Cr1.2.4a CSTA 1B-IC-20 CSTA 1B-AP-12 CSTA 1B-AP-16 CSTA 2-AP-18 CCSS.MATH.PRACTICE.MP3 CASEL Relationship Skills CASEL Social Awareness	→ Give peer feedback and collaborative troubleshoot → Engage in peer instruction → Pair program with the Chibi Chip → Collaboratively set goals, distribute tasks, and maintain a project timeline for a group project → Brainstorm and combine ideas towards a shared project goal that is meaningful and has purpose to the makers. → Practice teamwork and collaborative problem solving *See Collaboration for tips and ideas*
Communication	CSTA 1B-AP-17 NGSS Practice 8 CASEL Relationship Skills CCSS.ELA-LITERACY.RST.6-8.3	→ Describe choices made during project development using presentations and demonstrations. → Create artwork to convey a message or narrative → Seek or offer support and help when needed → Follow precisely a multistep procedure when carrying out experiments or performing technical tasks.
Project Planning	NGSS Engineering ETS1.A, ETS1.B, ETS1.C CASEL Self-Management	→ Design, prototype, troubleshoot, and refine a paper circuit artifact in response to a design challenge, taking into account materials and design constraints → Set goals; use planning and organizational skills

Physical Science NGSS	NGSS 4-PS3-2 NGSS 4-PS3-4	→ Design and build electrical circuits that transfer stored energy from a battery to produce light. → Plan and carry out investigations to answer questions about electricity and electric circuits
Computer Science & Computational Thinking CSTA Standards	CSTA 1B-AP-09 CSTA 1B-AP-10 CSTA 1B-AP-12 CSTA 1B-AP-15 CSTA 1B-AP-16 CSTA 1B-AP-17 CSTA 1B-IC-20 CSTA 1B-DA-07 CSTA 2-CS-02 CSTA 2-DA-08 CSTA 2-AP-13 CSTA 2-AP-17 CSTA 2-AP-19 CSTA 2-AP-18 CSTA 3A-DA-11 CSTA 3A-CS-03 CSTA 3A-AP-13 CSTA 3A-AP-16 CSTA 3A-AP-23	→ Individually and collaboratively develop computational artifacts for practical intent, personal expression, and/or to address a societal issue → Design projects that combine hardware and software → Test and debug programs → Modify and remix existing programs → Create programs that include sequences, events, loops, conditionals, and variables → Communicate through code comments, presentations, and demonstrations → Break problems down into smaller parts → Incorporate feedback from users *For more detail, see Suggested CSTA Standards for Part 2: Creative Coding with Love to Code*
Technology ISTE Standards	ISTE 1.4 a, b, c, d ISTE 1.6, a, b, c, d	→ Use a variety of technologies to identify and solve problems by creating new, useful or imaginative solutions. → Develop, test and refine prototypes as part of a cyclical design process.
Mathematics Common Core Mathematics Standards	CCSS.MATH.PRACTICE.MP1 CCSS.MATH.PRACTICE.MP3 CCSS.MATH.PRACTICE.MP4 CCSS.MATH.PRACTICE.MP6	→ Determine length and quantity of materials needed for different project designs, using appropriate units → Design and iterate on 2D and 3D paper forms → Work with patterns and rhythms → Reason with and analyze constraints and relationships between variables; looking for rules → Use diagrams to work out and communicate ideas Mathematical practices: → Make sense of problems and persevere in solving them → Construct viable arguments in support of a design or problem solution and critique the reasoning of others → Apply mathematics to solve everyday problems → Attend to precision → Reason abstractly and quantitatively
Cross-curricular projects	The sky's the limit! Examples: → Language Arts: Design an interactive representation of a text main idea → History: Create an interactive model representing a historical event or place	

Lesson Sequences

Grade Level Suggestions

We provide a few possible sequences through the lessons organized by grade level below. Please consider these to be starting points rather than rigid guidelines.

Grades 3-5	Grades 6-8	Grades 9-12
↓	↓	↓
Circuit Sticker Sketchbook Lessons 1-6	*Circuit Sticker Sketchbook* Lessons 1-6	*Circuit Sticker Sketchbook* Lessons 1-3
↙ ↘	↓	↓
Love to Code Lessons 1-3 using Microsoft MakeCode* / Illuminated Story	*Love to Code* Lessons 1-10 using Microsoft MakeCode	*Love to Code* Lessons 1-10 using **Chibi Script*** *or* Microsoft MakeCode

* *Love to Code*, our creative coding activity book, is available in two different programming languages, Microsoft MakeCode and Chibi Script. See MakeCode and Chibi Script Code Editors for more details.

Museum, makerspace, or library drop-in activity

↙ ↓ ↘

- Paper circuit card
- Add to a paper circuit mural (with or without Chibi Chip)
- Add to a paper city (with or without Chibi Chip)

"Hour of code" activity
(Intro to coding in 2-3 sessions)

↓

Illuminated Story

Circuit Murals: *Circuitree Mural, Making@Siggraph 2015*

Students collaboratively building a "paper circuit city."

Lesson Summaries

Part 1: Circuit Sticker Sketchbook	**Vocabulary**	**Learning Objectives**
Lesson 1: Intro to Paper Circuits *One 45 minute lesson*	LED (light emitting diode) battery positive negative emphasis	→ Build a working circuit with an LED, conductive tape, and a battery → Use an iterative troubleshooting process to fix circuits that aren't working → Use light as an artistic element in an illustration
Lesson 2: Switches, Silhouettes, and Shadows *Two 45-minute lessons or one 90-minute lesson*	switch diffuse silhouette	→ Build a paper switch to turn on and off LEDs → Explore effects of light through different materials and select a specific material and technique towards an artistic goal → Use the hiding and revealing of information to tell a story with interactivity
Lesson 3: Parallel Circuit + Design a Circuit *Two 45-minute lessons or one 90-minute lesson*	component trace parallel circuit	→ Build and troubleshoot a parallel circuit incorporating multiple LEDs → Plan, sketch, and build a paper circuit of their own design with multiple LEDs → Use circuit traces as an artistic element
Lesson 4: Blinking Slide Switch *Two 45-minute lessons or one 90-minute lesson*	switch gap rhythm tempo	→ Use a linear switch that blinks an LED in a rhythmic sequence → Use a light pattern or rhythm as a narrative technique in a media art piece
Lesson 5: Animated Slide Switch *Two 45-minute lessons or one 90-minute lesson*	animation switch contact switch gap	→ Use an animated slide switch to light up multiple LEDs in sequence → Use animation as a narrative technique in a media art piece
Lesson 6: Pressure Sensor *One 45 minute lesson*	conductor resistor sensor meaning	→ Use a pressure sensor circuit to fade an LED in and out → Use a pressure sensor to light colors in sequence & explore other pressure sensor effects → Use interactivity to tell a story
(Supplement) Circuit Science: Conductors, Resistors, Insulators *One 45 minute lesson*	conductor resistor insulator	→ Evaluate how conductive a material is by observing the brightness of an LED when the material is placed in the circuit → Categorize everyday materials as electrical conductors, resistors, or insulators → Consider artistic applications of the electrical properties of different materials

Part 2: Creative Coding with Love to Code	**Vocabulary**	**Learning Objectives**
Lesson 0: Illuminated Story *Two 60-minute lessons or one 120-minute lesson*	mood microcontroller program I/O (input/output) pins	→ Power an LED circuit from the Chibi Chip → Upload a program to the Chibi Chip → Write a Chibi Chip program that creates a unique blinking pattern and changes the brightness of an LED → Use a light to evoke a mood in an illustrated narrative
Lesson 1: Getting Started *One 45-minute lesson*	voltage current ground short circuit	→ Power an LED circuit from the Chibi Chip → Identify and fix broken connections, short circuits, and LEDs placed in reverse → Use light as an artistic element in an illustration
Lesson 2: Parallel and Series Circuits *Two 45-minute lessons or one 90-minute lesson*	parallel circuit series circuit conductor insulator	→ Build a parallel circuit and a series circuit to observe differences and similarities → Explore trace design techniques like turning corners, junctions and insulator bridges → Plan, sketch, and build a parallel circuit of their own design powered by the Chibi Chip → Use circuit traces as an artistic element
Lesson 3: Begin With Blink *Two 45-minute lessons or one 90-minute lesson*	microcontroller program I/O (input/output) pins loop	→ Upload a program to the Chibi Chip → Write a program that blinks an LED connected to the Chibi Chip with custom patterns → Use the "on start" and "forever" structures to write code that runs once or repeatedly in a loop → Express emotion and mood using light patterns
Lesson 4: Programming Multiple Pins *One 45-minute lesson*	narrative	→ Construct a circuit with multiple LEDs connected to different microcontroller pins → Make different LEDs in the circuit turn on and off in custom patterns by programming multiple microcontroller pins → Use animation sequences and silhouette "reveals" to narrate a story in time and space
Lesson 5: Design and Program a Circuit *Two 45-minute lessons or one 90-minute lesson*	circuit layout placement routing bill of materials	→ Sketch, built, and troubleshoot a circuit of the student's own design → Write a bill of materials (BOM), a list of the materials needed to build a particular circuit → Measure and estimate the length of conductive tape needed in a circuit → Optimize a design for artistic and technical goals
Lesson 6: Programming with a Switch *One 45-minute lesson*	switch event-driven variable conditional	→ Build and program a switch to control lights → Use event-driven logic to trigger a light sequence when a switch is pressed → Use a variable and conditional logic to program a switch that toggles lights on and off → Create art that responds to audience interaction

Lesson 7: Design a Switch *Two 45-minute lessons or one 90-minute lesson*	sense input switch contact switch gap mechanism	→ Build and personalize a variety of paper switches → Brainstorm and prototype a switch of their own design → Use models to communicate an idea or story
Lesson 8: Fading and While Loops *One 45-minute lesson*	fade out fade in analog PWM (pulse width modulation)	→ Use analog output with PWM (pulse width modulation) to set different brightness levels on the I/O pins → Use a variable to track and update the current brightness level of an LED → Use a while loop and comparison operator to smoothly fade in and out an LED → Create mood and express emotion using animated light patterns and lighting effects
Lesson 9: Multithreading *One 45-minute lesson*	thread multithreading race condition choreography	→ Use multithreading to make pins run different code simultaneously and independently → Avoid race conditions by writing code with instructions that do not conflict with instructions for other pins → Combine independent behaviors to create a coordinated, cohesive whole
Lesson 10: Love to Code Light Sensor Part 1 *One 60-minute lesson*	light sensor analog input digital input environmental sensing	→ Build a light sensor paper circuit → Use thresholds (high/low) to make decisions in code based on light sensor readings → Use analog input (read level) to read light levels and map it to the brightness or dimness of an LED → Create art that responds to environmental conditions
Lesson 11: Love to Code Light Sensor Part 2 *One 60-minute lesson*	calibrate threshold data art	→ Build a light sensor paper circuit → Use analog input (read level) to read the light level and map readings to a "light meter" readout → Adjust (calibrate) sensor thresholds in code to account for ambient light conditions → Create art based on sensor data

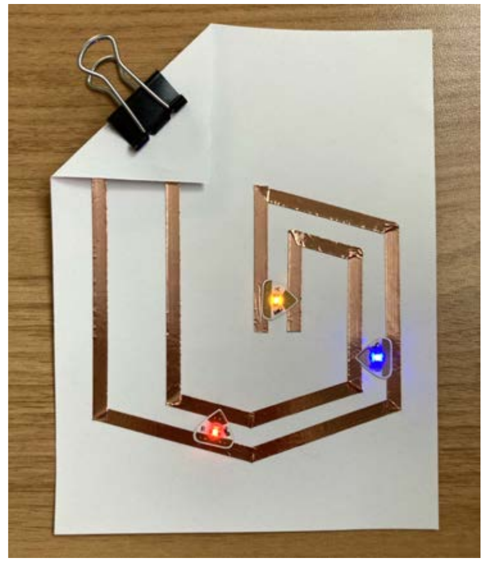
Getting Started with Paper Circuits

This section covers practical information for creating paper circuits: basic parts, choosing tools and materials, and core techniques. To try building a first paper circuit, check out our Paper Circuit Card project!

Anatomy of a Paper Circuit: the Electronics

Battery-powered LED circuits (covered in Part 1 lessons)

Conductive copper tape, LED Circuit Stickers, 3 volt "coin cell" battery, small binder clip



Parallel circuit assembled, with red, yellow,and blue LEDs. Battery is sandwiched inside the fold

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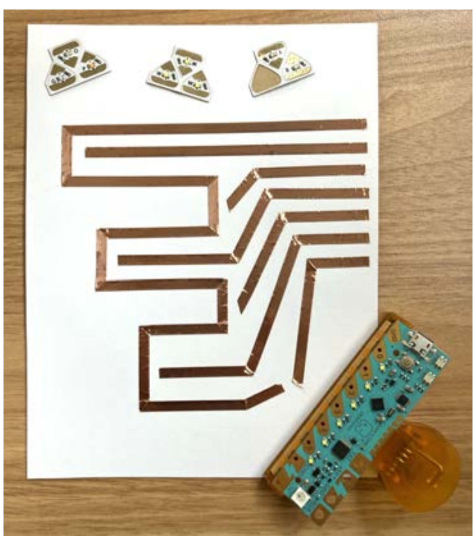
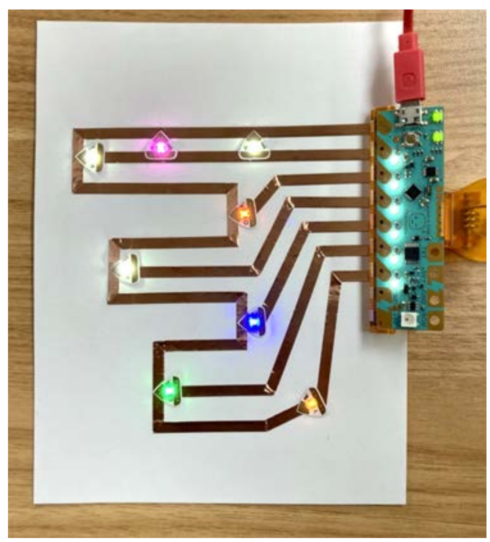
Chibi Chip (microcontroller) LED circuits (covered in Part 2 lessons)



Conductive copper tape, LED Circuit Stickers, Chibi Chip microcontroller with clip



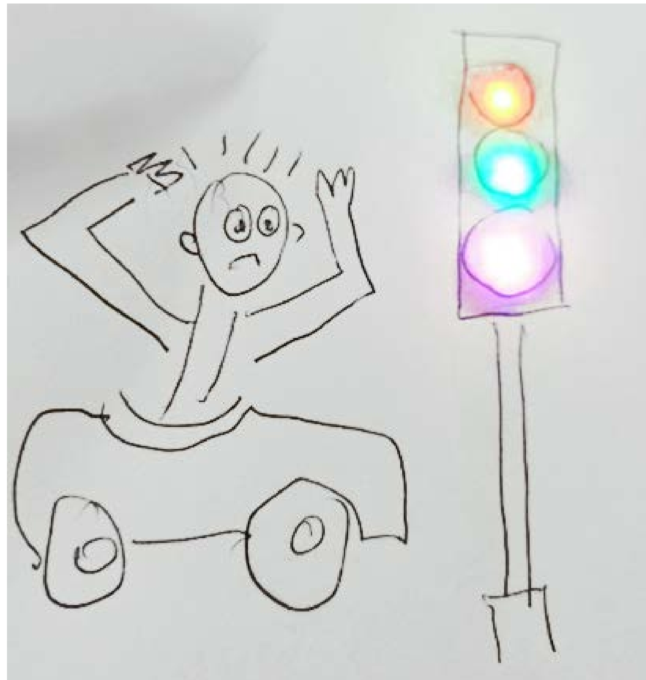
Circuit assembled, with one or more LEDs connected to each programmable "input/output pin"

How might these circuits tell a story? What will they illuminate?

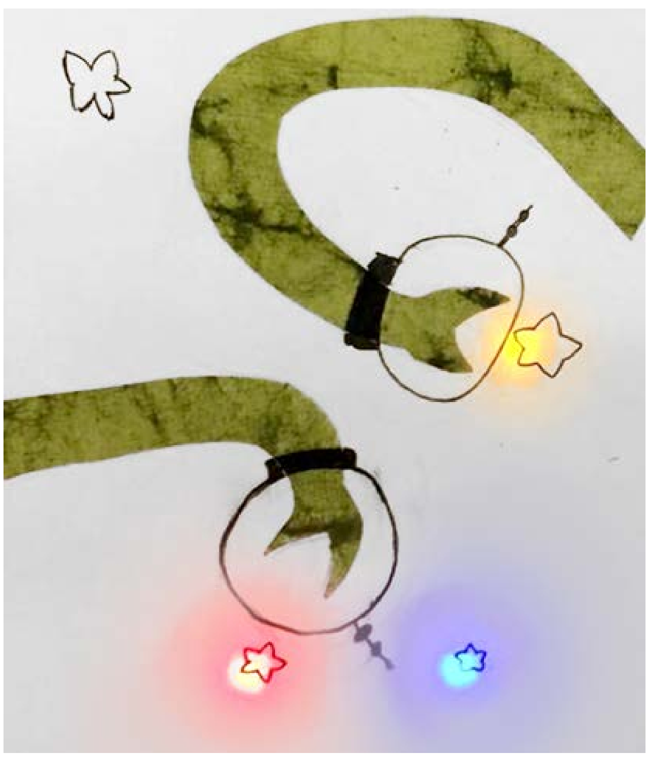
Anatomy of a Paper Circuit: the Art

Consider not just the ***how*** of a circuit, but the ***why***... These four versions of the parallel circuit on the previous page use the same materials to tell a different story. What emotion or idea did each artist express?

Suzanna



Anonymous



Asli Demir

Esther Gibert

And keep in mind: circuitry itself can be art too!

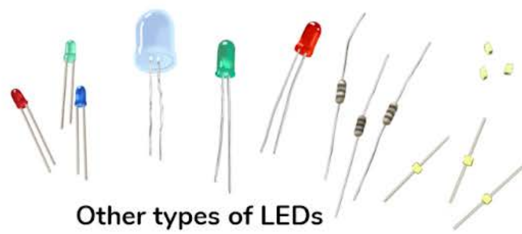
Materials and Tools

What defines paper circuits are the materials: instead of wires and breadboards, we use tapes, paper and conductive glues. However, there are so many different options to choose from! Where to begin?

Here are the basic materials and tools you need to get started with paper circuits. These are tried and true tools - some we've created ourselves! - chosen for their ease-of-use and versatility based on hundreds of workshops with learners of all backgrounds and skill sets.

LED Circuit Stickers

A LED Circuit Sticker is a tiny LED and resistor on a flexible mini circuit board with special conductive adhesive. The resistor protects the LED and allows all the different colors of LEDs (white, red, yellow, blue, green, orange, pink) to work together.

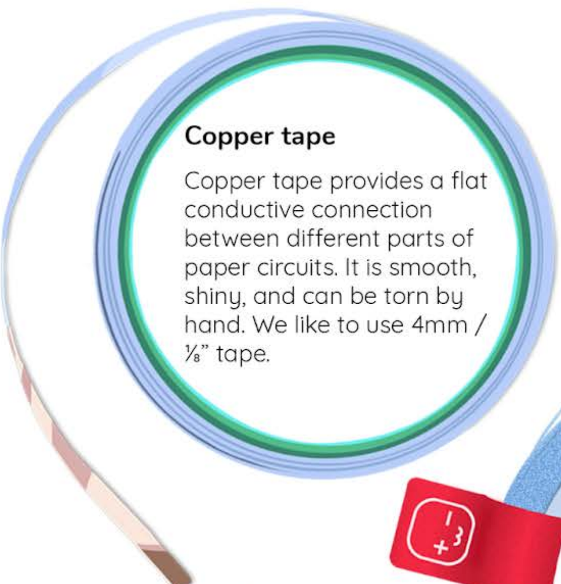


Other types of LEDs

LEDs exist in many shapes and sizes including through hole (look like gumdrops), axial (connectors stick out to the sides), and surface mount (tiny and flat).

CR2032 coin cell batteries

These small flat batteries provide 3V of power and a capacity of about 230 mAh. The number 2032 means 20mm diameter x 3.2mm thickness.



Copper tape

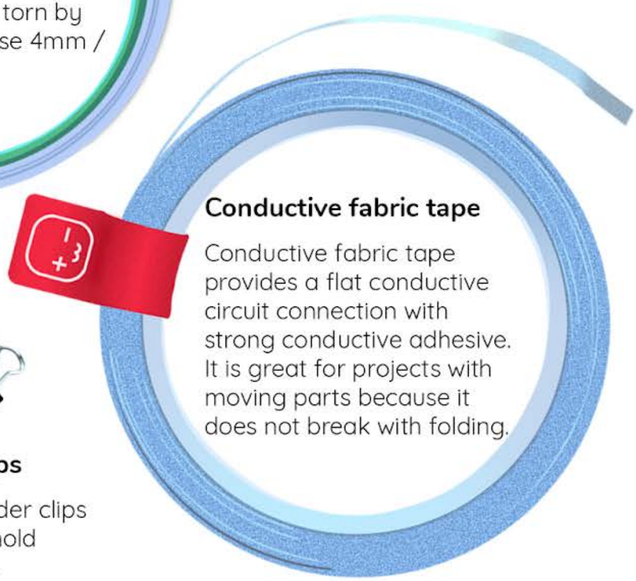
Copper tape provides a flat conductive connection between different parts of paper circuits. It is smooth, shiny, and can be torn by hand. We like to use 4mm / ⅛" tape.

Conductive fabric tape patches

Conductive fabric tape patches are pre-cut to act as small "circuit bandages" to repair circuits or add more secure hinges to copper tape connections.

Effect Stickers

Effect stickers are pre-programmed with different light effects: blink, fade, twinkle or heartbeat. Connect one or more LEDs to see the effect in action.

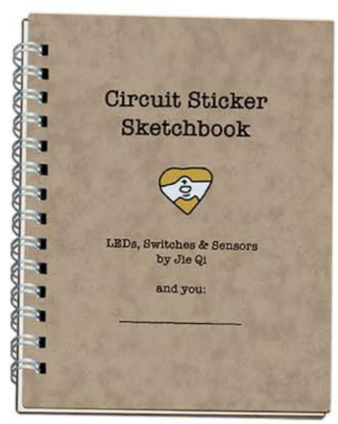


Conductive fabric tape

Conductive fabric tape provides a flat conductive circuit connection with strong conductive adhesive. It is great for projects with moving parts because it does not break with folding.

Small binder clips

We use office binder clips in size "small" to hold batteries in place.



Circuit Sticker Sketchbook

This interactive sketchbook teaches the basics of circuits and electronics with 5 paper circuit templates.

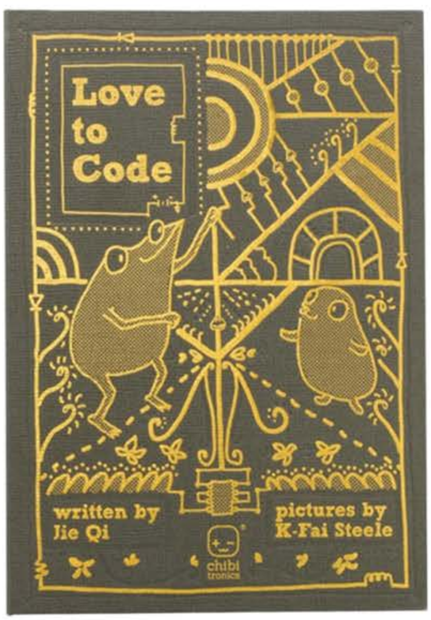
See [Circuit Sticker Sketchbook Suggested Tools and Materials](#) for supply lists and where to order.

Materials: Love to Code

Once your students are comfortable with basic paper circuits, we've designed these tools to level up their paper circuits with creative coding! See LTC Suggested Materials for supply lists and where to order.

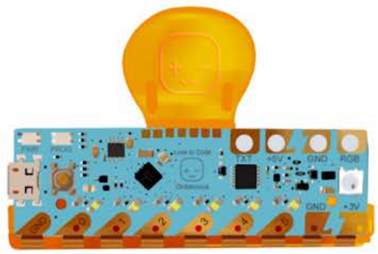
Love to Code Stencil

This stencil matches the Chibi Chip to help plan out circuits that use LEDs, sensors, and the Chibi Chip.



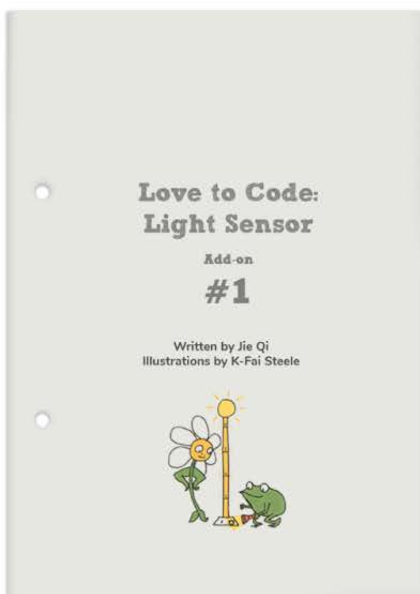
Love to Code vol 1 book and binder

Love to Code vol 1 is an activity book full of paper circuit templates that teaches coding and physical computing with the Chibi Chip. There are two versions: one uses Microsoft MakeCode block programming, and the other Chibi Script text code. An optional binder holds the pages and provides battery power for the Chibi Chip.



Chibi Chip

The Chibi Chip is a paper-friendly microcontroller that can be clipped to paper circuit creations, allowing them to be controlled with code to create interactive effects and animations. The Chip can be removed from the clip and attached more permanently to a circuit.

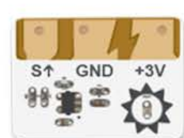


Love to Code Light Sensor Add-on

The Light Sensor Chapter is an extension to LTC Vol 1 that teaches you how to use the light sensor sticker with the Chibi Chip and build fun projects like a light-o-meter.

Chibi Scope

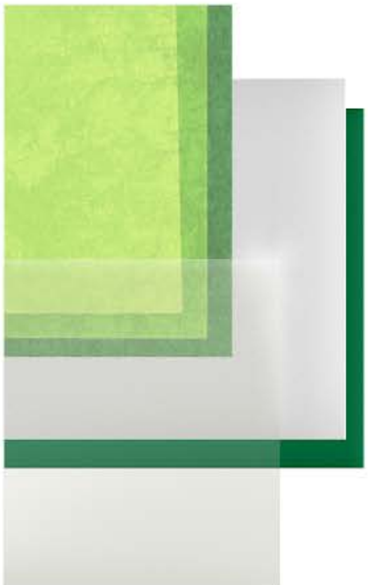
A tiny screen with probes designed to help you understand what's going on inside your Chibi Chip. You can print text to it, display sensor values, measure voltage levels, and visualize voltage changes over time with a tiny graph.



Light Sensor Sticker

Light sensor stickers measure visible light shining on the sticker so you can create circuits that respond to different light levels.

Materials: Papercraft



Paper

Tissue Paper: Adds color, texture and softness to light shining through.
Tracing paper or vellum: Translucent papers that beautifully diffuse light.
Cardstock: Great for making 3D pop-ups, moving paper circuit elements and sturdier circuits.

Pressure-sensitive conductive plastic

This special plastic conducts more electricity the harder you press on it. You can use it to make pressure sensors and create many interesting effects.

Clear Tape

Great for holding down non-sticker electronic parts and insulating between conductive traces.

Washi tape

Decorative and easy to remove, great for insulating between conductive tape traces.

Blue tape

Useful for practicing tape folds and insulating between conductive traces.

Multimeter

Device that measures voltage, current, and resistance and tests if two points in a circuit are electrically connected. Very useful for debugging circuits.

Brads, pushpins, paperclips

For making papercraft switches and moving mechanical paper circuit elements.

Magnets

Great for making switches, battery holders and generally securing mechanical connections.

Alligator clips

Clippable wires for making temporary electrical connections.

Soldering iron

This tool heats up to melt solder wire for making very secure electrical connections, an advanced technique for those ready to level up their paper circuit skills.

Tweezers

For working with small parts such as surface mount LEDs.

Scissors

For cutting conductive tapes and paper.

Choosing your Materials

Even within the world of paper circuit supplies, there are still lots of options to pick from. The following are some detailed comparisons to help you choose the right options for your particular project and classroom.

Types of Conductors: Copper Tape vs Fabric Tape

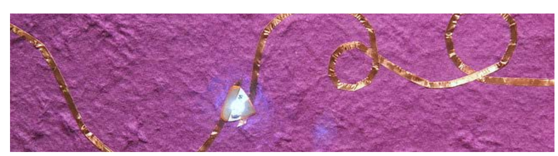
Conductors are conductive materials that connect the parts of your circuit and make up the bulk of the circuit itself. The most popular options for paper circuits are **copper tape** and **conductive fabric tape** (sometimes referred to as **fabric tape**) which also comes in the form of **fabric patches**.



	Copper Tape Made of copper metal so conducts as well as metal wire	**Conductive Fabric Tape** Made of conductive fabric and feels like ribbon, but conducts slightly less	**Fabric Patches** Pre-cut pieces of conductive fabric for patching circuits
Pros	→ **Holds its shape** so may be easier to work with → **Shiny copper color** is great for decorative circuitry → **Can be soldered** for more secure connections to electronic components	→ **Flexible and does not break** when folded repeatedly → **Does not tear** when turning corners → **Strong conductive adhesive** so you can patch or extend circuits just by taping on top of them	→ **Useful with copper tape** to branch, repair, or add hinges → **Great for classroom use** – teachers can hand out a few patches at a time for students to use in their circuits without waste.
Cons	→ **Cracks when folded repeatedly** and can tear at corners, making it tricky for some beginners → **Sharper metal edges**	→ **Less conductive across long lengths,** though not an issue for most paper circuits → **Requires scissors to cut** → **Cannot be soldered**	→ **Must be used in combination with other conductive tapes** (not long enough alone for making paper circuits)
Use For	→ Tiny to very large-scale projects → Circuits that need soldering	→ Circuits with lots of folds, bends and moving parts → Textile and paper-based projects	→ Patching copper tape circuits → Reusing circuit sticker components

In Summary:

Conductive fabric tape has more reliably conductive adhesive and is more forgiving of taped connections, though we still recommend folding rather than sticking where possible.



Some people find **copper tape**'s ability to hold a shape easier to work with, like its shiny appearance, or would like to solder to the tape.

Try both conductive tapes and see what you prefer for your students. We like to use both in combination, depending on what we are making!

Types of Components: Circuit Sticker vs Through Hole vs Surface Mount

Electronic components, such as LED lights, come in various shapes and sizes. The following is a table of popular paper circuit-friendly LED component types for you to choose from.



	Circuit Sticker Flexible sticker LEDs with conductive adhesive and an on board resistor	**Through Hole** Common bulb-shaped LEDs where you bend the legs out for paper circuits	**Axial (Prototyping)** Smaller bulb-shaped LEDs with legs already pointing out	**Surface Mount** Tiny LEDs that are about the size of a grain of rice
Pros	→ **thin and flat** profile → **friendly sticker form** → **easy to tell + and -** sides apart by shape → **built-in resistor** protects LEDs and circuits → **can mix all colors** in the same circuit	→ **low cost** LED (~5¢) → **fairly sturdy** and can easily be removed and reused → **builds familiarity** with commonly found electronics components	→ **medium thin profile** for flat projects → **fairly sturdy** and can easily be removed and reused → **medium cost** LED (~25¢)	→ **smallest size** for integrating seamlessly into thin paper projects → small size allows **highest density of lights** → **low cost** LED (~5¢)
Cons	→ **high cost** LED (~80¢) → **requires conductive fabric tape for reuse** and needs to be peeled up gently	→ **bulkier size and heavier weight** cannot be integrated into paper as smoothly → **requires external resistor** to mix colors and for microcontrollers → **rigid, pointy legs**	→ **requires external resistor** to mix colors and for microcontrollers → **slightly bulkier** shape than surface mount and sticker LEDs → **requires external resistor** to mix colors	→ **difficult to work with**, tweezers recommended → **easy to lose** due to small size → **requires external resistor** to mix colors → **solder connections** highly recommended
Use for	→ final projects where longevity and flatness are important to the design → when you want to combine multiple colors in one circuit → where friendliness & ease are very important	→ prototyping and getting students first acquainted with electrical concepts like polarity → projects where bulkier LEDs are acceptable → the most cost-effective option	→ prototypes where flatness or small size are important to the design	→ projects where longevity and discreet circuit integration with paper are important to the design → projects for advanced learners interested in soldering

In Summary:

LED Circuit Stickers were specially designed for paper circuit art: they are super-flat, easily attach to paper circuits, and come with a built-in resistor to protect LEDs and to allow different colors to work together in one circuit.

However, we know that costs can add up quickly when scaled to classrooms. One approach is for students to prototype with less expensive LEDs such as through-hole or axial LEDs and then move on to Circuit Sticker LEDs for their final projects!

Conductive Tape Core Skills

One of the core parts to mastering paper circuits is getting comfortable working with conductive tapes. This section shares basic techniques and useful tricks for working conductive tapes to craft circuit traces.

How To: Fold Mitered Corners with Tape

Conductive tape has two sides: the top conductive surface, and the adhesive underneath. Unfortunately, not all adhesive is conductive and all adhesives tend to peel up over time. This means that trying to connect separate pieces of conductive tape by overlapping and sticking them together creates weak points in the circuit.

So a core skill is folding the tape so that it can turn a corner without cuts in the tape. We like to have students practice this technique with wider non-conductive tape such as masking tape or painters tape.

Technique #1: First fold away from the target direction, then fold to target angle and flatten. This technique creates a small flap, and is a bit easier to explain and do.

Bend back tape, sticky side up

Fold away from target direction

Create angle and fold in target direction

Flatten and smooth

Technique #2: First fold back the way you came, then fold to target angle and flatten. This technique is a little trickier, but creates a smooth fold with no extra flap.

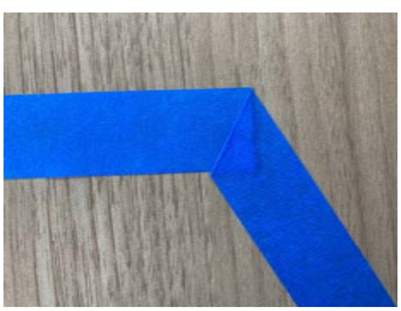
Bend back tape

Mark fold at edge

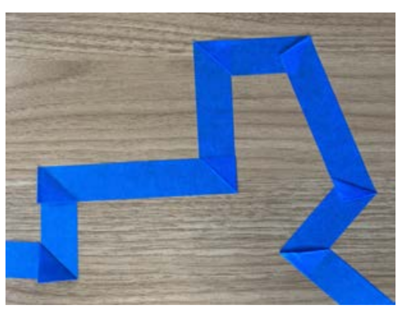
Fold in target direction

Flatten and smooth

Once you've tried these techniques:

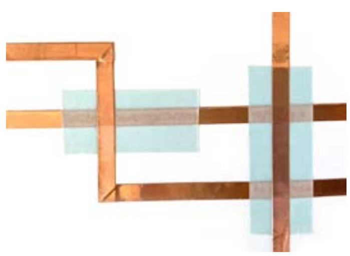
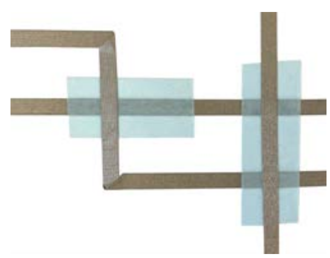


1. Adjust folds for other angles



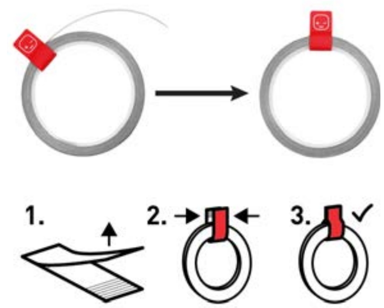
2. Practice with a nice long piece

3. Try with conductive tape!

Conductive Tape Trace Techniques	**copper tape + conductive fabric patches**	**conductive fabric tape**
Turning corners Don't break the tape when you reach a corner or angle! Instead, make a fold and keep taping.		
Repairing To repair broken circuit connections, patch with a conductive material so that the conductive part touches (reconnects) all parts of the the break	 To patch, make sure the shiny copper (non-sticky) side connects across the break	 The adhesive on conductive fabric tape is conductive enough to help patch circuits just by sticking
T-junctions / branching To extend an existing circuit path or create 3-way junctions, use patching/repair techniques	 To branch, fold copper tape on itself (so sticky side is inside and copper is outside) and tape down	 The adhesive on conductive fabric tape is conductive enough to create a branch just by sticking
Insulators / bridges To jump over traces, use a non-conductive material as an **insulator**. It's easier to debug if the insulator is not fully transparent, eg. washi tape or masking tape		
Curves To more easily create rounded curves, cut tape down its length to make it thinner		
Across pages or folds To avoid breakage from repeated folding, use conductive fabric tape across folds or pages		

Classroom Tips

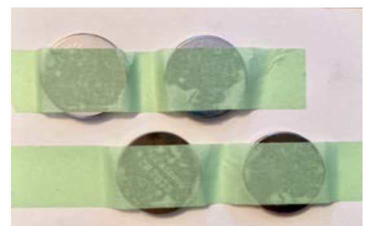
Storing conductive tape



Conductive tape rolls can unspool and end up as a tangled mess! A few options:

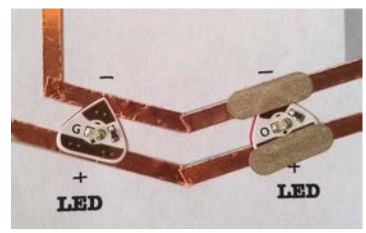
- Place tape in clear sandwich bags and cut off one corner of the bag to dispense the tape
- Pre-cut lengths of tape to hand out to students (this works especially well for make-and-take activities, such as in library or museum settings)
- Use a tape tag or a strip of paper stapled around the tape to keep the roll contained, and unspool as you go

Storing Batteries



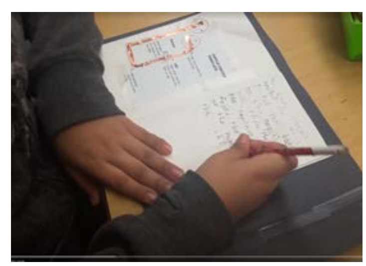
Because their + and - sides are exposed, make sure to store loose coin cell batteries separately from each other and away from anything conductive to save them for the next activity. For example, you can tape them to a piece of cardboard with removable tape. This will avoid short circuits and drained batteries!

Reusing Circuit Sticker LEDs



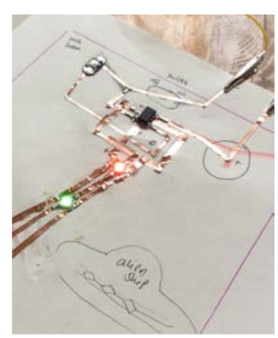
To reuse a Circuit Sticker, gently peel it off, trying not to bend it. If it peels off very cleanly, you may be able to reuse the conductive adhesive once or twice. If not, you can use conductive fabric tape patches or conductive fabric tape on top of the LED to connect it to your new circuit as shown in this photo

Project Planning



To help students plan ahead and use materials thoughtfully, you can incorporate **sketching**, planning, and feedback time into projects, and ask students to give you a **bill of materials** (list of materials they need) for their project before they forge ahead. You can also give them materials **constraints** that they need to design within. This approach helps foster design and engineering practices, and also helps students practice applied skills such as estimating the tape length they need.

Hack Your Notebook



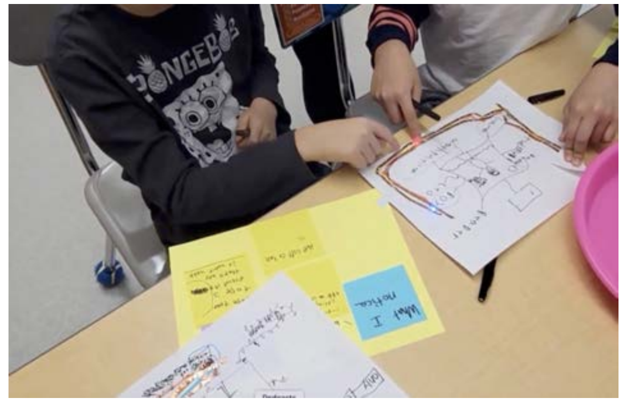
Paper circuits work great with notebooks because they’re thin and flat, especially spiral bound notebooks where the spine expands. Encourage students to build circuits right into their notebooks, and take notes and write questions right alongside their circuits. Creating in the pages of a notebook is a great way to document progress and learning over time as well as keep projects tidy and organized in one compact place! Learn more on the Nexmap webpage.

Collaboration

There are many ways students can practice collaboration and teamwork while building paper circuits!

Peer Feedback

Students can be resources for each other, such as giving each other feedback on design ideas, helping with troubleshooting, and brainstorming solutions together. Sometimes even just listening can help a collaborator discover new paths through a difficult challenge!



Shown on the right, students in [educator Shiela Lee's class](#) take on different "circuit checker" roles and help give each other feedback in a collaborative inquiry process.

Pair Programming

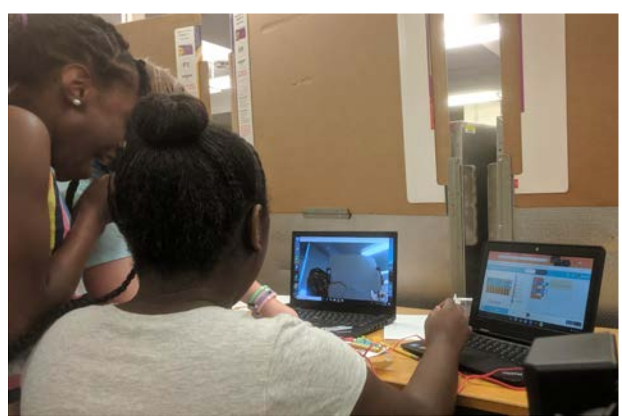
Two students can team up to program a Chibi Chip at a single computer. One student acts as the driver and controls the mouse and keyboard, while the other acts as the navigator and keeps track of the big picture, while also being a second set of eyes to catch errors.

Make sure that students swap roles often! This process helps students talk through their code, discover their own thinking process, and creates opportunities for them to learn from each other.

You can tell students that professional programmers in the software industry use this technique often!

Peer Instruction

Students can do an amazing job teaching one another (and even adults!) paper circuits. When students become teachers, they are given the opportunity to take ownership of the classroom and each other's learning.



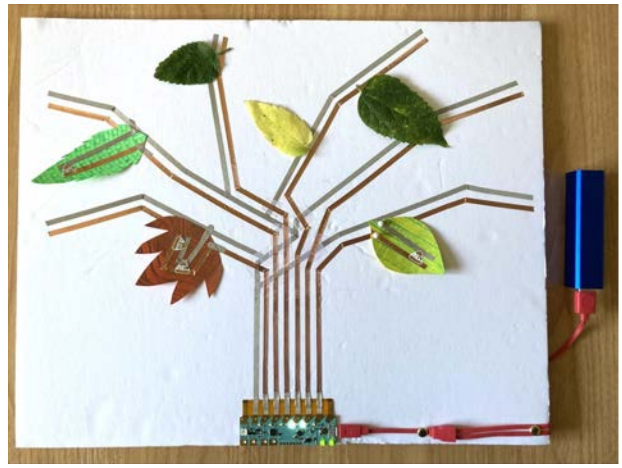
Students can even support one another from different places in the world! On the right, 4th graders in Maryland taught 8th graders in Chicago how to build a circuit and program Chibi Chips.

Example Collaborative Projects

The following are some paper circuit projects that are specially designed to be collaborative, though any paper circuit project can be a collaborative experience! In addition to the ones highlighted below, check out the full collection of projects in the Featured Projects section.

Paper Circuit Mural

(see here for full activity)

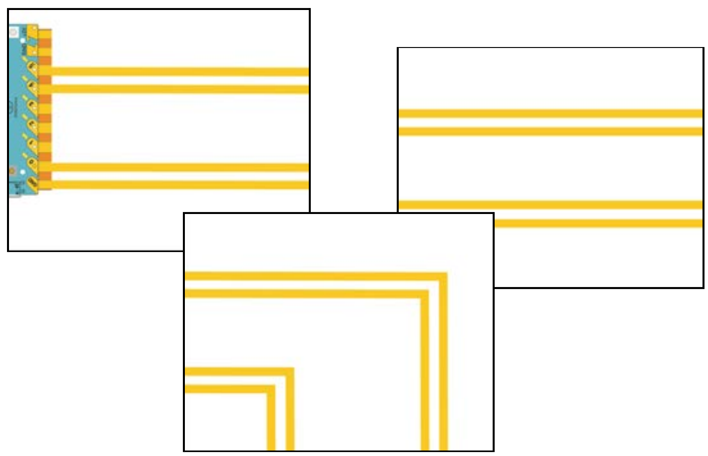


In a paper circuit mural, each participant adds their own smaller circuit to a larger art piece. Each small circuit can represent something that is meaningful to the maker (such as a word, image, or poem).

The smaller circuits turn on when attached to powered traces on the background mural. The more circuit contributions there are, the brighter the mural shines!

Paper City / Parts of a Whole

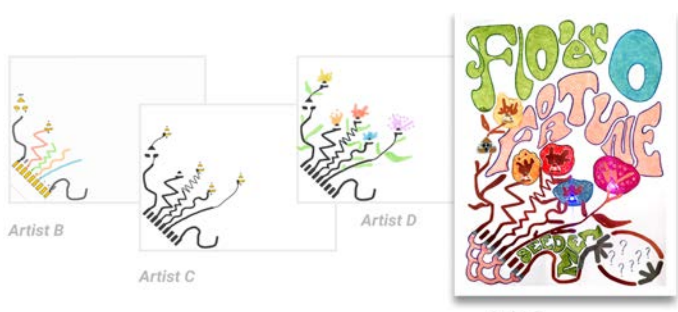
(see here for full activity)



Students work together to collaboratively design and build a "paper city." Give students time for planning and discussing with other teams:

→ How will their designs work together?
→ When it is time to connect the designs, use conductive fabric tape patches to join the individual circuits into a whole design.
→ Then reflect: what parts of the designs worked well together?

Exquisite Circuits



This game builds on the drawing game "exquisite corpse," in which each player adds something to a drawing without being able to see the full drawing passed to them by the previous player.

In Exquisite Circuits, each "player" can add a component or trace to a circuit starting point, then pass it to the next player. Read or watch to learn more.

Troubleshooting Guide

Learning to resourcefully **troubleshoot**, or "**debug**," technical problems is a wonderful learning outcome of working with paper circuits. This section shares approaches for nurturing a collaborative troubleshooting culture in the classroom, as well as practical tips for finding and fixing common issues in your paper circuits.

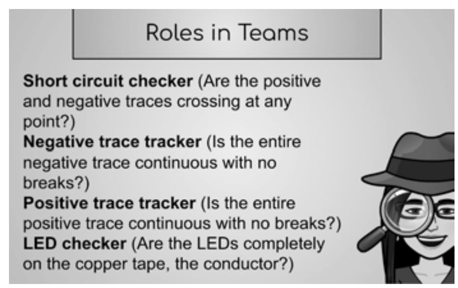
In the Classroom

It can be scary to explore an unknown world of technology and feel like you are doing it "wrong" when something doesn't work. It can also be scary as a teacher to not have all the answers! We think of cultivating wonder and curiosity as antidotes to this fear.

Know that when your students run into issues, you don't necessarily need to fix the problem; rather, you can empower them with strategies to solve it themselves. For example, you can ask them to talk you through what isn't working and what they have checked so far.

It is helpful to be aware that technology may also be a space where hierarchies can emerge, where students from identity groups who have historically had more access might dominate the conversation or stifle others' voices. Educators can disrupt these patterns by naming them, celebrating multiple paths to ideas and different ways of knowing, creating opportunities for students to make personally meaningful connections to what they are learning and making, and other equitable teaching strategies.

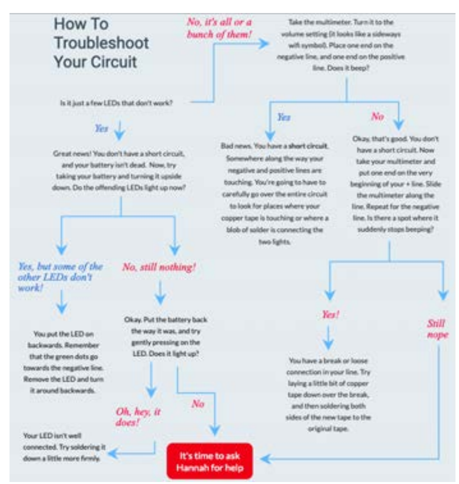
Peer Feedback



Educator Shiela Lee (featured here) created different "circuit checker" team roles for students to give each other feedback through a collaborative inquiry process. Shiela says:

"...my students have a great resource to lean on, each other! .... By letting students examine three different types of [circuits] on their own, doing their own comparing and contrasting, students took agency of their learning and helped each other through this collaborative approach."

Problem-Solving is Part of the Project



Educator Hannah Grimm created a paper circuit troubleshooting flowchart and video guide for their 7th grade students to consult independently before asking for help with their soldered circuits. Their students also use multimeters to help debug connections. Hannah's words to their students about circuits that aren't working:

"Don't worry, this is a normal and expected part of the project! Follow the flow-chart of troubleshooting steps to see if you can figure it out on your own. Only ask Hannah for help once you've been through this chart (using this chart and the multimeter to assess your own work for mistakes is part of how your Independence/troubleshooting score is determined)."

Troubleshooting Battery-Powered Paper Circuits

Below are the most common issues to check for when your paper circuit doesn't work. For projects that use the Chibi Chip, jump to the Love to Code Troubleshooting Guide in Part 2 of this guide.

Is the LED connected securely?

Sometimes a connection just isn't strong enough. Try pressing on the metal pads of the LED stickers for a count of 5 to make sure they are firmly connected to the conductive tape. Check that the metal pads on the LED stickers are sitting on top of the conductive tape with enough surface area overlapping, and that the conductive tape under the sticker is smooth and flat.

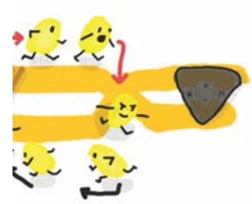
Is there a break in the circuit?

Inspect your circuit for breaks or tears in the tape, sometimes caused by repeated folding. Use the tips under conductive tape techniques to patch a broken connection.

Is the LED backwards?

If your LED is in reverse, it won't shine. A quick way to check is to flip the battery over in the battery holder. This reverses the (+) and (–) terminals, thus matching the connections of a reversed LED.

Is the battery connected?



Try re-clipping the battery to ensure that the copper tape tabs are touching the battery's contacts.

Is there a short circuit?

If the (+) and (–) sides of your battery are connected directly, you will drain power from the battery rather than turn on the light. Inspect your circuit and make sure that the conductive tape traces from the (+) and (–) sides of the battery are not accidentally touching.

Is the battery dead?

Sometimes the circuit doesn't turn on simply because the battery is out of power. Try switching your battery out for a fresh one. Check for short circuits first - one could have caused the battery to drain!

Support & Community

Contact the Chibitronics education team with any curriculum questions: **education@chibitronics.com**
Visit our website at **www.chibitronics.com** for tutorials and more!

Join our Educator Community on:
- Facebook: Here we share lesson plans, post and answer questions, chat with educators, and share announcements about upcoming events and conferences.
- Twitter: Another place to get the latest announcements. We love to repost awesome work by educators and makers! To share your creations, please tag us: @chibitronics.
- Instagram: Browse inspiring examples of paper circuit art, craft, and learning. Tag @chibitronics to share your own projects with the community!

Credits

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Thank you to the artists, educators, and others whose inspiring work is featured in the guide, and to those who gave us feedback. We couldn't have made this without you!

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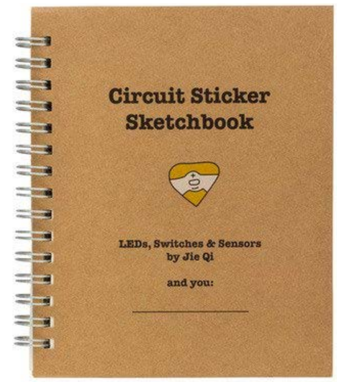
PART ONE

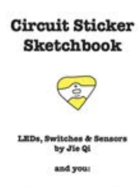
Circuit Sticker Sketchbook

The Circuit Sticker Sketchbook

The *Circuit Sticker Sketchbook* is an interactive paper circuit notebook written by Jie Qi. This book includes 5 project templates: simple circuit, parallel circuit, DIY switch, blinking slide switch, and DIY pressure sensor. Part 1 of this Guide uses the Sketchbook as a foundation for a creative STEAM lesson sequence. We've also added a special bonus template, the *animated slide switch*, created just for this guide!



The *Circuit Sticker Sketchbook* is available under a CC BY-SA-NC- 4.0 license. This means you are free to download, copy, print, translate, and remix elements of the book as long as you attribute us, use it for non commercial purposes and share any remixes under the same license. Here are PDF download links for popular translations:



English (Original)
By Jie Qi

Spanish
Translated by Susana Monteagudo

Chinese
Translated by Gavin Zhao

Japanese
Translated by Masahiro Yachi

German
Translated by Helga Tauscher

French
Translated by Fanny Passeport

For more free download options including classroom and booklet formats, visit chibitronics.com/templates

Suggested Tools and Materials

For Part 1 of this Educators Guide, we recommend using the following supplies:

STEM Starter Kit

(Links to purchase individual kit and supplies for 12 students)
This kit contains the materials to do activities described in Part 1 of this Educators Guide. The kit includes:

- Circuit Sticker Sketchbook
- 6 white, 2 red, 2 yellow, 2 blue circuit sticker LEDs
- 2 batteries, 2 binder clips 1 roll copper tape
- 1 pressure-sensitive conductive plastic strip

Additional Craft Tools and Materials

- Scissors
- Adhesives: tape and glue sticks
- Pencils for sketching out circuits
- Colored pencils, markers, watercolors, and other art tools of your choice for decoration.

Lesson 1: Intro to Paper Circuits

Two 45-minute lessons or one 90-minute lesson

Materials

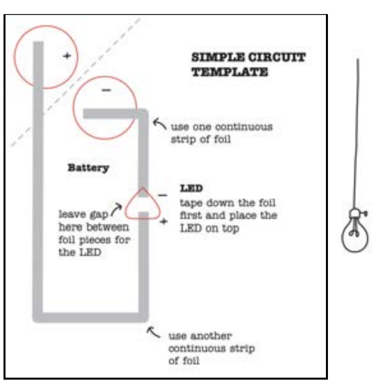
- [ ] 1 Circuit Sticker LED
- [ ] 9 inches conductive tape
- [ ] 1 CR2032 coin cell battery
- [ ] 1 small binder clip
- [ ] Painters tape or masking tape for corner folding practice
- [ ] Art materials for circuit illustrations such as colored pencils, watercolors, or collage materials
- [ ] Simple Circuit Template

Resources

- Copper Tape Tutorial
- Simple Circuit Tutorial and Video
- Circuit Sticker Sketchbook Templates and Translations

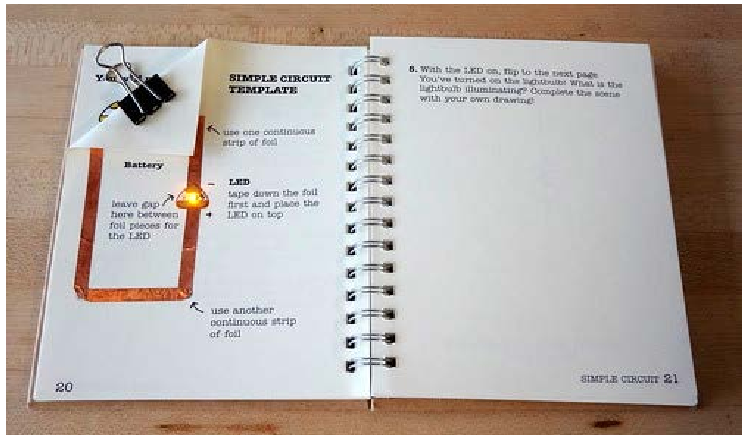
Inspiration

- Dandelion Painting by Jie Qi
- Tech Support Cheat Sheet from xkcd.com



Lesson Overview

Students will construct paper circuits with an LED to light up their drawings. They will discuss problem-solving strategies as a group, and create a class resource to help each other troubleshoot their circuits.



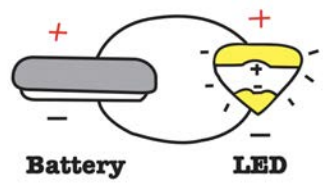
Learning Objectives

- Build a working circuit with an LED and a battery
- Turn corners with conductive tape
- Use an iterative troubleshooting process to fix non-functioning circuits
- Use light as an artistic element in an illustration

Vocabulary

- **electron**: particles in a circuit that flow to create electricity or electrical energy
- **LED** (light emitting diode): an electronic **component** that emits light when electricity flows through it
- **battery**: a device that can generate a flow of electrons
- **positive**: the part of the battery that electrons flow to (connect to the wide "+" side of the LED sticker)
- **negative**: the part of the battery that electrons flow from (connect to the pointed "-" side of the LED sticker)
- **emphasis**: draw attention to a particular object or element of an art piece to help convey importance or meaning

Background



Using the Simple Circuit template, students use conductive tape to connect a battery to the LED in a loop. This complete loop, or **circuit**, allows electrons to flow from the battery, through the LED, and back into the battery. This flow of electrons, called electricity, causes the light to turn on and shine.

Teacher Preparation

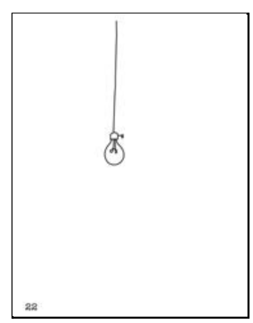
1. Build your own Simple Circuit using the template. Refer to the troubleshooting guide to solve problems you run into, thinking ahead to issues students might encounter.

2. Add your own creative element to the overlay page: what will you illuminate to share with your students?

Lesson Sequence

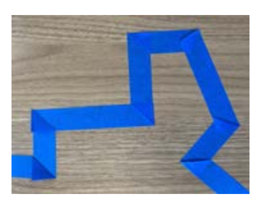
1. Start with Art: Watch the Dandelion Painting video. Ask: what do you notice and what do you wonder?

Artist: Jie Qi



2. Show the teacher's demo circuit and brainstorm with students: what will they illuminate? You can provide a specific prompt, such as:

   - Use the lightbulb overlay in the *Circuit Sticker Sketchbook*: what does the lightbulb illuminate?
   - Light up your name
   - Light up a scene from a story
   - Light up a vocabulary word



3. Students practice making curves and folding corners without cutting the tape using removable masking tape or painters tape (see "Conductive Tape Core Skills"). This type of tape can be applied directly to tables and easily removed.

4. Students place conductive tape on the template, add LEDs, then clip on their battery.

5. Discussion and creation of class resource: What are ways to troubleshoot your circuit if the light is not turning on? Have students list as many answers as possible on sticky notes and place them on the wall to discuss. Or have students work in small groups to brainstorm and then share out, with the teacher recording answers.

The goal is to work together to create a class poster for getting "un-stuck," written in the students' own words. Questions to consider (none of these have "correct" answers - this is up to the class!)

- Which strategies should they try first? What if those don't work?
- Which strategies should they try last, if all else fails? Why?

Folding a corner with conductive tape

Troubleshooting strategies to help guide students (see also Troubleshooting Guide)

- Check for breaks or tears in the conductive tape path and patch them if needed.
- Make sure the positive side of the battery is connected to the positive side of the LED, and the negative side of the battery is connected to the negative side of the LED. Students can experiment by turning the battery over.
- Check for short circuits - places where the positive side of the circuit makes an accidental connection to the negative side of the circuit.
- Make sure the LED is solidly connected to the conductive tape path. Press down on the LED to test if the connection is secure.
- Make sure the battery is not out of charge by testing it on a working circuit. If a student has tried all other strategies, give them a fresh battery to try.
- Other valuable troubleshooting strategies that students can suggest include:
  - asking a classmate for help
  - looking over the instructions again
  - comparing their circuit to a working circuit
  - changing one element at a time

6. When they are done, students fold over the page and use their lights in an illustration, using the light to emphasize an element of their art piece.

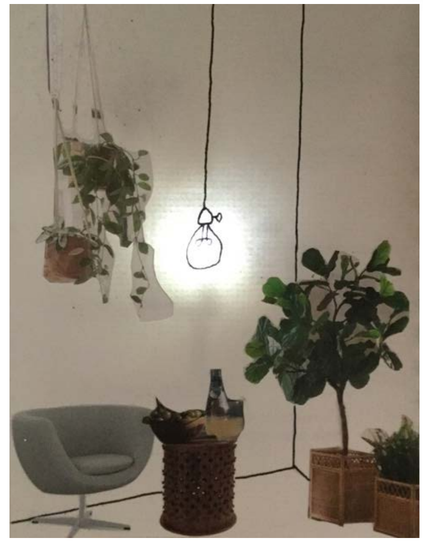
7. Gallery walk: students hold up their art for others to see, or place on tables for a walk around. Celebrate the many different ideas and styles!

8. Clean up materials. Show students where paper circuits materials should be put away so that the next activity will run smoothly. **Tip:** check for pieces of conductive tape stuck to the floor or tables!

Extensions and Adaptations

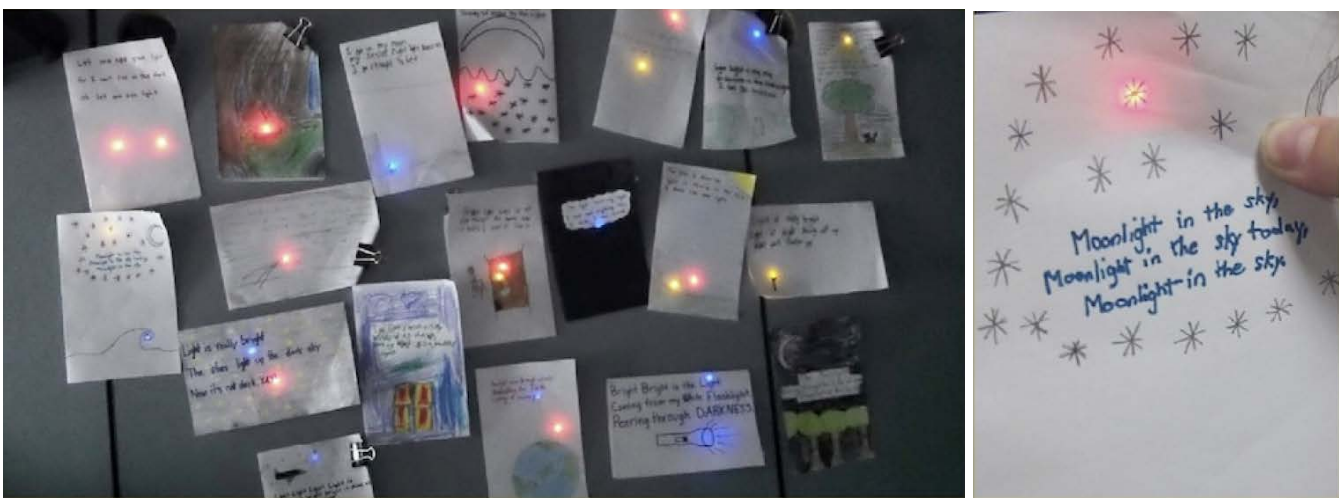
1. As an alternative to the poster, students can create their own "troubleshooting flowcharts" with steps to try if they get stuck. See for example the Tech Support Cheat Sheet from the comic xkcd.com and Hannah Grimm's paper circuits troubleshooting flowchart. This activity connects to the computational thinking ideas of Decomposition and Algorithmic Thinking.

2. The *Circuit Sticker Sketchbook* is available in Spanish, French, Mandarin, German, and Japanese. These printables can supplement a lesson in students' native languages, or in a language they are learning! World language teachers might consider a paper circuits lesson as a hands-on activity.



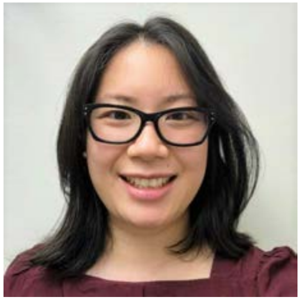
This beautifully collaged piece was created by Taia Saurer, age 12

Inspiration



Light Up Poetry: Educator Kevin Hodgson's students wrote, illustrated, and illuminated haiku about light

Featured Educator: Shiela Lee’s Identity Portraits



Shiela Lee is a K-5 STEM teacher and technology coordinator based in NYC, a coder, and a CSTA Equity Fellow. Her paper circuits identity portrait unit is a beautiful example of equity, art, and technology woven together. In this feature, Shiela shares her story of developing identity affirming activities as well as how to implement them in your own classroom.

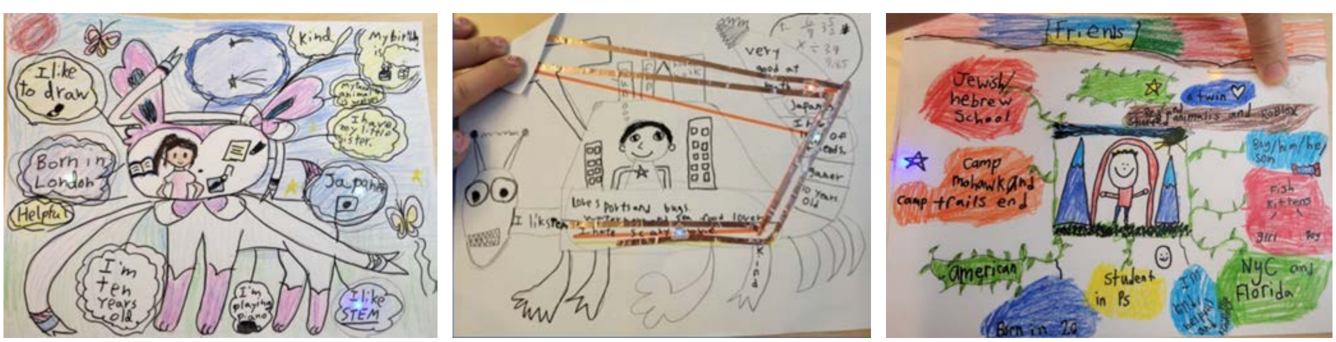
You can read more about Shiela’s paper circuits work in her full blog post here.
Website: www.shielalee.com **Twitter:** @leeshiela.

Shiela’s Journey

“Over the years, I have worked with students on creating identity webs, identity statements, and affirming who they are. I was the only Chinese-American at my predominantly white elementary school in Colorado. One of my teachers, Ms. Isenhart, assigned projects and activities that helped me embrace my Chinese culture. Channeling her and my own beliefs about good teaching, I knew that students learned best when they felt included, welcomed, and affirmed in the classroom.

The moment I saw the LED stickers light up, I knew this would be an excellent way to take my work on affirming students’ identities to the next level. I often thought about how I could integrate more science, technology, engineering, and math with my students’ art work around thinking about the intersectional identities they have.

I was so excited to make my own identity portrait as an example for my students that I knew they would have the same excitement. I was not wrong! When I did this activity with my twenty-four fourth grade students, all students were engaged, excited and eager to show their classmates who they are. They loved this project!”



Illuminated Identity Portraits made by students from Shiela’s class

Designing through Collaboration

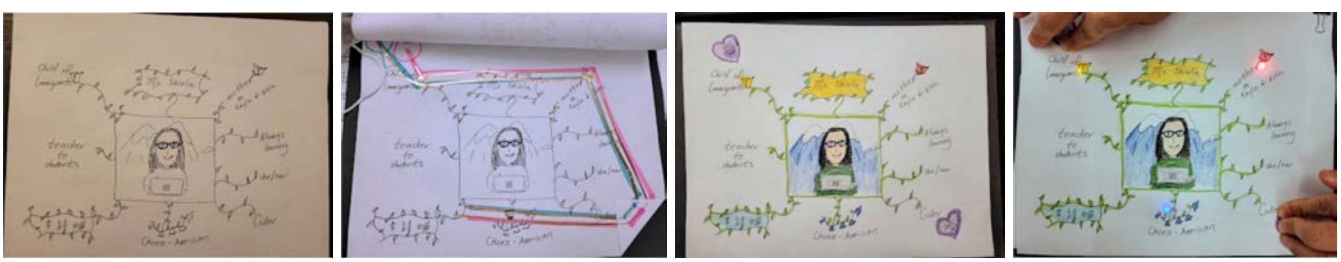
"I've designed new units before, but I especially loved how I could collaborate with other colleagues on this project.

I collaborated with the science teacher at my school to see what gaps were missing when they learned about energy forms in her class. I extended the students' learning around electrical energy, light energy, and circuits. I also consulted with the art teacher to see if the graphic organizers and templates I created might help my students with disabilities, particularly those with fine motor difficulties and spatial awareness difficulties. In preparing for this unit, I also did each step myself to see where my students might encounter difficulties."

Creating Identity Webs

At the core of Shiela's Identity Portrait unit is helping students explore their identities and relationships with each other through identity webs. An identity web is a chart or graph showing different aspects of what we consider core to who we are, from our physical characteristics, to our hobbies, to our cultural backgrounds.

Sharing identity webs among students is a great way to help them get to know one another, build connections over shared identities and learn about each other through their differences.



Shiela's process for creating an illuminated Identity Portrait from line drawing to finished paper circuit (left to right)

While there are many variations on identity webs, a simple way to begin is to have students write their name or draw their self-portrait in the middle of a sheet of paper, and then add words, phrases, drawings and anything else that students come up with to represent who they are. There is no wrong answer!

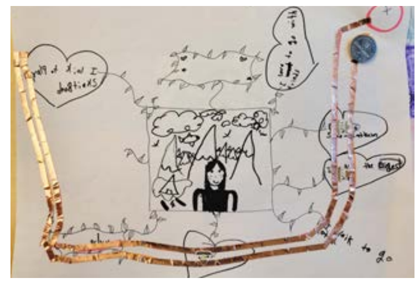
For a more detailed guide on creating identity webs and variations, here is a great guide from FacingHistory.org.

Identity Portraits Lesson Sequence

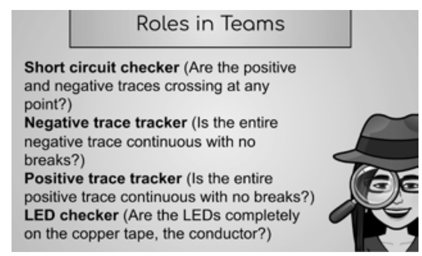
You can also find Shiela's accompanying slide deck here.

1 **Lesson**: Introduction to me, each other, and brainstorming various identities we have
Activity: Draw their identity web. Note: Let students know you will make a black and white copy of this identity web so they can make sure their LED light lines up with where their identities are on the web. They will color the original identity web at another time.
Share: Pick 1-2 students' work to share with the class, highlighting the various identities we all have.

2 **Lesson**: Introduction to circuits and energy forms
Activity: Guided exercise in applying copper tape to our black and white copies of our identity web. This paper will serve as the back of the portrait.



3 **Lesson**: What are conductors? Small group work around what we notice about our conductors
Activity: Everyone colors their original identity web while the teacher meets with small groups to go over how students put on their copper tape and provide more 1-1 support for copper tape



4 **Lesson**: What is the LED, making predictions based on our observations about the copper tape and potential errors if the LED does not light up
Activity: Making predictions and attaching LED lights

5 **Lesson**: Review of circuits and inquiry around portraits
Activity: Students work in groups of 3 to look at other classmates' portraits and give them feedback on what they might want to try in order to fix their circuit (team roles)

6 **Lesson**: Parallel vs Series circuits
Activity: Work in heterogeneous partnerships to fix our portraits if they don't light up.

7 **Lesson**: What is effective feedback?
Activity: Gallery walk and viewing all circuits and giving effective feedback

Lesson 2: Switches, Silhouettes, and Shadows

Two 45-minute lessons or one 90-minute lesson

Materials

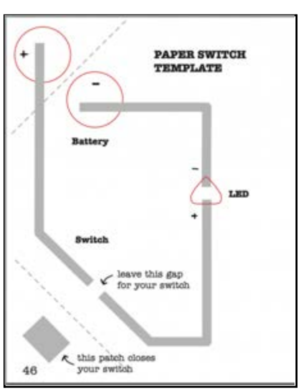
- [ ] 1 Circuit Sticker LED in any color (mix of colors among the class is ideal)
- [ ] 14 inches conductive tape
- [ ] 1 CR2032 coin cell battery
- [ ] 2 small binder clips
- [ ] glue stick
- [ ] scissors
- [ ] drawing tools (pens, markers, pencils)
- [ ] paper (eg. colored printer paper, tissue paper, etc.)
- [ ] Switch Circuit Template
- [ ] Shadows and silhouettes handout

Resources

- Switch tutorial and video
- Shadows and Silhouettes tutorial

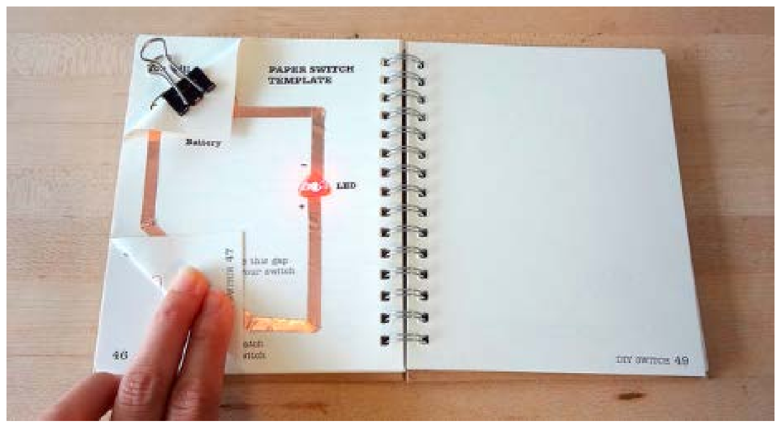
Inspiration

- Silhouettes with Light by Jie Qi
- TickyTown by K-Fai Steele



Lesson Overview

In this lesson, students will build a paper switch that turns on and off an LED. Then they will explore light effects through different materials. Finally, students will apply these skills to create a scene with a "reveal" when the switch is pressed.



Learning Objectives

- Build a paper switch to turn on and off LEDs
- Explore effects of light through different materials
- Select a specific material and technique towards an artistic goal
- Use the hiding and revealing of information to tell a story with interactivity

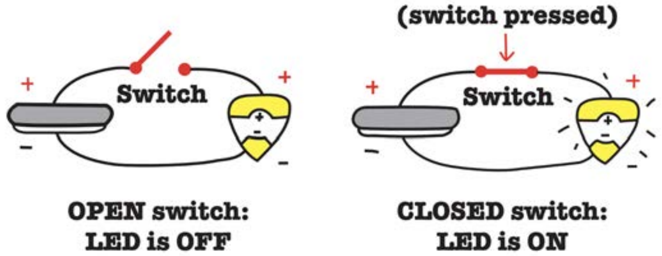
Vocabulary

- **switch**: a mechanism that can close and open a connection in a circuit
- **diffuse**: cause light to be softer and more spread out
- **silhouette**: the outer shape of something visible against a lighter background

Background

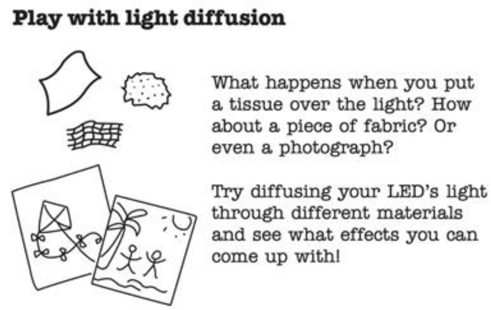
Part 1: Switch

A **switch** is a gap in a circuit that can be connected and disconnected, turning parts of the circuit on or off. When the switch is closed, the light turns on because the loop is complete and electrons can flow through the circuit. When the switch is open, electrons will not flow, and the light will turn off.



Part 2: Light effects

Paper layered over LED light creates beautiful effects! Translucent papers **diffuse** the light, creating a softer glow. Layers of paper create **silhouettes** that only appear when the page is lit from behind. Pen or marker drawings on the back of a page become hidden messages that are revealed with light. Paper flaps cut into interesting shapes also project interesting shadows.



This activity is about experimenting with different techniques and materials – like artists, scientists, and engineers do – to see what effects they produce.

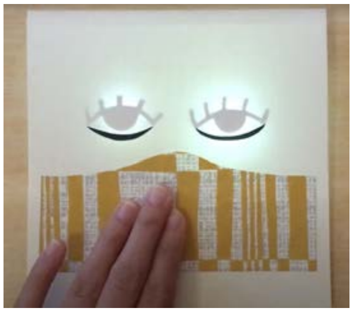
Teacher Preparation

1. Build the switch template as a class example and experiment with the Shadows and Silhouettes handout, using different materials to see the variety of light effects.
2. Optional: customize the Shadows and Silhouettes handout to match tools and materials available in your classroom (for example, a certain type of pen or paper)
3. Print all handouts for students

Lesson Sequence

1. Start with Art: Show the "Revealing Silhouettes with Light" video

2. Class brainstorm: what will they reveal? Some possible class themes:
    a. Reveal something about yourself that others don't often see
    b. Who lives here? Create a nature or urban scene and reveal an animal or insect that might be hiding in plain sight
    c. Who made this? Reveal the person or people behind an everyday invention
    d. Reveal hidden words that change the meaning of a sentence or short poem
    e. Reveal a fear that is less scary once it comes into the light



3. Show the switch circuit tutorial video

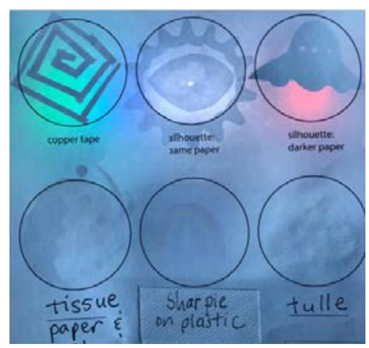
4. Hand out a mix of differently colored LEDs, one LED per student, so that students have different colors. They will share and compare with each other during the Shadows and Silhouettes activity. Consider forming groups so that there is one LED of each color in a group.

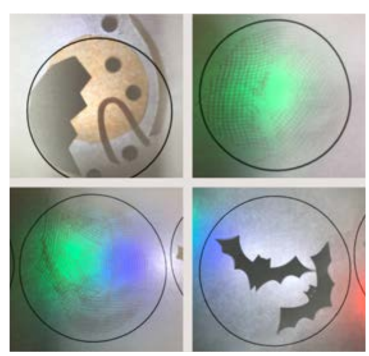
5. Students build the switch circuit. Encourage students to watch the switch video again if they get stuck, and refer to the class troubleshooting guide from Lesson 1.

Jill Dawson

6. Introduce the Shadows & Silhouettes activity. Explain that artists and engineers experiment with different techniques and materials to understand them better. That way they can choose the one best fit for their design!

7. Draw, glue, cut, and tape materials to the templates to experiment with different shadow, silhouette, and layering effects when they are lit from behind. Students can write and/or sketch notes as they go: what do they notice? What do they wonder? Some questions to consider:
    a. What does it look like without the light? Can you see what's behind the page?
    b. When you shine light from behind the page, what do you see?
    c. What changes when you move the light closer or farther from the page?
    d. What changes when you add colored light versus white light? (try comparing with classmates who have differently colored LEDs!)
    e. What changes if you use more than one material to make your layers?
    f. What happens to the shape of your shadows as you move the light around?
    g. What changes when you bring your circuit to darker or brighter parts of the classroom?
    h. What is your favorite combination of colors and materials so far? What do you like about it?





8. Class discussion: students share their observations and discoveries with the group.

9. Design and build: on the fold-over panel of the switch template or on a separate blank page, students create something that is revealed only when they press the switch.

10. Gallery walk: students walk around to admire each others' designs and see the "reveals" in action!

Extensions and Adaptations

1. Simplify this activity by using only the silhouettes (the circle page) and not the shadow handout. Use the shadow handout as an extension only for students with extra time.
2. For added challenge, encourage students to add more than one switch to their circuits.

Inspiration

TickyTown by K-Fai Steele uses the "reveal" technique in a playful way to tell the story of a community of ticks that lives on a furry dog's back.

Art: K-Fai Steele; Photo: Asli Demir

Lesson 3: Parallel Circuit + Design a Circuit

Two 45-minute lessons or one 90-minute lesson

Materials

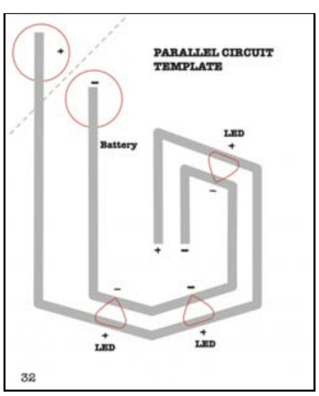
- ☐ 6+ Circuit Sticker LEDs, 3 for the parallel circuit template, and 3 or more for their own circuit design
- ☐ 22 inches conductive tape for first parallel circuit + ~30 inches for their own circuit
- ☐ 1 CR2032 coin cell battery
- ☐ 1 small binder clip
- ☐ Parallel Circuit Template
- ☐ Blank page for their own circuit design

Resources

- Parallel Circuit Tutorial and Video
- Working with Copper Tape Video

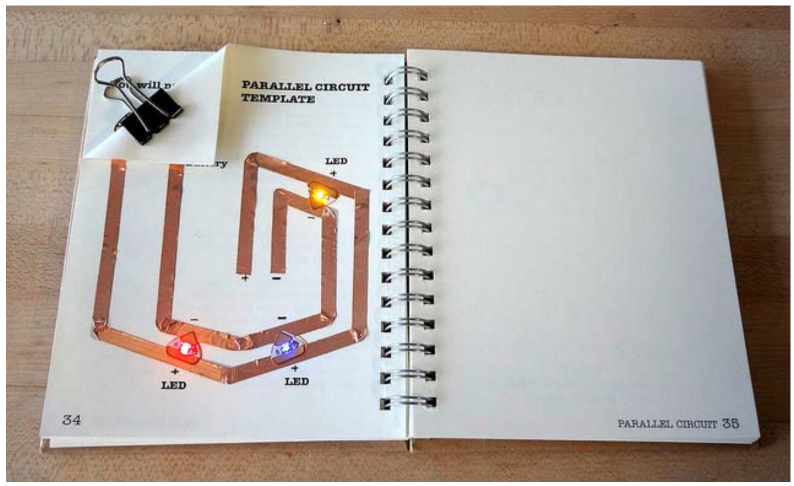
Inspiration

- Stephanie Lee's students' art
- Sketching in Circuits by Jie Qi



Lesson Overview

Students will create a parallel circuit with multiple LEDs, then sketch and build a parallel circuit of their own design.



Learning Objectives

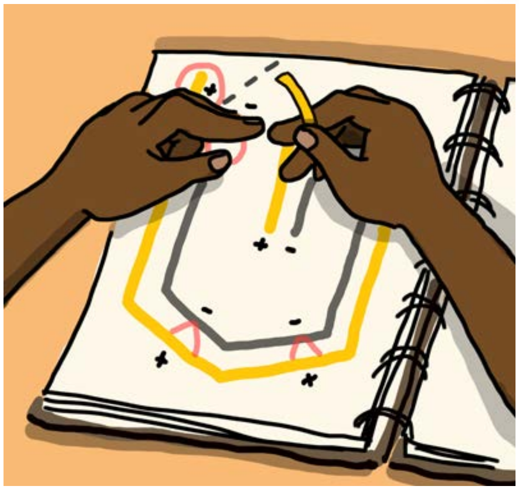
- Build and troubleshoot a parallel circuit incorporating multiple LEDs
- Plan, sketch, and build a paper circuit of their own design with multiple LEDs
- Use circuit traces as an artistic element

Vocabulary

- **component:** an electronic device in a circuit, such as an LED
- **trace**: an electrical connection between components in a circuit (for example the conductive tape in a paper circuit)
- **parallel circuit:** a circuit where components connect directly to the power source, in "parallel" like rungs on a ladder, rather than being connected end to end.

Background

To add more than one LED to our paper circuits, we can create a **parallel circuit**. In a parallel circuit, each **component** has a direct connection to the power source (battery) on both the + and - sides, rather than components being connected end to end.



The electrical properties of a parallel circuit allow multiple LEDs to be powered from a single battery. The more LEDs are added, the more energy they will use, and the sooner the battery will drain. We recommend turning off your circuits when they are not in use.

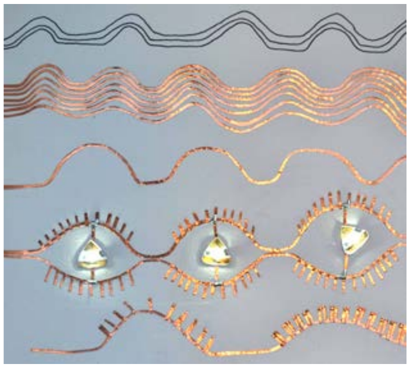
A parallel circuit can look a bit like a ladder, where + and - are the rails and the LEDs are placed like rungs across them. As long as these same connections are present, the ladder can take any shape! The **traces** can curve, bend, or meander across the page, creating a circuit that is both beautiful and functional. In this activity, students will sketch their own circuit layout and build a circuit of their own design.

Teacher Preparation

1. Build the parallel circuit from the *Circuit Sticker Sketchbook*
2. Sketch and build a parallel circuit of your own design across a page to anticipate what questions and issues students might encounter
3. For a deeper dive into the science behind a parallel circuit, read LTC Lesson 2: Series and Parallel Circuits

Lesson Sequence

1. Start with Art: as a group, take a look at the parallel circuits in the art pieces below. Ask students: what do you notice, and what do you wonder?



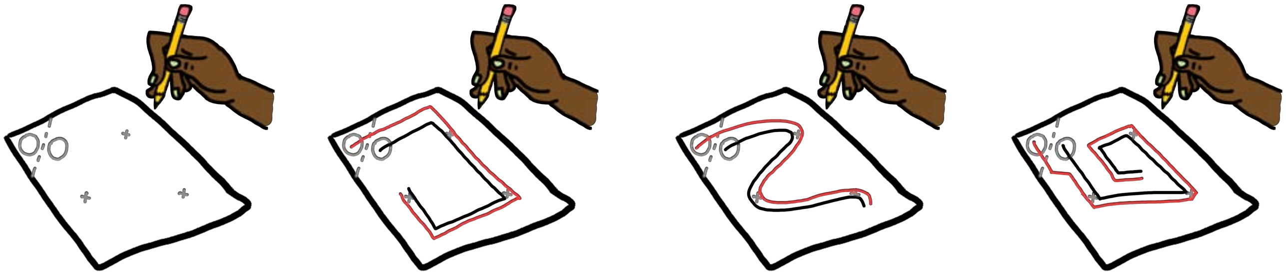
Becca Rose: Sketchbook

Neta Bomani: Paper Circuit Zines

Fay Shaw; collaboratively designed circuit

All of these are parallel circuits, made in different shapes!

2. Build the parallel circuit in the *Circuit Sticker Sketchbook* and add an illustration to the star scene on the next page. Alternatively to create a scene from scratch, add a blank page over the circuit.
3. Discuss: how would they add more LEDs? What would they do to make the circuit a different shape?
4. As a design challenge and art prompt, ask students to create a beautiful parallel circuit! Students will "draw" with conductive tape, using the lines of tape to create an illuminated illustration. Demonstrate cutting the tape thinner to make curves, and give students some time to practice with the tape.
5. Before building the circuit, brainstorm and sketch! Engineers, artists, and designers explore multiple solutions before deciding which one to prototype. Ask students to sketch out different possible shapes for their circuit in a notebook or on scratch paper, then choose one to build.



Begin by marking placement of LEDS

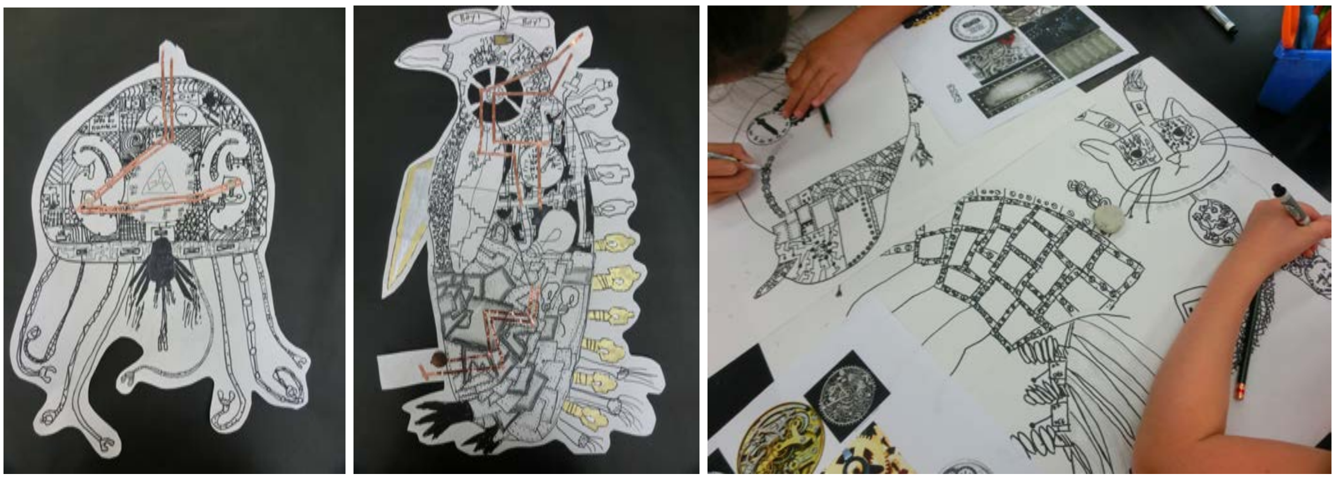
Draw parallel traces that connect all of the LEDs, marking + and - sides. Many shapes are possible! (colors help! **Red for +** and **black for -**)

6. Build and test the circuits, then do a class gallery walk!

Extensions and Adaptations

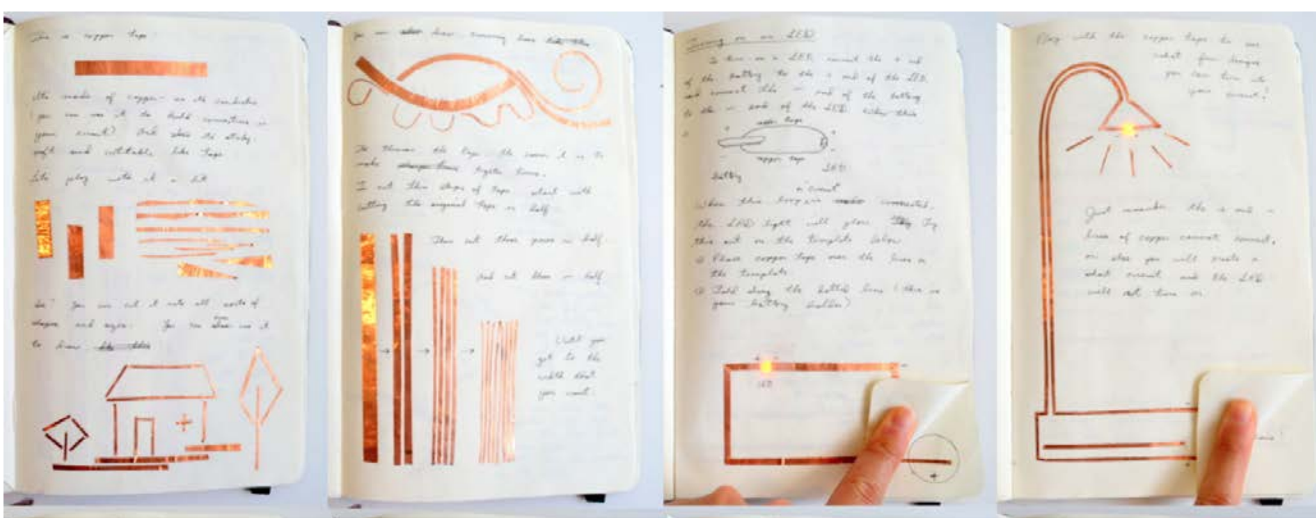
- Going further: this activity can incorporate some of the terms and concepts in LTC Lesson 5: Design and Program a Circuit, such as measuring the length of conductive tape needed and presenting a bill of materials before building the circuit.
- See Appendix A for a sample rubric for the circuit design activity which can be adapted for different projects and prompts.

Inspiration



Stephanie Lee

In this paper circuit activity by educator Stephanie Lee, students built their own parallel circuits to illuminate hand drawn steampunk creatures. In many of these, the shape of the circuits follows the shape of the creatures, becoming its own "high tech" visual element of the design.



Jie Qi

Sketching In Circuits: Artist Jie Qi's notebooks tell a visual story of her explorations with conductive tape and paper circuitry, told both through words and through the lines of the circuits themselves

Lesson 4: Blinking Slide Switch

Two 45-minute lessons or one 90-minute lesson

Materials

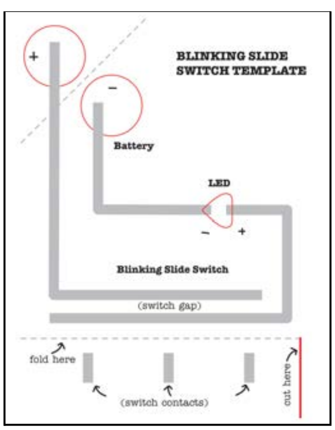
- [ ] 1-3 Circuit Sticker LEDs
- [ ] 17 inches conductive tape for small template, ~50 inches for wide template
- [ ] 1 CR2032 battery
- [ ] 1 small binder clip
- [ ] Overlay paper and drawing and/or collage materials
- [ ] Switch circuit from lesson 2 to start the lesson
- [ ] Blinking Slide Switch
    - Small Template (from Sketchbook)
    - Wide Template

Resources

- Blinking Slide Switch Tutorial and video

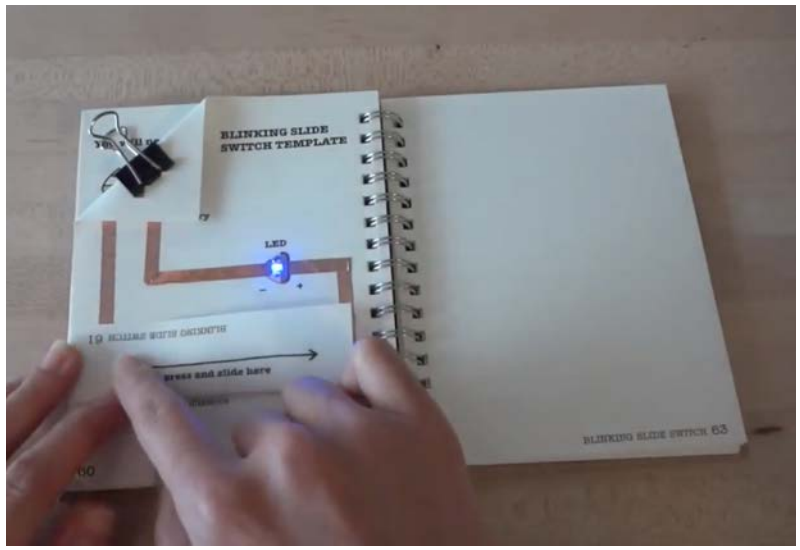
Inspiration

- Sketchbook Gallery



Lesson Overview

Students will build a blinking slide switch, design their own rhythmic sequence and make an LED blink this rhythm when pressing along the slide switch.



Learning Objectives

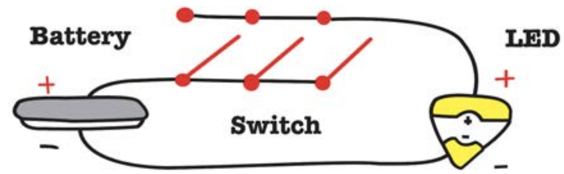
- Use a linear switch to blink an LED in a rhythmic sequence
- Use a light pattern or rhythm as a narrative technique in a media art piece

Vocabulary

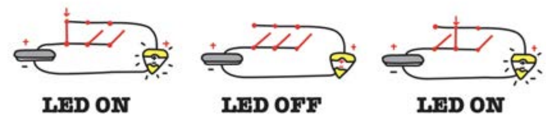
- **switch gap**: a break in a circuit path that can be closed by a switch
- **rhythm**: a repeated pattern involving a contrast between "high" and "low" beats or steps (in our case, a light that is on or off)
- **tempo**: the speed at which a rhythm is played

Background

Building on the idea of a simple switch, you can craft all sorts of switches that open and close gaps in a circuit, and even combine them to create more complex switches.



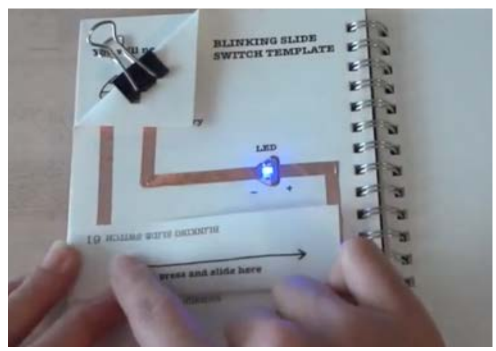
Circuit diagram for blinking slide switch, showing a series of switches that can turn an LED on and off



In this activity and the next, students will explore circuits that use switches for a more complex effect: animation! Both types of switches respond to a sliding motion. As you press down and slide your finger along the switch, **switch contacts** close different gaps in the circuit.

In the *blinking slide switch*, there is one long **switch gap** and a series of **switch contacts** (small pieces of conductive tape). Sliding your finger along the switch causes an LED to blink on and off in a blinking pattern matching the spacing of the switch contacts. It is a great way to make rhythm and pattern visible!

Teacher Preparation



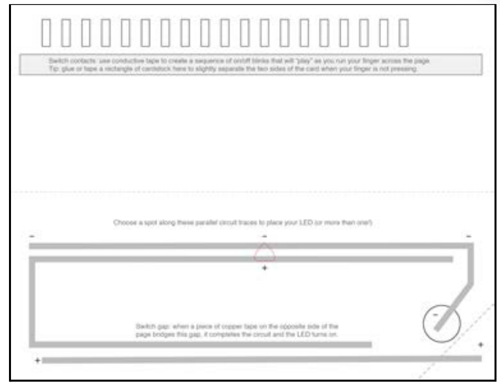
1. Use the template to build a blinking slide switch circuit as a class example
2. Read the overview on pg. 59 of the *Circuit Sticker Sketchbook*
3. Consider breaking out of the template and creating your own freeform design on a larger page, moving the LEDs and slide switch contacts. This is a really helpful exercise to check your understanding of the connections - they take some practice to wrap your head around!

Lesson Sequence

1. Start with Art: Ask students to contribute and vote on a favorite song that they think has a good beat, or choose a current song that is meaningful to students. Play the song for the class, asking students to gently tap out the beat with their switch circuits (from lesson 2), blinking their LEDs to the rhythm.
2. Next, ask students to draw out the rhythm in any way they choose on a sheet of paper. Ask for volunteers to share their "rhythm sketches," comparing different approaches. There are many ways to draw out a rhythm!
3. Demonstrate the blinking slide switch. Using the video as a guide, have students build their own using the small template
4. Discuss: in their own words, how does this circuit work? Encourage students to use the vocabulary terms **switch gap** and **switch contact** to help explain. How would they change the circuit if they wanted to:
    a. move the LED to a different place on the page?

b. change the blink pattern? (to consider: two things that affect the blink pattern are 1) the spacing of the switch contacts, ie. the **rhythm** and 2) the motion of the sliding finger along the page, ie. the **tempo**!)

5. Using the wide template, have students plan out their own blink rhythm by marking switch contact pieces along the template. Demonstrate by marking areas on the board, then show students how to tap out the rhythms of their lights to test out their ideas. The outlined areas are suggestions for switch contact patterns, but it's ok to break out of the template and add contacts in between the outlines!



Project theme ideas for the blinking slide switch:

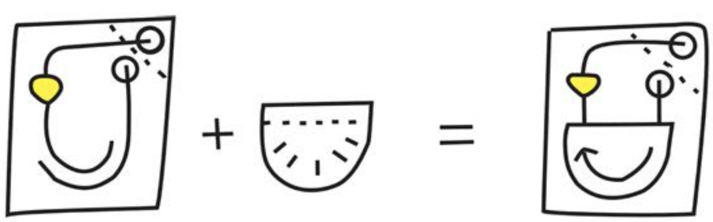
a. Blink the pattern in time to a musical beat by spacing the switch contacts like notes on a score. This could be used for a poster presentation about a favorite musician, or the history of a musical genre or movement.

b. Create the mood in a story scene through a blink sequence: an irregularly flickering neon light, the beat of a heart, a candle in the dark. Consider illustrating a scene from fiction, a moment in history, or a story from students' lives.

c. Send a secret message! Use the wide template to create a morse code or binary sequence using a pattern of switch contacts.

Extensions and Adaptations

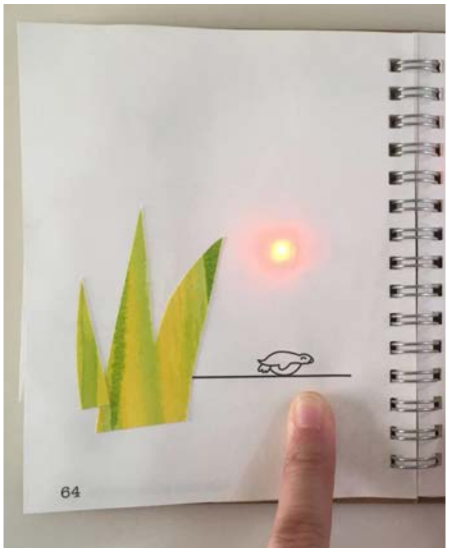
Go beyond the templates and build their own slide switch circuits, changing the placement of the LEDs and the shape of the slide switch.



Slide switches can follow a path of any shape - just make the switch gap a different shape and add a flap for the switch contacts. Don't be afraid to think big and work with larger sheets of paper!

Inspiration

View these projects and find more inspiration by visiting the Chibitronics Circuit Sticker Sketchbook Gallery.

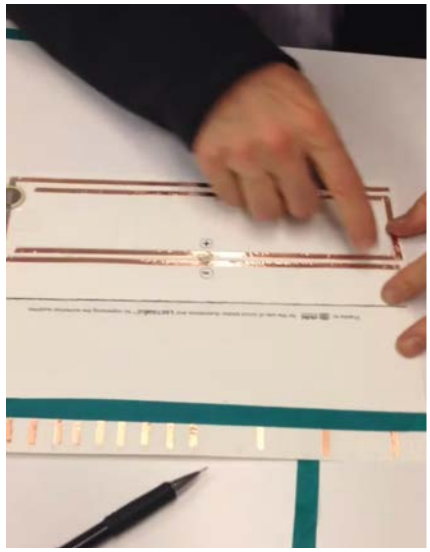


Jie Qi

The light above the penguin blinks as it slides across the ice in the *Circuit Sticker Sketchbook*!

Alexa Guthery (age 9)

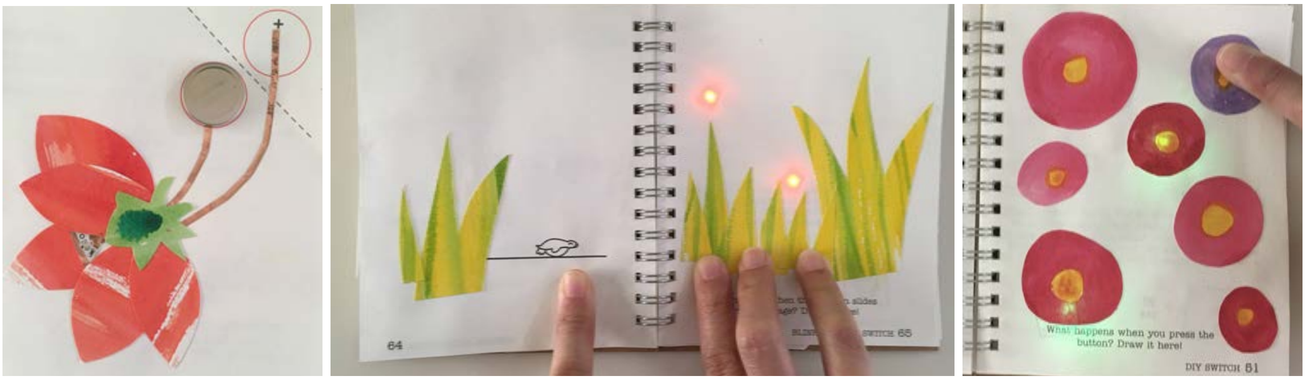
To illustrate her original story about the adventures of an acorn, Alexa (age 9) created a blinking UFO in the night sky



video: NEXMAP

Paper Circuitry Meets Beethoven's 5th: a music teacher explains his paper circuit project during a Art Educator workshop with SFUSD

Featured Art Technique: Collage



Artwork and images: Jie Qi

Collage techniques work beautifully with paper circuits! Watercolor, tempera, and acrylic paints add textures and patterns to white or colored paper. Upcycled printed papers like magazines or packaging add a different look. Translucent papers, such as tissue paper or vellum, make great diffusers over lights. For those intimidated by drawing, collage is a more approachable starting point!

Left and upper middle by Taia Saurer. Lower middle and right by Jie Qi

Collages blend textures, colors, and other qualities of the materials we choose to collage with. Scrapbooking, for example, uses photos and paper memorabilia to create a collection of personal stories.

Artist Aurora Robson (see Start with Art from LTC Lesson 7) creates social and environmental commentary through her Junk Mail Collages. Collages allow us to use not only the physical properties of the materials but also the memories and emotions that we associate with them. Try this out by collaging with newspapers, souvenir papers, or photographs in your paper circuits!

Lesson 5: Animated Slide Switch

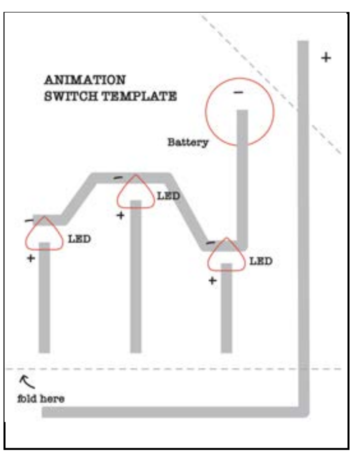
Two 45-minute lessons or one 90-minute lesson

Materials

- [ ] 1-3 Circuit Sticker LEDs
- [ ] ~17 inches conductive tape for small template or ~42 inches for wide template
- [ ] 1 CR2032 battery
- [ ] 1 small binder clip
- [ ] Extra sheets of paper, drawing and/or collage materials
- [ ] Animated Slide Switch
  Small Template
  Wide Template
- [ ] Storyboard worksheet

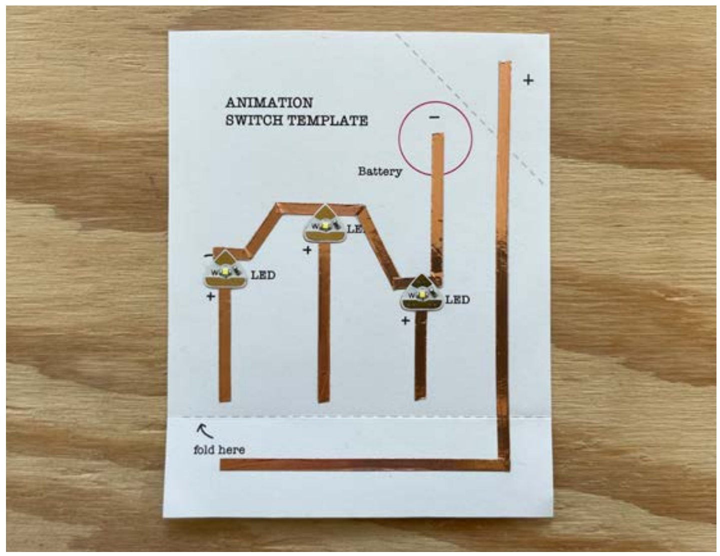
Inspiration

- Birds in Flight animation by Becca Rose
- Hannah Grimm's Student Animation Circuits
- Horses in Motion animation by Muybridge



Lesson Overview

Students will practice an iterative design process by sketching a storyboard and then building an animated circuit that illuminates multiple LEDs in sequence.



Learning Objectives

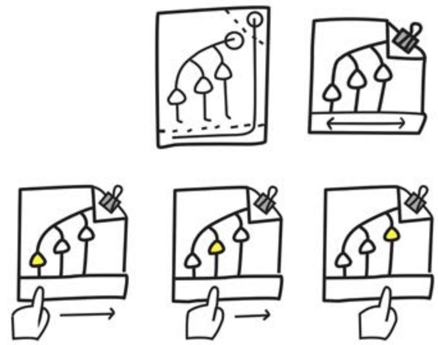
- Use an animated slide switch to light up multiple LEDs in sequence
- Use animation as a narrative technique in a media art piece

Vocabulary

- **animation:** the technique of sequencing individual drawings or forms to create the illusion of movement
- **switch contact**: conductive parts in a circuit used to make contact when closing a switch
- **switch gap**: a break in a circuit path that can be closed by a switch

Background

The *animated slide switch* is another type of switch that uses multiple contacts to create an interesting effect. In this design, there is one long **switch contact** and multiple **switch gaps**, one per LED. Sliding your finger along the switch causes one LED after the next to turn on. This can create a sense of movement or animation across the page, as the light appears to move from one place to the next in sequence.



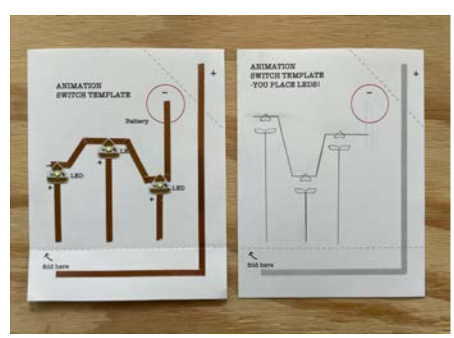
Teacher Preparation

1. Use the template to build an animated slide switch as a class example
2. Consider breaking out of the template and creating your own freeform design on a larger page, moving the LEDs and slide switch contacts. This is a really helpful exercise to check your understanding of the connections - they take some practice to wrap your head around!

Lesson Sequence

1. Start with Art: Show Becca Glowacki's birds in flight. How was the effect of motion created? You can also show some of the first moving pictures!
2. Build the small animated slide switch template
3. Discuss: in their own words, how does this circuit work? Encourage students to use the vocabulary terms **switch gap** and **switch contact** to help explain their circuits. How would they change the circuit if they wanted to:
   a. move the LEDs to different places on the page?
   b. add another LED?
   c. make the animation move up and down instead of left to right?
4. Design the story! Sketch a storyboard to use with either animated slide switch template, planning out the sequence of images that will be represented on the circuit.
5. Build the circuit and create the story overlay! Students can use the small template or the wide template for more space. Shown at right, students can place the LEDs anywhere on the page, or stick to the template placement.

Animated paper circuit by Becca Rose showing the motion of a bird in flight.



Storyboard

What happens first?	Then what?	How does it end?

Project theme ideas for the animated slide switch:

1. As in the bird in flight example, show an animal, person, or process in action by breaking down the motion into separate frames. Consider zoetropes as inspiration! How might this connect to your students' interests? For example, their favorite animals, sports, holidays or performances.
2. Use animation to show a process in science or nature. Lovely past examples from teachers include the flow of magnetic fields, the circulatory system in plants or animals, and the water cycle.

Extensions and Adaptations

1. Team up to make a joint project incorporating one blinking LED and one animated LED sequence to tell a cohesive story.
2. Go beyond the templates and have students design their own slide switch circuits, changing the placement of the LEDs and the shape of the slide switch. Slide switches can follow a path of any shape and likewise the LED sequences can animate along any path. The slide switch motion and LED sequence also don't have to move in the same direction. For example, a slide switch moving left to right could animate LEDs top to bottom. It all depends on how the switches gaps and LEDs are connected.

Inspiration


This animated page by Becca Rose shows the motion of a bird in flight. Each "frame" of the bird's wing movement is illuminated one at a time in sequence, creating a sense of motion.

Educator Hannah Grimm's students create beautiful animated fireworks, rockets, and more using tiny surface-mount LEDs and a special wide-tape technique (see these examples in motion!)

Lesson 6: Pressure Sensor

One 45-minute lesson

Materials

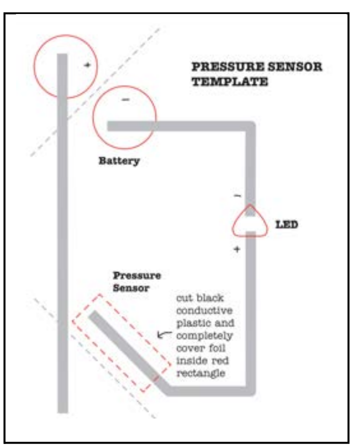
- [ ] 1 Circuit Sticker LED in any color (mix of colors among the class is ideal)
- [ ] 13 inches conductive tape
- [ ] 1 CR2032 battery
- [ ] 1 small binder clip
- [ ] Small strip of pressure-sensitive conductive plastic
- [ ] Pressure sensor template

Resources

- Pressure Sensor Tutorial and Video

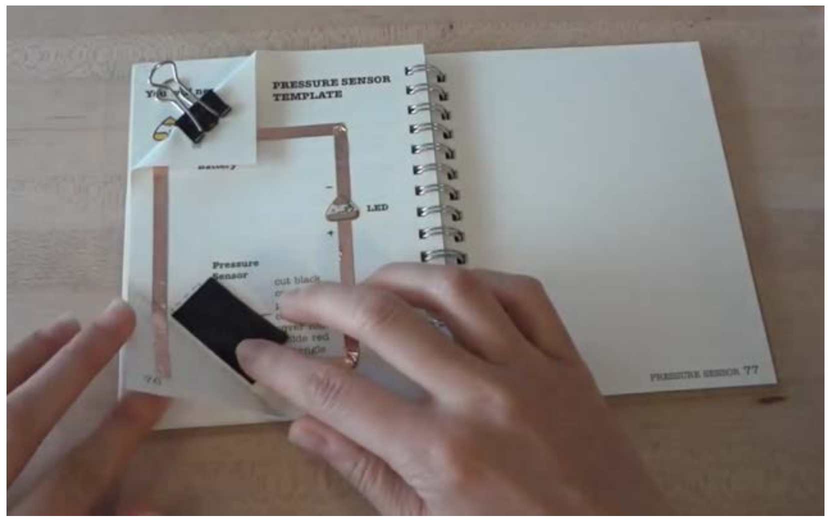
Inspiration

- 6 ways to use a pressure sensor
- Heart Card by Jie Qi
- Haunted House Pressure Sensor Part 1 and Part 2 by Jill Dawson



Lesson Overview

Students will use a special pressure-sensitive conductive plastic that becomes more conductive when pressed to create a pressure sensor that can fade an LED both in and out.



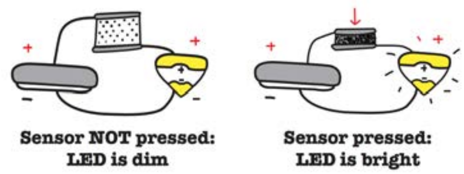
Learning Objectives

1. Use a pressure sensor circuit to fade an LED in and out
2. Use a pressure sensor to light colors in sequence and explore other pressure sensor effects
3. Use interactivity to tell a story

Vocabulary

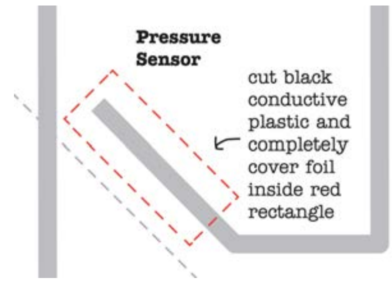
- **conductor (conductive)**: (property of) a material that allows electricity to flow easily
- **resistor (resistive)**: (property of) a material that resists or slows the flow of electricity
- **sensor:** a component that can perceive something in the physical world (for example, how much pressure) and turn it into an electrical signal in a circuit
- **meaning**: a message or story communicated by a piece of art

Background



Going beyond blinking your lights fully on or fully off with a switch, you can gradually fade your LEDs in and out using a pressure sensor.

Pressure sensitive conductive plastic, sold by the brand names Velostat or Linqstat, is a thin plastic containing **conductive** carbon particles. This gives it an electrical **resistance** that changes with pressure. In other words, how well it conducts electricity changes when you press on it. We can use this to make a pressure sensor.



The pressure sensitive plastic is sandwiched within a switch gap between two contacts

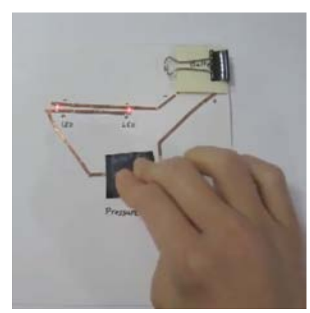
When you are not pressing on the plastic, the conductive particles in the material are spaced farther apart. Electrons cannot flow as well, so the light is dimmer. The harder you press, the closer the conductive particles become and the better the material conducts, so the light shines brighter.

Tip! There are different types of pressure sensitive conductive plastic; some more conductive than others!

Teacher Preparation

1. Watch the pressure sensor video and/or read the tutorial. Then use the template to build a pressure sensing circuit as a class example
2. Watch the 6 ways to use a pressure sensor video. Optionally, build an "advanced" pressure sensitive circuit of your choice.

Lesson Sequence



1. Start with Art: Watch the heart card video, pausing at the 20 second mark, before the card is flipped over. Ask students to brainstorm: what different stories could this circuit tell?
2. Next, show the reveal: a puppy that blushes more and more when the heart is pressed. The circuit made the animation possible, but the drawing turned it from a circuit into a story!
3. Pointing to the pressure sensitive conductive plastic in the video, explain that a special material is used to create the dimming effect.
4. Show the pressure sensor tutorial video.
5. Students build their pressure sensor circuits on the template, referencing the tutorial.
6. What kind of meaning will their pressure-sensitive circuit communicate? Building on the initial group brainstorm, ask students to sketch ideas before creating the illustration to go with their circuit.
7. Students illustrate their pressure sensor circuits.
8. Class gallery walk of projects.

Extensions and Adaptations

1. Try sandwiching a piece of the pressure sensitive conductive plastic between the battery and battery flap in any of the circuits students have built so far to see the blink effect become a gradual fade! The same trick works for gaps in switch circuits, creating a more gentle effect.

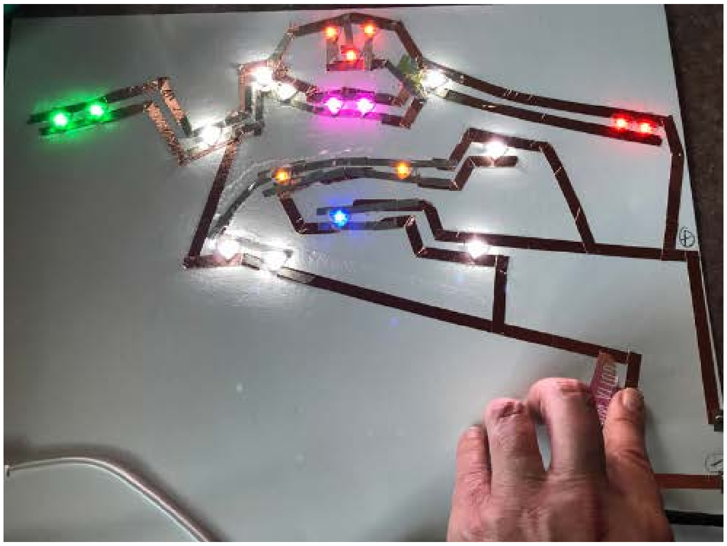
   Try moving the conductive plastic piece around different existing circuits. But watch out for short circuits: make sure the conductive plastic does not bridge the + and - of the circuit.

2. Use the pressure sensor circuit to explore the electrical properties of other materials, as in the *Circuit Science: Conductors, Resistors, and Insulators* activity that follows.

3. Build on pressure sensor effects using the ideas in 6 ways to use a pressure sensor. Students can work in groups to plan out how to explore one of the techniques, and then request the materials needed for their project.

Inspiration

In her Haunted House with Pressure Sensor Part 1 and Part 2, Jill Dawson creates beautiful fading and glowing effects. She uses the same drawing but different pressure sensor circuits to create entirely different ways to interact with the scene.



Jill Dawson

Circuit Science: Conductors, Resistors, Insulators

One 60-minute lesson

Materials

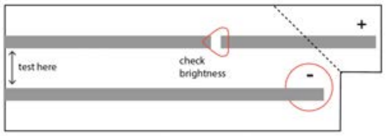
- [ ] 1 white LED Circuit Sticker
- [ ] 11 inches conductive tape
- [ ] 1 CR2032 battery
- [ ] 1 small binder clip
- [ ] Scissors
- [ ] Some materials you'd like to measure the resistance of
- [ ] Resistance sensor template printed onto cardstock or transparency plastic
- [ ] Materials Table Worksheet

Resources

- Introduction to Copper Tape
- Simple Circuit tutorial
- DIY Switch Tutorial

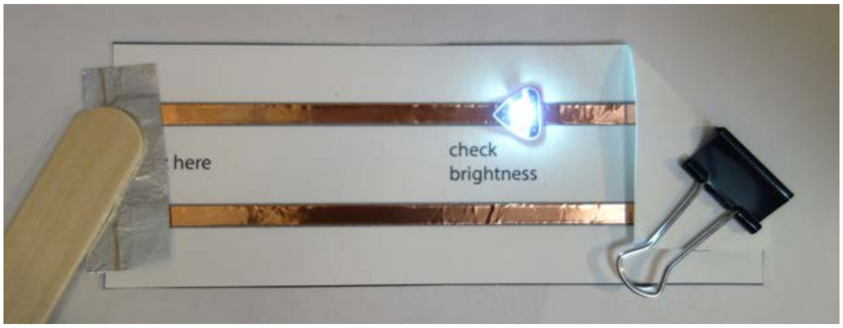
Inspiration

- Electronic popables video, image gallery and blog by Jie Qi



Lesson Overview

In this activity, students will make their own pocket-size resistance tester and use it to explore electrical properties of different materials. Students will measure which materials conduct, resist, or insulate electricity.



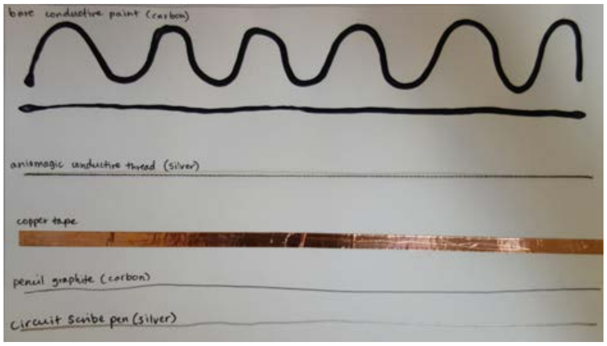
Learning Objectives

1. Evaluate how conductive a material is by observing the brightness of an LED when the material is connected in the circuit
2. Categorize everyday materials as electrical conductors, resistors, or insulators
3. Consider artistic applications of the electrical properties of different materials

Vocabulary

- **conductor (conductive)**: (property of) a material that allows electricity to flow easily
- **resistor (resistive)**: (property of) a material that "resists" or slows the flow of electricity
- **insulator**: a material that blocks the flow of electricity

Teacher Preparation



Example of a materials sample sheet. Materials can be taped down to a sample board or sheet, or given to students in a bag or box.

1. Follow the directions on the template to build your own resistance tester and use it to measure different materials in your home and classroom.
2. Select an assortment of materials for students to test, such as:
    a. aluminum foil
    b. metallic paper
    c. metallic thread
    d. carbon (in pencil lead or other forms)
    e. conductive paint (often made from carbon)
    f. water or other liquids (eg. water, juice, salt water)
    g. resistors (the electronic component)
    h. leaves or other natural materials
    i. play-dough (see Squishy Circuits for how to make modeling dough with different electrical properties!)

Lesson Sequence

1. Print and cut out the template. **Tip:** print or trace onto plastic, such as an overhead projector sheet, if you'd like to test the resistance of wet materials. Otherwise, use standard printer paper or cardstock.
2. Lay copper tape over the shaded lines on the template. You can wrap the tape a centimeter or two around the edge of the bookmark on the "test here" side if you'd like to be able to test materials from both sides of the bookmark, or just stop at the edge. Just make sure the tape lines don't cross each other.

3. Add a Circuit Sticker LED over the outline on the template
4. Fold over the corner. Sandwich the battery into the fold, - side down, and clip with a binder clip. Note: if you made the plastic version, it can be pretty slippery, so students may need help with the clipping step.
5. Place each test material so that it bridges the two lines of copper tape where the words "test here" are printed. This will close the circuit and allow current to flow through your material to the LED. Hold them in place with something non-conductive, such as a popsicle stick or a pen.
    - If the material you are testing is a good **conductor** of electricity, the LED will shine brightly. This means the resistance is low.
    - If the LED is dimmer, you can call the material a **resistor**, meaning that it blocks some, but not all of the flow of electricity.

If the LED doesn't visibly turn on, the material could be a resistor with very high resistance, or it could be an **insulator**, a material that fully blocks the flow of electricity. We would need a more sensitive tester - such as a multimeter - to tell the difference.

Testing a piece of aluminum foil.
Tip: *for testing wider materials, attach alligator clips as test leads.*

6. Students record their observations in this table, then share out. Did everyone classify the materials in the same way? Where did they differ?

Name of material	Insert photo or sketch	Your prediction: how bright will the LED be?	Brightness (0 is off, 1 is dimmest, 5 is brightest)	Conductor, resistor, or insulator?

Questions for students to consider:

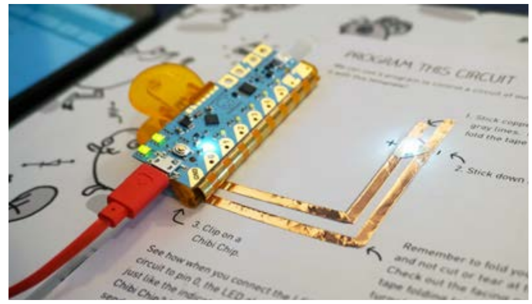
1. What is the relationship between the brightness of the LED and the resistance? How does one change as the other changes? What experiment could we design to figure this out?
2. What kinds of artistic applications might there be for a circuit that changes its brightness as different materials are added? Where else could you use this idea?

PART TWO

Love To Code

Love to Code

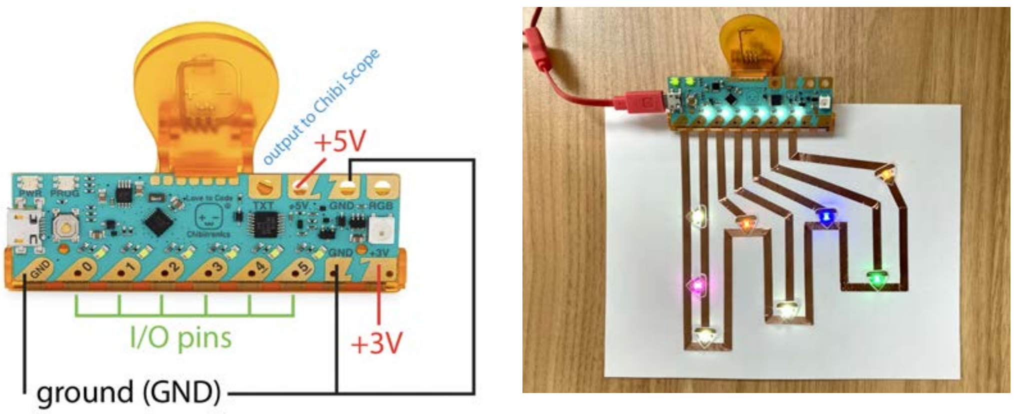
Love to Code is an electronics and coding toolkit designed for paper circuits! Its three core parts are the **Chibi Chip microcontroller**, **MakeCode** and **Chibi Script** online code editors, and **Love to Code book.**



Part 2 of this guide goes through each chapter of the Love to Code book as well as the supplemental chapter on light sensors and analog input. Let's take a closer look at each part!

Chibi Chip Microcontroller

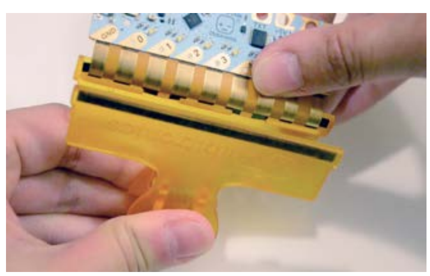
The Chibi Chip is a paper-friendly programmable microcontroller designed to clip onto paper circuits, allowing us to code interactive effects and animations. It has six pins that we can program to do different behaviors, from lighting up LEDs to reading switches and sensor values.



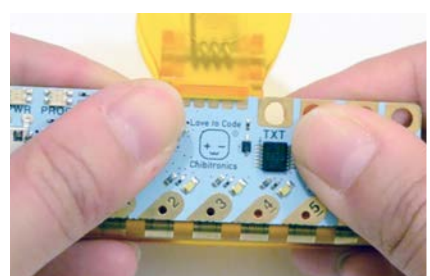
The Chibi Chip and its programming cable (left). The Chibi Chip clipped to a paper circuit, with its metal connectors aligned with the copper tape traces.

We designed the Chibi Chip to be removable from its plastic clip so that you can lay it completely flat for more integrated projects. See the tutorial and video for detailed assembly instructions. The basic steps are:

1. Open the plastic Clip.



2. Slide the flexible part into the three notches at the mouth of the clip.



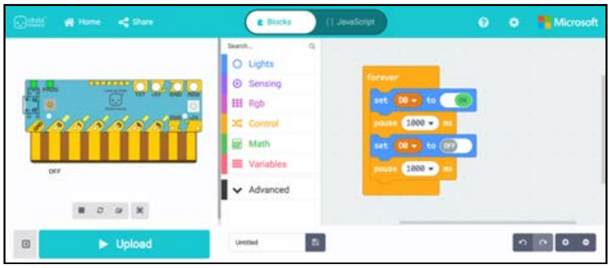
3. Press and snap the board into the notch at the top of the clip. Done!

To attach the Chibi Chip more securely, stick double sided tape underneath between the Chibi chip and clip. To remove the Chibi Chip, open the clip and gently slide the yellow, flexible part out of the notches inside the clip. It should slide right off!

MakeCode and Chibi Script Code Editors

To write code and upload code to the Chibi Chip, we use online browser-based coding environments. You can choose between two languages: the visual block-based Microsoft MakeCode and the text-based Chibi Script. Here is a comparison table to help you decide which is the best fit for your classroom:

Microsoft MakeCode



Access at **makecode.chibitronics.com**

- Visual and block-based programming, similar to Scratch
- Has simulator to preview code
- Translates to Javascript code
- Doesn't support programming servo motors
- Good for use on tablets and touchscreens
- Better support for multithreading
- Great for beginner programmers of any age

Chibi Script

Access at **ltc.chibitronics.com**

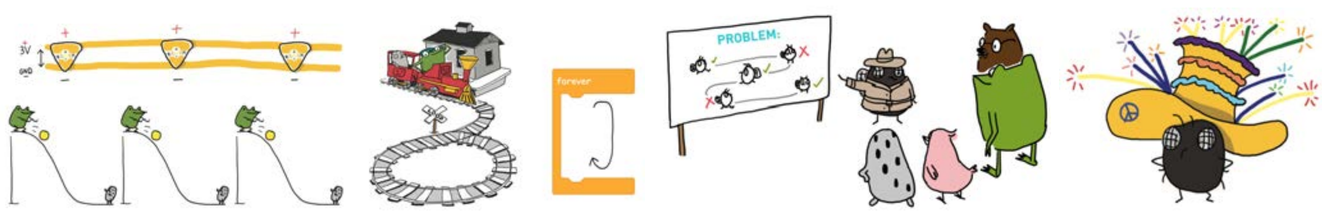
- Text-based coding, building up to Arduino
- Has a debugger to point out basic errors in your code
- Does not have a simulator
- More text output options on Chibi Scope
- Supports programming servo motors
- Supports using the Chip as a keyboard
- Good for more advanced learners

In general, even with older learners, we recommend starting with Microsoft Makecode for a quicker, more friendly introduction to coding. While many of the examples in this guide show only the Microsoft Makecode version of programs, this guide is written to work with both programming languages.

Love to Code Book

The Love to Code book is a blend of storybook, textbook and hands-on activity guide that gives an overview of core paper circuits, electronics design and programming topics.

The book covers powering and programming the Chibi Chip, turning lights ON and OFF with digital output, reading input from switches, fading lights in and out with analog output, and debugging strategies. In the additional light sensor chapter, we show how to read analog input using light sensors. We introduce computer science concepts like loops, logic, conditionals, variables and multithreading as well as circuit design theory like current, voltage, series versus parallel circuits and pulse width modulation.

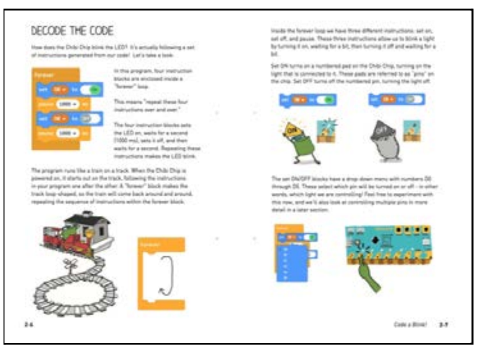


Just like the Circuit Sticker Sketchbook activities, each circuit building and programming activity is paired with an open-ended art activity to give students room to make the circuits and code their own!

We wrote this book not only to convey information about circuits and coding, but we also created a cast of friendly characters to portray the social and emotional side of learning new and difficult topics. We hope these humorous characters and their misadventures can help keep your students engaged and encouraged while learning!

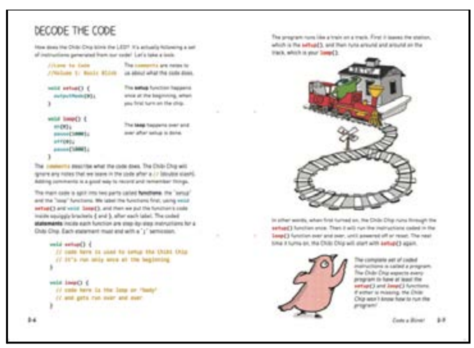
As with the Circuit Sticker Sketchbook introduced in Part 1, the Love to Code book is licensed under a CC BY-SA-NC- 4.0 license. This means you are free to download, copy, print, translate, and remix elements of the book as long as you attribute us, use it for non commercial purposes, and share any remixes under the same license. Here are links for downloading PDFs of the full books and chapters:

Love to Code Makecode Edition



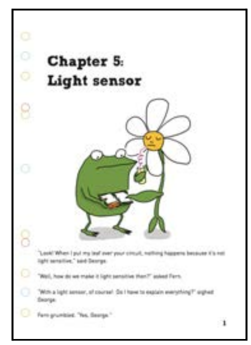
- For viewing on a screen
- For printing out

Love to Code Chibi Script Edition



- For viewing on a screen
- For printing out

Light Sensor Chapter



- For screen and print

Google slide deck of Love to Code Makecode Edition

Suggested Materials to Use with this Guide

We recommend the following tools and materials for completing Part 2 lesson activities.

Love to Code Kit (Links to purchase individual kit or supplies for 12 students)
This kit contains all the materials to do the core activities described in LTC Lessons 1 through 9 of this Educators Guide. The kit includes printed copies of both the Microsoft Makecode and Chibi Script versions of the Love to Code book. Kit contents:

- Printed books in Microsoft MakeCode and Chibi Script
- Reusable binder with battery pack for 3 AA batteries (batteries not included in the kit)
- Chibi Chip microcontroller with clip
- Programming cable
- 36 white LEDs, 64 fabric tape patches, 2 rolls copper tape

The Love to Code binder is a portable battery-powered USB power supply for your Chibi Chip, as well as contained for the Love to Code book pages.

Light Sensor Chapter & Materials Pack (Link to purchase)
LTC Lessons 10 and 11 of this Educators Guide use the supplementary Light Sensor Chapter and accompanying light sensor sticker materials pack. This kit contains:

- 3 light sensor circuit stickers
- Printed Light Sensor chapter (in Chibi Script only)
- 32 fabric tape patches, 9 white LEDs, 1 roll copper tape

Color LED Stickers *(optional)*
(Link to purchase Red/Yellow/Blue, Pink/Orange/Green, and Color Sampler packs)
While they are not required to complete the circuits, we suggest giving students LED stickers of various colors to provide a wider range of expressive possibilities!

Power and Programming Device
The Chibi Chip requires USB power to run. Instead of the battery-powered binder, you can also use USB wall power, the USB port from a computer or a USB charger. Students will need a programming device such as a computer, tablet or smartphone with an audio jack. The coding environments run in a web browser and do not require any special installation. However, students will need access to a reliable internet connection.

Additional Craft Tools and Materials

- Scissors
- Adhesives: tape and glue sticks
- Pencils for sketching out circuits
- Colored pencils, markers, watercolors, and other art tools of your choice for decoration.

Suggested CSTA Standards

All Lessons

1B-AP-15 3-5 Test and debug (identify and fix errors) a program or algorithm to ensure it runs as intended.
1B-AP-12 3-5 Modify, remix, or incorporate portions of an existing program into one's own work, to develop something new or add more advanced features.

Lessons 3-7, 9-12

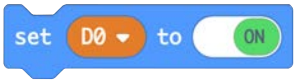
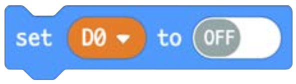
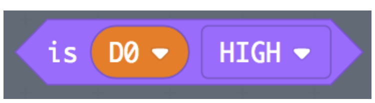
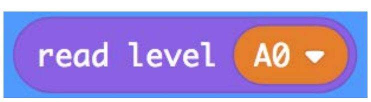
1B-AP-09 3-5 Create programs that use variables to store and modify data.

1B-AP-10 3-5 Create programs that include sequences, events, loops, and conditionals.

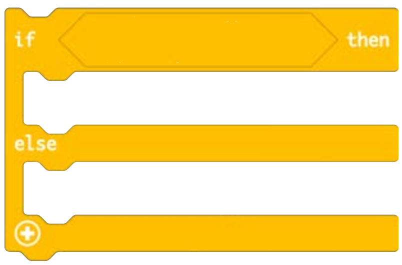
Projects

1B-AP-16 3-5 Take on varying roles, with teacher guidance, when collaborating with peers during the design, implementation, and review stages of program development.
1B-AP-17 3-5 Describe choices made during program development using code comments, presentations, and demonstrations.
1B-IC-20 3-5 Seek diverse perspectives for the purpose of improving computational artifacts.
2-CS-02 6-8 Design projects that combine hardware and software components to collect and exchange data.
2-DA-08 6-8 Collect data using computational tools and transform the data to make it more useful and reliable.
2-AP-18 6-8 Distribute tasks and maintain a project timeline when collaboratively developing computational artifacts.
1B-DA-07 3-5 Use data to highlight or propose cause-and-effect relationships, predict outcomes, or communicate an idea.
3A-DA-11 9-10 Create interactive data visualizations using software tools to help others better understand real-world phenomena.
2-AP-19 6-8 Document programs in order to make them easier to follow, test, and debug.

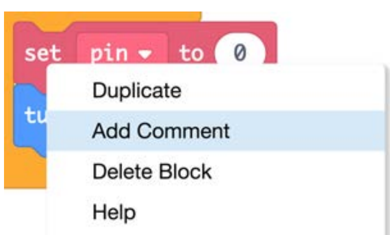
Love to Code Reference Table

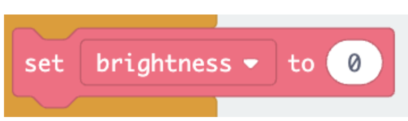
Microsoft MakeCode	Chibi Script	Arduino	What it does
	`on(pin)`	`digitalWrite(pin, HIGH)`	Turn LED on by connecting the I/O pin to +3V.
	`off(pin)`	`digitalWrite(pin, LOW)`	Turn LED off by connecting the I/O pin to GND.
	`setLevel(pin, value)`	`analogWrite(pin, value)`	Set brightness level on pin between 0 and 100.
	`pause(milliseconds)`	`delay(milliseconds)`	Do nothing for some number of milliseconds (there are 1000 milliseconds in 1 second). For example, leave a light on for a certain amount of time before turning it off.
	`read(pin)`	`digitalRead(pin)`	Sense whether pin is high (ON) or low (OFF). Use this to read whether a switch is pressed or not.
	`readLevel(pin)`	`analogRead(pin)`	Read the voltage level between 0-3V and return a number between 0 and 100 based on the reading. Use this to read sensor values, such as a light sensor.
n/a (happens automatically!)	`inputMode(pin)`	`pinMode(OUTPUT)`	set pin to be used as an output (eg. an LED)
n/a (happens automatically!)	`outputMode(pin)`	`pinMode(INPUT)`	set pin to be used as an input (eg. a switch or sensor)
	`void setup() { }`		The setup or "on start" function: everything in this block will run once at the start of the program, when the Chibi Chip is first powered on.

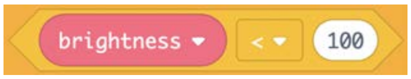
	`void loop() {`
	
	`}`
		The loop function: everything in this block will run repeatedly after the setup / on start function finishes.

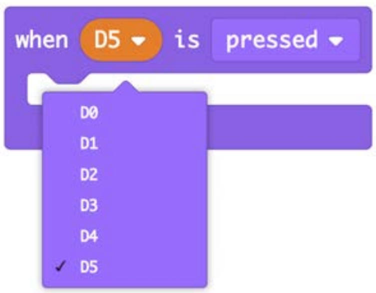
	`if(`*`condition`*`) {`
	
	`}`
	`else {`
	
	`}`
		if else statement (conditional statement)
		
		check if the condition is true, if so run code inside the *if* block. Otherwise, run code inside the *else* block.

	`while(`*`condition`*`) {`
	
	`}`
		while loop: check if condition is true. If so, run code and loop until the condition is false.

	`//this is a comment`
	
	`/*`
	`this is a`
	`comment spanning`
	`multiple lines`
	`*/`
		Add text to explain code to humans; this will be ignored by the microcontroller

	`int brightness;`	create, or *initialize*, a variable
	`brightness`	reference the variable
	`brightness = 0;`	set the variable to a specific value

	`brightness += 5;`		Add to the current value of a variable.
	`brightness < 100`		comparison operator that outputs a true or false value

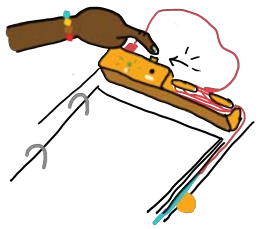
	(similar but not equivalent)
	`void loop() {`
	
	`if(readLevel(5) == HIGH) {`
	
	`}`
	`pause(100);`
	`}`
		(similar but not equivalent)
		`void loop() {`
		
		`if(digitalRead(5) == LOW) {`
		
		`}`
		`delay(100);`
		`}`
			Respond when a pin is high or low, eg. with the press of a switch.
			
			The Microsoft MakeCode version here is **event-driven** and responds when the pin is changed from high to low or low to high.
			
			The Chibi Script and Arduino versions here are "**polling**" based, and continually check the state of the pin.
			
			For event-driven code on the Arduino, see: interrupts.

	(similar but not equivalent)
	`void loop() {`
	
	`if(readLevel(5) == LOW) {`
	
	`}`
	`pause(100);`
	`}`
		(similar but not equivalent)
		`void loop() {`
		
		`if(digitalRead(5) == LOW) {`
		
		`}`
		`delay(100);`
		`}`	

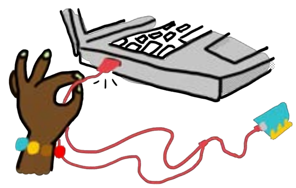
	`100 - readLevel(pin)`	`100 - analogRead(pin)`	Math operator to perform addition, subtraction, etc.

Uploading a Program to the Chibi Chip

1. Power the Chibi Chip by plugging it into a USB port on a computer, a USB wall power adapter, or the powered Love to Code binder, then plugging the other end into the Chibi Chip itself. Check that the green **PWR** light comes on.



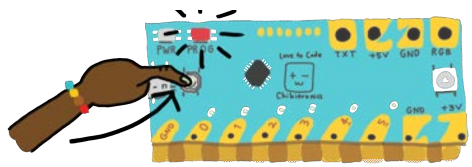
Love to Code Binder



USB port on a computer

USB wall power adapter

2. Press and hold the **program** button on the Chibi Chip, for about three seconds, until the **PROG** light stays red. This will put the Chibi Chip into programming mode so it is ready to listen for your code.



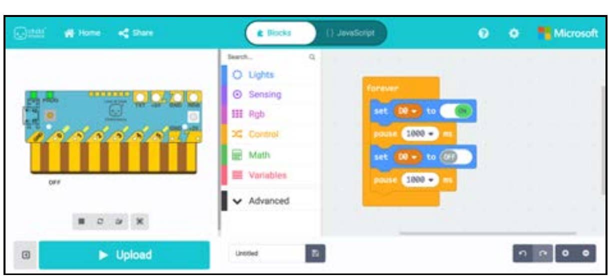
3. Plug the audio cable into your programming device (such as a laptop or tablet). Turn the volume all the way up and make sure it is not muted! Your computer should behave as if it is sending its audio to a pair of headphones. If you hear a staticky sound at any point, check this connection!

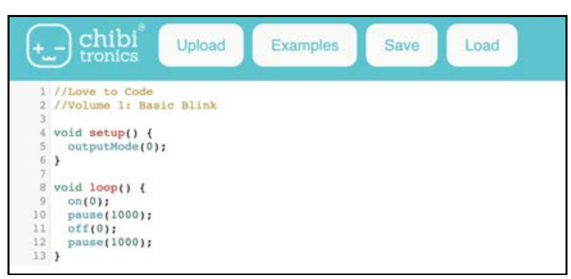
4. On your web browser open the coding environment (see the table below for details) and then open the code you want to upload. Press the **Upload** button in your browser to start sending code to your Chibi Chip! You should see an orange bar appear at the bottom of the screen.

   While the code is uploading the **PROG** light will flash. Once the code has been successfully uploaded to your Chibi Chip, the **PROG** light will go back to green. Congrats you've uploaded your code!

Microsoft MakeCode
Visit **makecode.chibitronics.com** in a web browser, then load the code (for example, Love to Code -> Blinky). Notice the blinking light on pin 0 in the simulator. That's the code in action!

Chibi Script
Visit **ltc.chibitronics.com** in a web browser, then load the code from the Examples menu (for example, Love to Code Basic Blink). Here is a video demo of the process.





Love to Code Troubleshooting Guide

You can find a more detailed guide in the Debugging Chapter of LTC Vol 1 (Chibi Script version / Microsoft MakeCode version). Here's a cheat sheet:

4 main areas to troubleshoot:

1. **Power**: Is the Chibi Chip getting enough electricity to turn on and run the circuit?
2. **Circuit**: Is everything in the circuit connected properly?
3. **Upload**: Are we able to send code from our programming device to the Chibi Chip?
4. **Code**: Are there errors in our code? Does the code actually say what we intend?

Power	1. **Is the PWR light on the Chibi Chip off?** Make sure the USB cable is plugged into a working source of USB power. Some models of Chromebook do not supply enough USB power; a good rule of thumb is if it can power your phone, it can power a Chibi Chip circuit. If you are using the battery-powered binder, make sure the power switch is turned on and the batteries are inserted correctly. 2. **Is the PWR light red instead of green?** That is a sign of a short circuit! Unplug the Chibi Chip from the power source and check for stray connections in your circuit. Make sure the Chibi Chip pins are aligned properly with your circuit, and that each pad is only touching one line of conductive tape.
Circuit	Check: 1. Are your LEDs installed in the correct orientation? (-) to GND, (+) to +3V or I/O pins 2. Is there a short circuit? See above note in power section. 3. Is your Chibi Chip aligned with your circuit traces and firmly clipped in place? See the battery powered circuits troubleshooting section for more tips on troubleshooting and repairing circuit connections.
Upload	1. After you click upload, does the programming light blink red and then turn green? If not, check that you are following the upload steps exactly, starting with pressing and holding the upload button until the programming light turns red. 2. Is the volume on your computer turned all the way up? Is the sound accidentally muted? Make sure to unmute and turn the volume all the way up so that the Chibi Chip can receive the audio-transmitted code. This is one of the most common issues! 3. Do you hear a staticky sound when you click upload? That means audio is playing to your computer speakers instead of to the Chibi Chip. Make sure the audio cable is securely plugged in so that the code plays to your Chibi Chip! 4. Is the audio being distorted? Some computers automatically apply audio filters (such as bass boost) to the audio. Try to turn this off in your sound settings so that the audio can come through clearly.
Code	1. Chibi Script only: Check the red X circles next to your code for **syntax errors**, such as missing semicolons, mismatched parentheses or curly braces, or duplicate variables. 2. **Logic errors** are when the code uploaded correctly, but it is not behaving as the programmer intended. Some strategies: trace through the code line by line, test one change at a time, and simplify the code to isolate the bug. Feeling stuck? Talking out your problem with others often leads to new solutions. Check out our Troubleshooting section for tips on collaborative debugging!

Lesson 0: Illuminated Story

Two 60-minute lessons or one 120 minute lesson

Materials

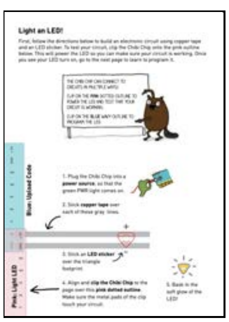
- ☐ 1 Circuit Sticker LED
- ☐ 7.5 inches conductive tape
- ☐ Chibi Chip, cable, and programming device
- ☐ Illuminated Story Template

Resources

- Lesson Printable
- Plugging in and Powering On the Chibi Chip video
- Programming the Chibi Chip
- Programming Demo video

Inspiration

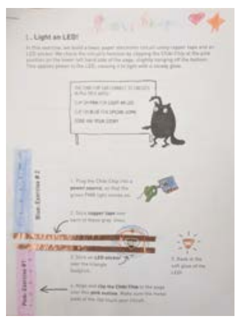
- Dandelion Painting by Jie Qi



The Illuminated Story is a standalone activity. It's a great intro if you have only a few hours total for a creative coding and paper circuit activity. You can skip directly to LTC Lesson 1 if you will be doing the full *Love to Code* sequence.

Lesson Overview

In this activity, students will complete sentence blanks to describe a scene, then turn them into an illustrated story. Students will add an LED circuit to the page, then use the Chibi Chip to program the lights and animate their stories.



Learning Objectives

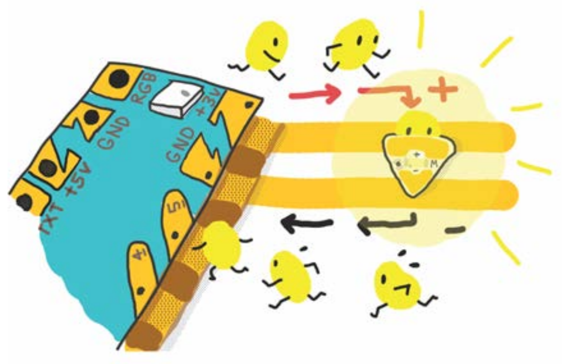
- Power an LED circuit from the Chibi Chip
- Upload a program to the Chibi Chip
- Write a Chibi Chip program that creates a unique blinking pattern and changes the brightness of an LED
- Use a light to evoke a mood in an illustrated narrative

Vocabulary

- **mood**: the atmosphere and emotions evoked by an art piece or story
- **microcontroller**: a type of tiny computer often used to control physical devices
- **program**: a sequence of instructions, or code, for a computer to follow
- **I/O (input/output) pins**: connections on the Chibi Chip that can be switched from 0V (GND) to 3V to turn LEDs or other components on and off.
- **ground (GND):** the reference point that voltage is measured from; 0 volts, or the negative (-) side of the power source.

Background

The Chibi Chip is a **microcontroller** board on a removable clip that allows us to power and to program paper circuits.



The edge of the Chibi Chip has metal pads that clip onto conductive tape traces. To power a circuit, we can use the (+3V) and either of the (GND). The GND, or **ground**, pads are at 0 volts. These act like the (+) and (-) sides of a battery. This means that you can use any USB power source connected to the Chibi Chip to power your circuits.

The six numbered pads (0-5) are called **input/output (I/O) pins**. Unlike the (+3V) and (GND) pads, which are permanently wired, all the numbered pads can be switched between either (+3V) or (GND) by instructions in a computer program. This program can be written in a web browser, then uploaded to the Chibi Chip to run whenever it is powered on.

In the Microsoft MakeCode language, the code instructions to switch pads between +3V and GND are **set pin to ON** and **set pin to OFF**. When pin 0 is set to ON, it is connected internally to (+3V). When pin 0 is set to OFF, it is connected internally to (GND). This allows us to turn LEDs connected to the Chibi Chip on and off. The **set level** instruction gives us a way to set a value between fully on and fully off (more on this in LTC Lesson 8) for different brightness levels.

To write a program with a blink pattern, two more blocks come in handy: **forever loop** and **pause**. The forever loop causes the code blocks inside to repeat. The pause allows us enough time to see the changes. Pause times are in milliseconds (1 second = 1000 ms).

Teacher Preparation

1. Read through the printable and build the LED circuit using the template.
2. Test out a program upload on your own computer and on one of the computers that students will use. Troubleshoot any connection issues (see Love to Code Troubleshooting Guide)
3. Try modifying the code to create your own blink pattern, then uploading the new code
4. Print template and prepare materials for students or teams

Lesson Sequence

1. Start with Art: Watch the Dandelion Painting video. Ask: What do you notice and what do you wonder?

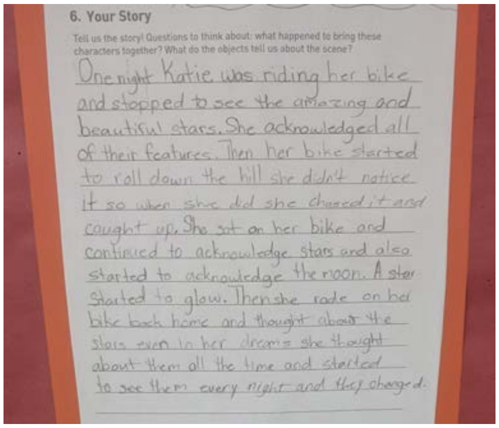
2. Begin with the story starter page. In teams of two, students fill in the blanks to create a story starter for another team.

Who is in the scene?
A ___________(adjective) __________ (identity)
and a _______(adjective) __________ (identity)

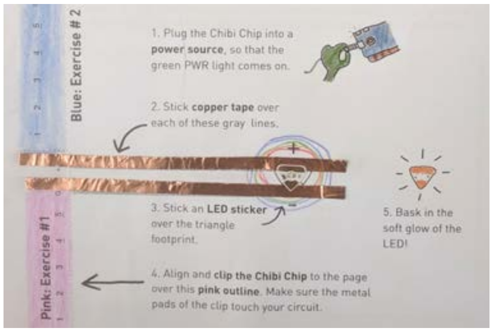
a grumpy pirate and a tired toddler. A curious librarian and a tall musician.

What is in the scene?
A __________(adjective) __________ (object)
and a ______(adjective)_______ (light source)

a damp shoe and a flickering neon light. A wobbly shelf and a cloudy moon.

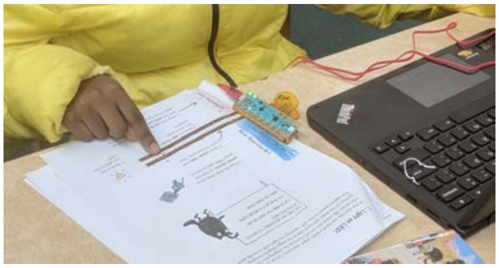


3. Students then exchange story starters with other teams. Based on the starter, teams write out their story. What is happening in the scene?



4. To begin their illuminated illustrations, students move to building their circuits. First, lay conductive tape down over the lines on the template. Then, add a Circuit Sticker LED.

5. To test their LED circuits, by powering them on, students clip the Chibi Chip over the bottom outline and then plug the Chibi Chip cable into USB power. This part of the template aligns the (GND) and (+3V) pins with the circuit, powering on the LED. Ask students to use their fingers to follow each line of copper tape back to the Chibi Chip, checking that the (+) side is lined up with (+3V) and the (-) side is lined up with (GND) on the metal pins of the chip (not the yellow plastic parts in between)



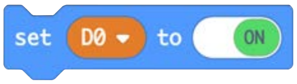
6. Students can now create glowing illustrations for their stories using the illustration box and their LED circuit. Use the LED to illuminate the light source in the scene from in their story starter!


Illustration

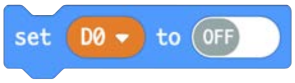
Show us the scene! Use drawings and your programmable light to show us what is happening to your characters. Lay this page over your circuit page and illustrate it below:

7. Finally, it's time to program! Now that students have an illuminated scene, they can use code to create an animated light that helps set the emotional tone or **mood**. Open the Microsoft Makecode editor at makecode.chibitronics.com in a web browser and use the code blocks in the table below to create light patterns. Encourage students to play with brightness and timing to create the type of light that they imagine in their story.

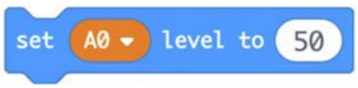
Code Blocks



Turn LED on by connecting the I/O pin to +3V.



Turn LED off by connecting the I/O pin to GND.



Set brightness level between 0 and 100.

Do nothing for some number of milliseconds (there are 1000 milliseconds in 1 second). For example, leave a light on for a certain amount of time before turning it off.

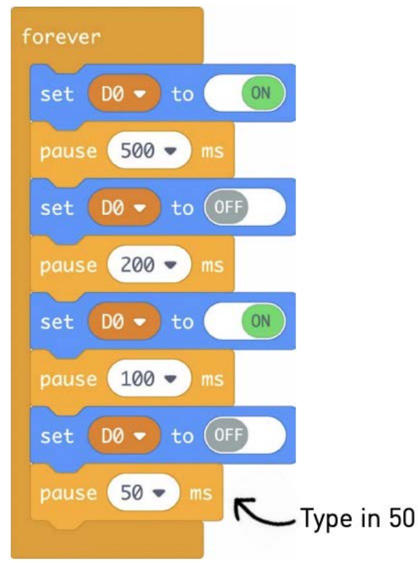
The setup or "on start" function: everything in this block will run once at the start of the program, when the Chibi Chip is powered.

The loop function: everything in this block will run repeatedly after the setup / on start function finishes.

Example Code

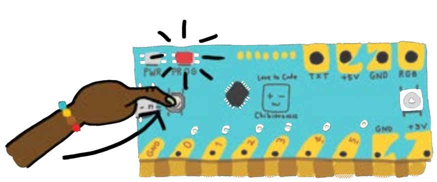
Below are two example programs to help students get started creating their own blink sequences

Blinking:



Fading:

8. To upload the code to their Chibi Chip, so that their LED plays the pattern written in the code, follow the instructions at Uploading a Program to the Chibi Chip. Next, move the Chibi Chip to the top position on the template to connect their LED to (GND) and pin 0. Students can continue to iterate on their code and upload new code until they get the desired effect for their story!



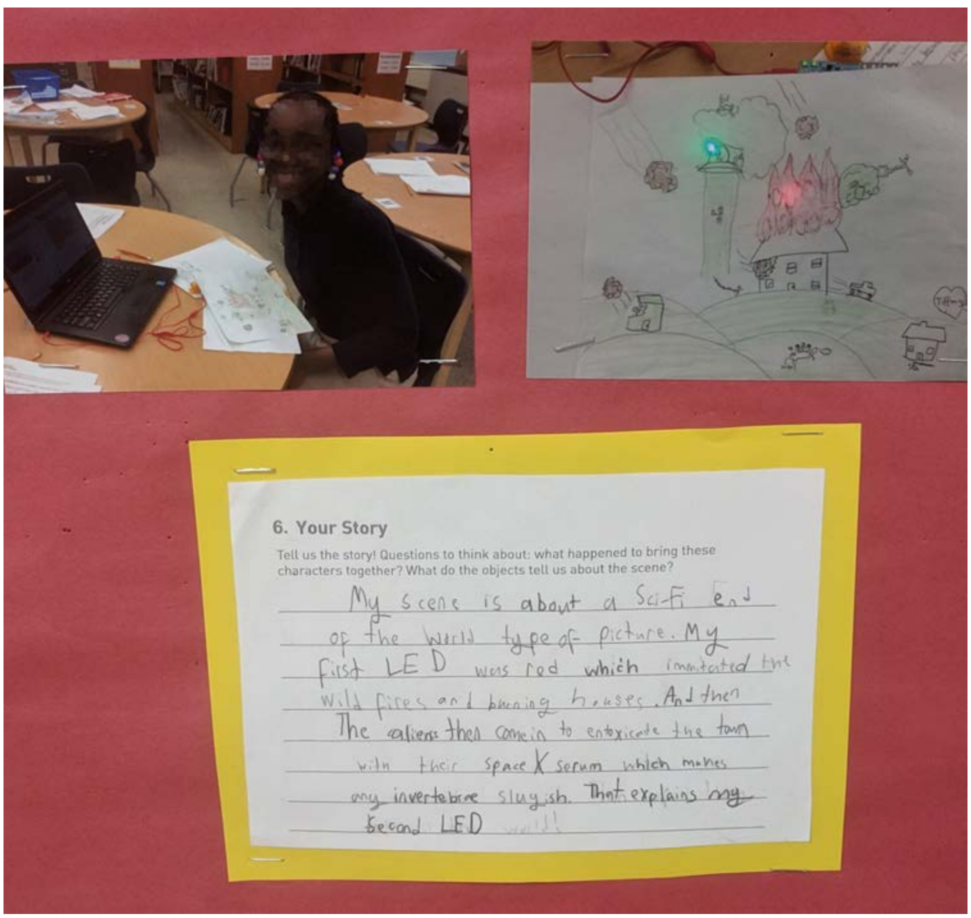
Extensions and Adaptations

1. Work individually rather than in pairs.
2. Adapt the story prompts! For example:
    a. For students in a world language class, write stories in the language they are learning.
    b. Incorporate content-specific vocabulary words into the stories.
    c. Explore a content-specific theme, such as a moment in history or literature.
3. Add more LEDs by extending the parallel circuit traces. See Part 1 Lesson 3 and Part 2 Lesson 2.

The order of this activity is flexible. Students can build their initial circuits before writing their story, or vice versa. Ideally it is an interactive and iterative process of matching the code and electronics to their story, creating a cohesive media arts piece!

Inspiration

An Illuminated Story that was written, illustrated, and programmed by a Maryland 4th grader and presented on a class art wall.



Lesson 1: Getting Started

One 45-minute lesson

Materials

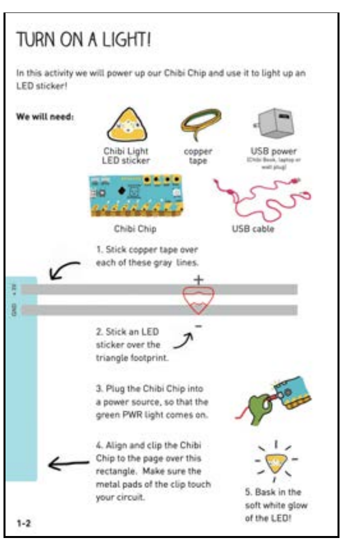
- ☐ 1 Circuit Sticker LED
- ☐ 8 inches conductive tape
- ☐ Chibi Chip with cable and power source
- ☐ Turn on a light template:
  Chibi Script: 1-2 to 1-4,
  MakeCode: 1-2 to 1-4

Resources

- **Lesson page numbers**:
  Chibi Script: 1-5 to 1-9
  MakeCode: 1-5 to 1-9
- MakeCode Book Slides
- Chapter 1 Walkthrough
- Plugging in and Powering On

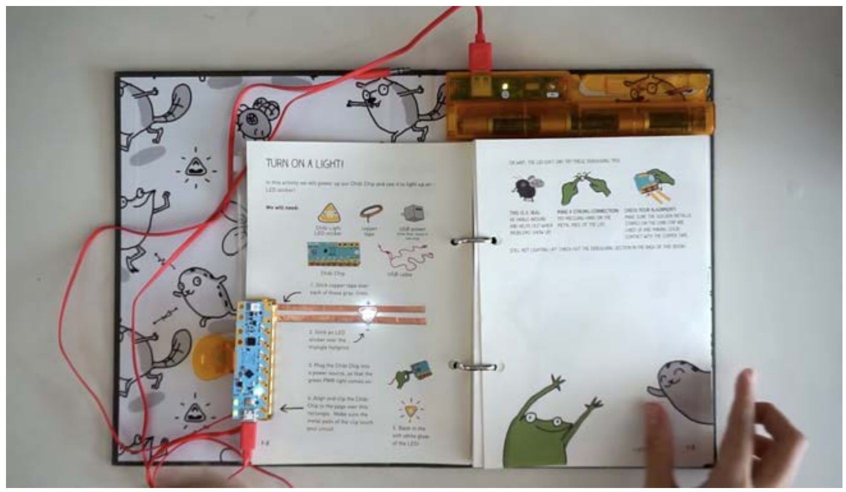
Inspiration

- Dandelion Painting by Jie Qi



Lesson Overview

In this activity, students will learn to power their Chibi Chip and connect it to a paper circuit. They will learn what makes an LED turn on and how to troubleshoot if it does not!



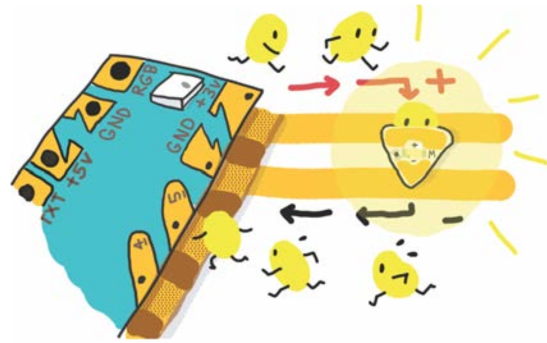
Learning Objectives

- Power an LED circuit from the Chibi Chip
- Identify and fix broken connections, short circuits, and LEDs placed in reverse
- Use light as an artistic element in an illustration

Vocabulary

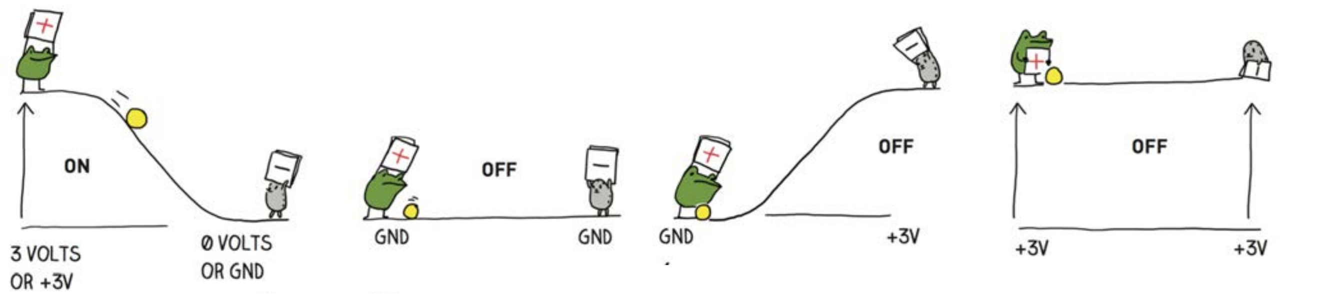
- **voltage:** the difference in electrical potential between two points, such as the positive and negative sides of a battery.
- **current:** the rate of flow of electrons through a circuit
- **ground (GND):** the reference point that voltage is measured from; 0 volts, or the negative (-) side of the power source.
- **short circuit**: when current flows in a circuit with too little resistance, such as when the (+) and (-) sides of a power source touch

Background

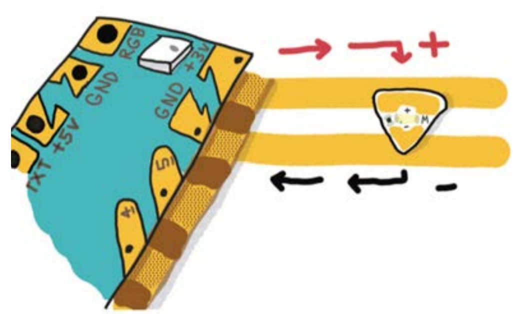


Like the battery in other paper circuits, the Chibi Chip provides electrical energy to power circuits. This energy is the movement of electrons. When the positive (+) side of an LED is connected to +3V on the Chibi Chip and the negative (-) side is connected to 0V or **ground** using conductive tape, electrons have a path to flow through the LED and light it up. Ground, the negative (-) side of the power supply, is shortened to **GND** on the Chibi Chip.

The flow of electrical energy is called **current**. Like a ball rolling down a hill, current will only flow when there is a difference in height, from high to low. In electronics, this difference in height is called **voltage**. Voltage is a measurement of potential energy, just like the height of a ball on a hill.

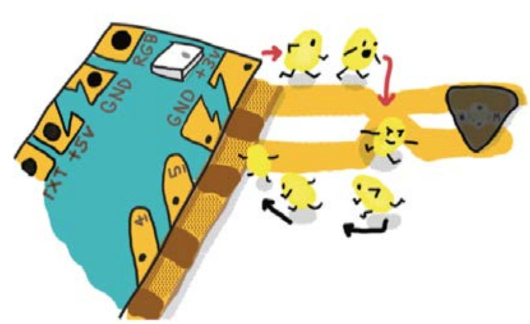


For an LED to turn on, current must flow through the LED from a higher voltage on the (+) side to a lower voltage on the (-) side. To the right is an illustration of what happens when you connect the (+) and (-) ends of your LED to different voltages.



What does this mean for our circuits? The LED must be connected with its (+) side to +3V of (+) on the Chibi Chip, and (-) side to GND or (-) on the Chibi Chip in order to turn on. Connected it backwards by accident? No problem; it won't hurt the LED! Just gently peel it up and place it the opposite way (or patch it if it has lost its stickiness) to see it light.

Later, we will see how to use programmable pads on the Chibi Chip to switch some of these connections using code.



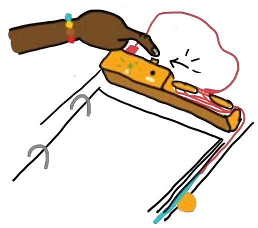
Be aware of **short circuits**! Short circuits are direct electrical connections between +3V and GND. Electrons are "lazy" and will take any shortcut they can find instead of going through your LED to turn it on. If there is a conductive path from (+) to (-) that bypasses the LED, electrons will rush to flow through it. A red warning light on the Chibi Chip will turn on until the short circuit is disconnected. If you ever notice this light or notice that your Chibi Chip is getting warm, turn off the power and check for short circuits.

Lesson Sequence

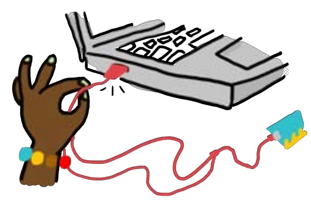
1. Start with Art: Watch the Dandelion Painting video. What materials did the artist use? How do light and interaction play a role in the artwork? By the end of this lesson series, students will have learned the skills to create animated and interactive artworks of their own!

2. Build the Turn On A Light template by running two lines of conductive tape on the template lines and sticking down a LED Circuit Sticker.

3. Power the Chibi Chip by plugging it into a USB port on a computer, a USB wall power adapter, or the powered *Love to Code* binder, then plugging the other end into the Chibi Chip itself. You can leave the audio jack part of the cable unplugged - we won't use this until it's time to program the Chip in lesson 3. Check that the green PWR light comes on to make sure the Chibi Chip is properly powered.



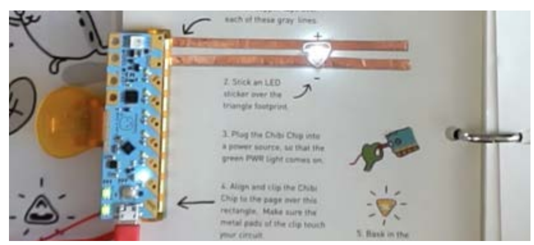
Love to Code Binder



USB port on a computer

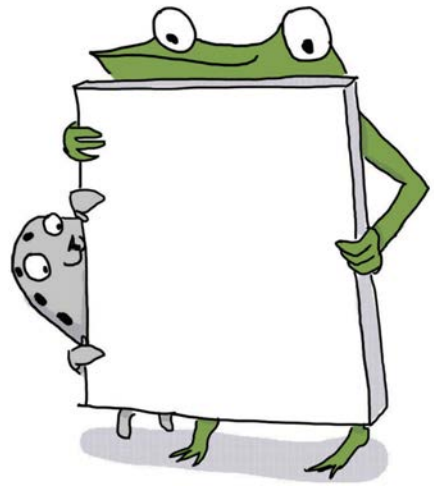
USB wall power adapter

4. Clip the Chibi Chip onto the template, making sure to align the shiny metal pads with the conductive tape on the page. The light should turn on! But what if it doesn't? Not to worry. In fact it is helpful for students to discuss and see examples of non-working circuits to practice debugging and normalize the experience of circuits not working the first time around!



5. Discussion, idea sharing and collaborative debugging:
   a. What are ways to troubleshoot your circuit if the light is not turning on?
   b. What are some ways you could make the LED *not* turn on? In those cases, what is happening in the circuit? As students make suggestions, try them out on a test circuit (ideally, projected via a document camera so that everyone can see what's happening). A few concepts that are especially helpful to show:
      i. Sliding the Chibi Chip so that it is no longer aligned with the conductive tape
      ii. Flipping the LED upside down so that the (+) on the LED is connected to GND
      iii. Creating a short circuit: you can (briefly!) lay down a piece of conductive tape (with metal side facing down) to bridge the two traces and show them the red warning LED on the Chibi Chip. Another way to create a short circuit is to align the clip so that both (+3V) and GND touch the same piece of conductive tape.

6. Draw, paint, or collage on the overlay page! Students can use a blank page, the illustration on the facing page, or a template that relates to a class theme. A few theme ideas:
    a. Think of someone important to you and put their name in lights!
    b. Depict the light source for an object that casts a shadow (draw the shadow, too!)
    c. Look through magazines or old books and find a piece of information to highlight, such as something that is usually hidden



Extensions and Adaptations

1. This lesson can run in a different order, depending on the flow of the class. For example, students can start by planning and designing their overlay page, then building and powering the circuit, and finally troubleshooting and discussing the ideas behind the circuits.
2. This template can be reused for programming activities by sliding the Chibi Chip down so that GND and pin 0 make contact with the conductive tape. See Lesson 0: Illuminated Story for an example!

Inspiration

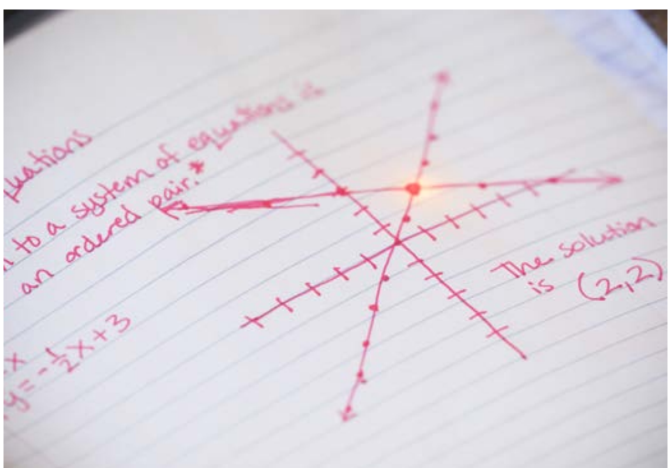


photo: NEXMAP

"Hack Your Notebook!" Math teachers in a workshop by San Francisco NEXMAP experimented with using light to highlight a key piece of information in their notebooks

photo: @NorthStarTxWF

"Kandinsky, angles, lines, and circuitry!" An activity from the North Star of Texas Writing Project combining Kandinsky-inspired artwork

Lesson 2: Parallel and Series Circuits

Two 45-minute lessons or one 90-minute lesson

Materials

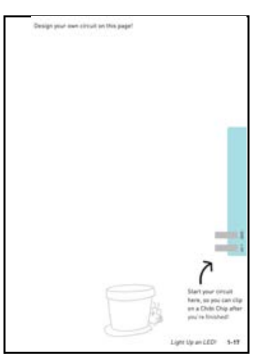
- [ ] 4 white Circuit Sticker LEDs
- [ ] ~60 inches conductive tape
- [ ] 3-4 fabric tape patches
- [ ] 3 alligator clips
- [ ] Chibi Chip with cable and power source
- [ ] Paper to cut up or non-conductive tape
- [ ] Parallel Circuit template: Chibi Script: 1-15 to 1-17, MakeCode: 1-15 to 1-17

Resources

- **Lesson page numbers**: Chibi Script: 1-10 to 1-14, MakeCode: 1-10 to 1-14
- MakeCode Book Slides
- Turning Corners with Copper Tape
- Introduction to Copper Tape
- Parallel and Series Circuits

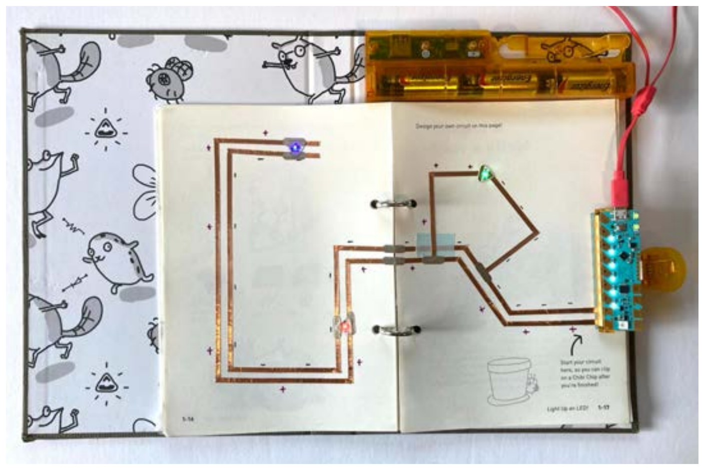
Inspiration

- Stephanie Lee's class
- Circuits on Glass Tutorial
- Michele Guieu's class
- Sketchbooks by Jie Qi



Lesson Overview

Students will compare the properties of series and parallel circuits, then sketch and build a parallel circuit of their own design powered by the Chibi Chip. They will practice conductive tape techniques, including folding corners, reinforcing folds, making t-junctions, and making bridges across conductive tape traces using insulators.



Learning Objectives

- Build a parallel circuit and a series circuit to observe differences and similarities
- Explore trace design techniques like turning corners, junctions and insulator bridges
- Plan, sketch, and build a parallel circuit of their own design with multiple LEDs powered by the Chibi Chip
- Use circuit traces as an artistic element

Vocabulary

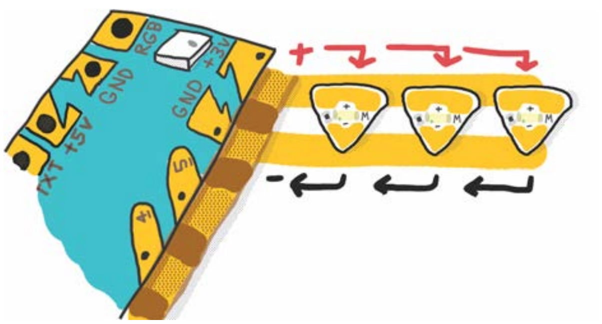
- **parallel circuit:** a circuit or part of a circuit where the terminals of each component connect directly to the power source
- **series circuit:** a circuit or part of a circuit where components are connected end to end
- **conductor**: a material that allows electricity to flow easily
- **insulator**: a material that blocks the flow of electricity

Background

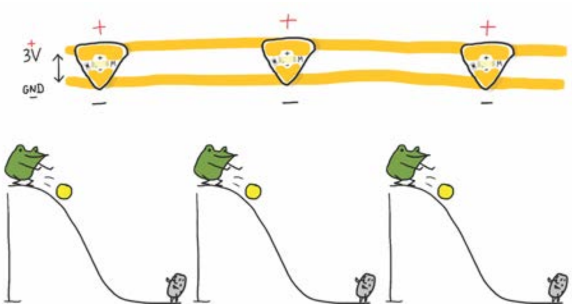
To add more than one LED to our paper circuits, we can choose between creating a **parallel circuit** and a **series circuit**. For our LED projects, we recommend a parallel circuit (we'll explain why!) but both configurations are useful to understand.

The first thing to know is that each LED has a minimum voltage that it needs in order to light up. This value is different for different colors of LEDs, but we can estimate that they need at least 2.5V. This impacts what you will see in a parallel versus series circuit.

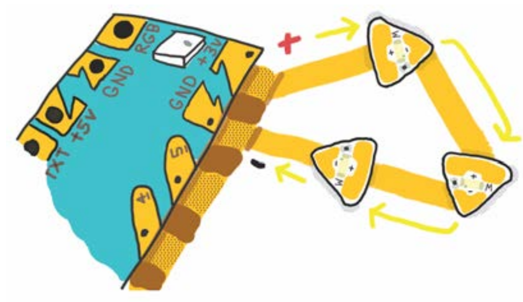
In a parallel circuit, each component has a direct connection to the power source on both the (+) and (-) sides. The LEDs are like rungs in a ladder, attached to (+) and (-) rails. Each LED sees the full voltage difference. Since each LED needs at least 2.5V, connecting them in parallel to the +3V pin will turn all the LEDs on.



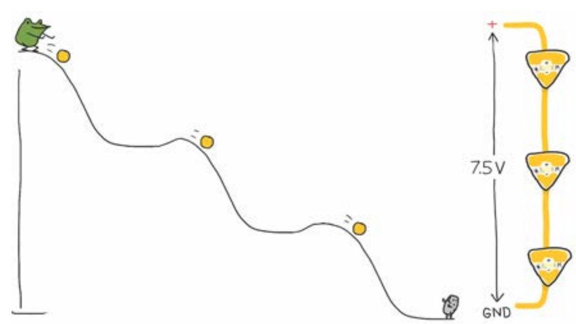
One useful property of parallel circuits is that if one component or "rung" fails, the others will continue working. It's also a good way to debug: if only one LED is off, then you know that the rest of the circuit is properly connected and there are no short circuits.



In a series circuit, components are connected end to end, like beads in a chain. The (+) of one LED goes to the (-) of the next. In this setup, the voltage required adds up, so we need a higher voltage power source. Since each LED needs 2.5V to shine, to turn on 3 LEDs in series we need a 7.5V power supply.



In a series circuit even if one component fails, the others in the chain will ***not*** continue working. This is often the case when all the lights in a chain of fairy lights do not turn due to only a single broken light!

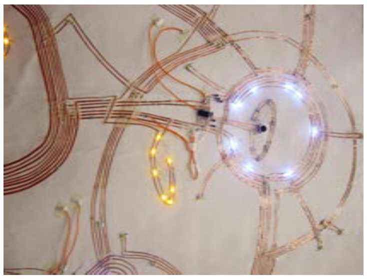


Teacher Preparation

1. Read about series and parallel circuits in *Love to Code* pgs. 1-10 to 1-14.
2. Try out the parallel and series circuit experiment
3. Practice the copper tape folding techniques in part 2 to design a demo circuit

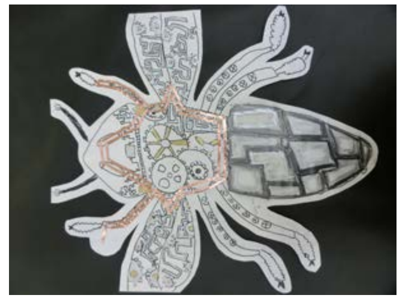
Lesson Sequence

1. Start with Art: As a group, compare and contrast the different circuit layouts in these images or others. What do students notice? What choices did the designers make about their circuits?

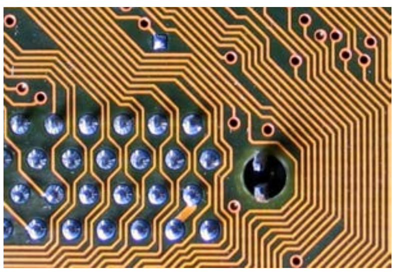


Pu Gong Ying Tu (Dandelion Painting) by Jie Qi

"Circuit Board" by saaby (CC BY-SA 2.0)

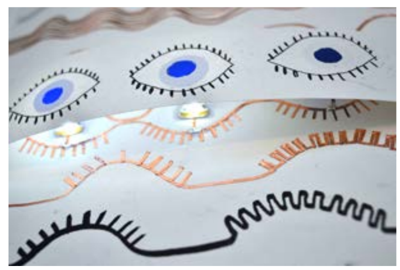


Circuit art by students of educator Stephanie Lee



"Labyrinthine circuit board lines" by quapan (CC BY 2.0)

Circuits on glass by Heliox on Instructables



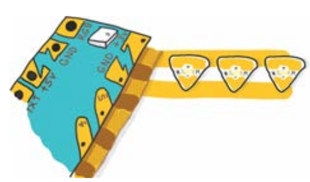
Sketches for Curiosity of Rain by Becca Rose

Part 1: Series and Parallel Circuits

Draw the path of current flow

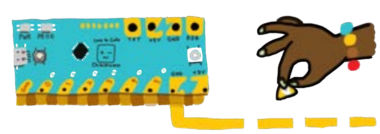
1. Ask students to go back to the circuit from lesson 1 and mark the circular path of current flow through the LED using arrows.

2. Ask: what ideas do they have about how they could add more than one LED to this circuit? Ask them to draw at least 3 ideas.

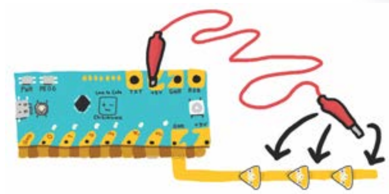


Adding LEDs in parallel

3. Once students are done drawing, ask them to share with their table partner, and then share out with the group. Ask students to look for commonalities between their ideas and categorize them into 2 or 3 possibilities. These may align with series vs. parallel circuit configurations, or they may not - that's ok! Keep it flexible and let students create and describe their own categories.



4. Go over the parallel and series circuit experiment. Divide students into groups of 3 and ask them to work together to build and compare series and parallel circuits using the directions on page 1-11 while documenting their observations to share out. What do they notice, and what do they wonder?



Adding LEDs in series

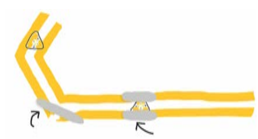
Part 2: Design a Circuit

1. Introduce the circuit challenge: students will work together to build a circuit that showcases their circuit building techniques! Demonstrate the following from the Conductive Tape Core Skills:

Turn Corners

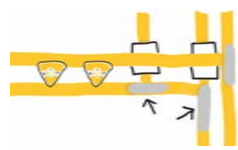
Folding corners of different angles with conductive tape, without cutting the tape, for more reliable connections

Reuse LED Stickers



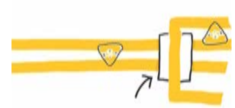
Reuse Circuit Sticker LEDs by using conductive fabric tape or patches. Students should reuse the LEDs in their parallel and series circuit experiments for this new circuit.

Branches



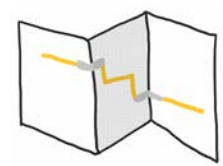
Make a t-junction, where one trace branches into multiple traces. Use conductive fabric tape when working with copper tape.

Bridges



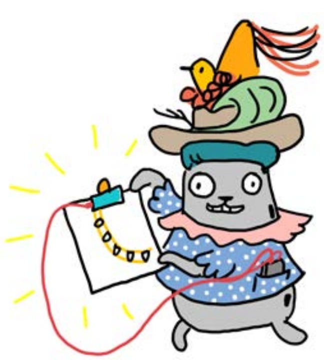
Bridge or jump over an existing trace using an insulator - either a small piece of paper or a piece of non-conductive tape such as masking tape.

Make Hinges



Use conductive fabric tape or patches to bridge across pages and creases to create reliable circuit hinges that frequently fold

2. Ask teams to showcase as many of these techniques as possible in a circuit of their own design. They can use the "What's growing? What's glowing?" flowerpot overlay: what kind of imaginative plant or creature will their circuit illuminate? Challenge students to not only create functional circuits, but explore how the lines of traces can be used to "draw" parts of their fantastical beings.

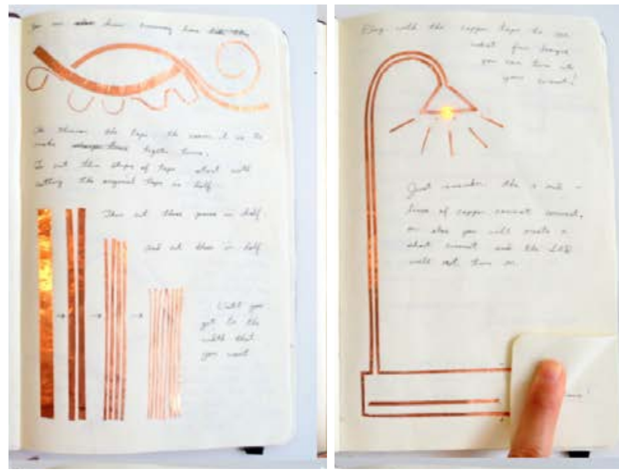


Extensions and Adaptations

1. Draw on the art ideas from Circuit Sticker Sketchbook Lesson 3: guide students to use their circuit traces as an artistically expressive element, and demonstrate how to cut the tape down thinner to create curved and rounded lines.
2. Experiment with more than one color of LED for the series and parallel comparison. This is more challenging as different colors work with different amounts of voltage.

Inspiration

Data mapping: in this activity by art educator Michele Guieu, students use a parallel circuit powered by a Chibi Chip to highlight points of interest, such as fault lines, on local maps



Circuit traces can be used as artistically expressive elements. Artist Jie Qi's sketchbooks combine written text with functional circuit traces to tell a visual story about her paper circuit explorations.

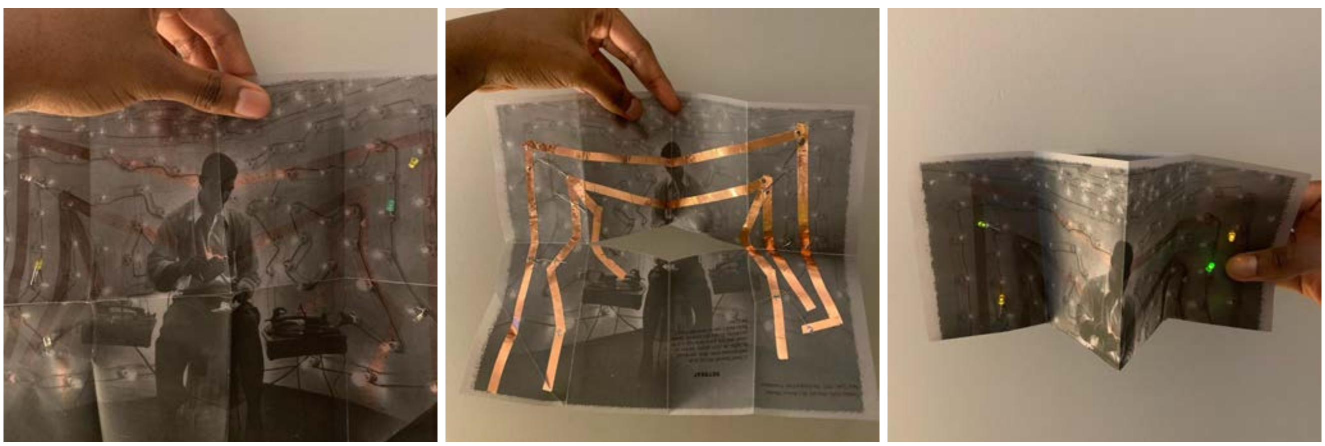
Featured Artist: Neta Bomani's Zines

Neta Bomani is "an abolitionist, learner and educator who is interested in parsing information and histories while making things by hand with human and non-human computers." Neta is currently an instructor in the Collaborative Arts Department at New York University and a co-organizer of the School for Poetic Computation (SFPC), an interdisciplinary and experimental school that explores the intersection of art, code, hardware, and critical theory.

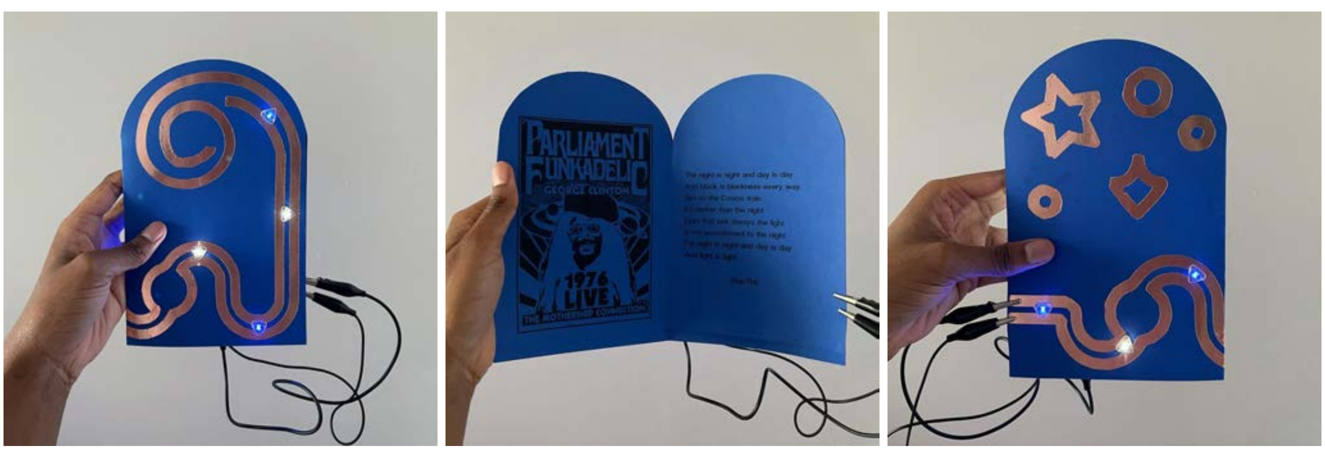
Website: netabomani.com **Twitter:** @netabomani **Instagram:** @mchapoarchive

100 Days of Zines

A zine (pronounced "zeen," from magazine) is an independently produced small-scale publication, often in the form of a small booklet. Zines feature heavily in Neta's work, such as "100 Days of Zines" where she posted a zine study every day for 100 consecutive days! Here are some inspiring studies from the series:

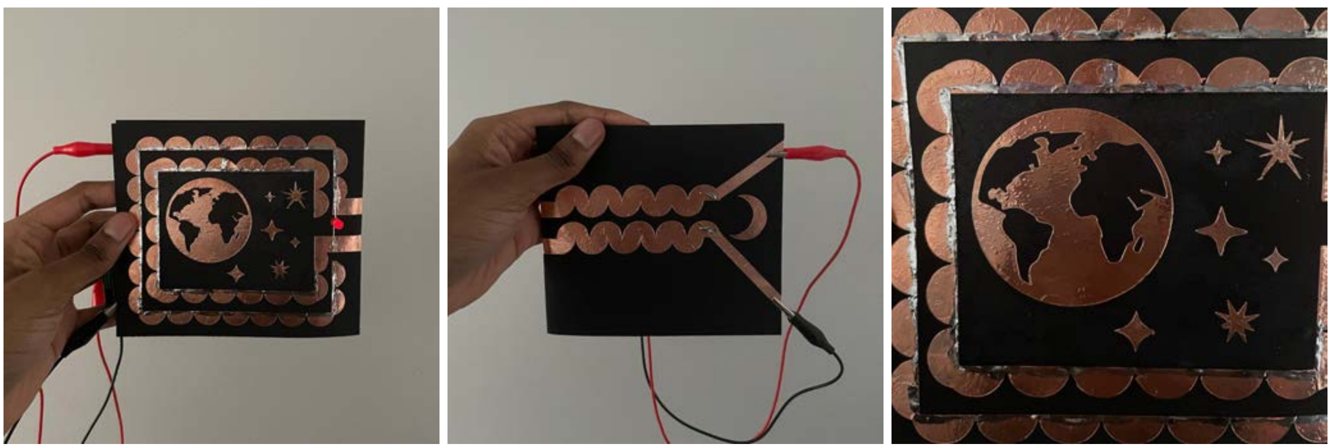


"008/100 This photograph by Gordon Parks [was] taken for Ralph Ellison's book the Invisible Man in 1952. The actor in the photograph is an invisible man who lives in a basement apartment in Harlem, New York. He's surrounded by a maze of lights connected to two record players that he's listening to while he eats ice cream and gin." - Neta Bomani



"089/100 a paper circuit zine on blue cardstock featuring Parliament Funkadelic's Mothership Connection, a quote from Sun Ra and abstract copper tape galaxy traces and leds powered by Chibitronics microcontroller." - Neta Bomani

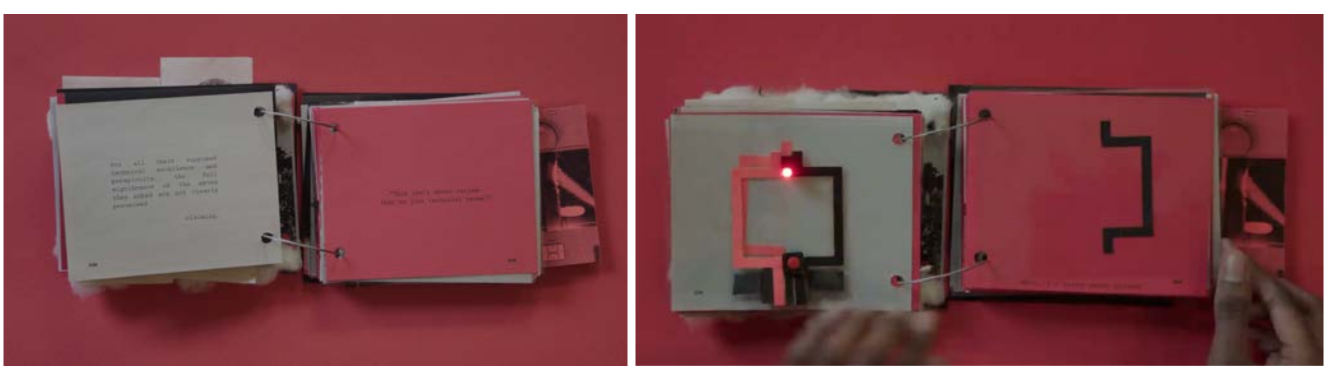
"091/100 a paper circuit zine on black and periwinkle blue cardstock depicting an image of an astronaut in space with blue, yellow and white leds in a 2d lightbox." - Neta Bomani



"098/100 a paper circuit zine on black cardstock featuring a copper tape and solder collage of the earth, abstract star shapes, and abstract circular traces that powers a red, blinking led with a chibitronics microcontroller." - Neta Bomani

Neta's Take: "Zines as Love Letters"

"Zines are a technology, or a tool for sharing information, building and maintaining networks for affinity, or larger socio political movements. Simply put, a zine is a handmade – or homemade – collection of paper or other physical or digital media compiled, bound, or intentionally linked together to create a publication. Often people put things they're interested in zines and make copies to share and distribute among an interested community of people engaged in a discourse, or following around the interest."



Dark Matter Objects: Technologies of Capture and Things That Can't Be Held by Neta Bomani

No Sleep No Breaks (NSNB) by Neta Bomani and Fum Fum Ko, featuring Te'aunna Moore (aka Blakchyl) and Darrion Borders (aka Chiclopz)

"We can feel the sort of affective quality of zines in their capacity to serve as resources for oppressed communities, communicate through prison walls, support a world of movements, from the Black freedom struggle to the Hawaiian sovereignty movement. They also build timeless networks and expand publishing capacities outside of mainstream channels and expand radical imaginations as well.

We might even consider zines as love letters to neighbors, friends, family and network computer devices, of whom in which we share a world." - from Neta's zine making workshop at Science Gallery Detroit

Bring Zines to Your Classroom

Clearly, zines are much more than little books! By their nature as unofficial, non-professional publications, zines are counter-cultural objects that break the rules and question existing power structures. They have historically provided socially marginalized groups and subcultures with opportunities to form community, express themselves, and share ideas and information. They are personal rather than mass-produced, often tactile rather than digital, made to be shared but not scaled, and can be created by anyone regardless of expertise.

Many libraries have public zine collections for browsing or special collections available for school visits. The Douglas College Library compiled an extensive directory of virtual zine collections. Ask students to explore, then choose examples that speak to them. Discuss for each zine: in what ways does it represent an act of resistance? What might students choose as their own act of resistance? Consider hosting a showcase to share student zines with the community and spark conversations about issues that students care about.

No Sleep No Breaks at the Austin Public Library, in the zine collection. Photo by Neta Bomani

Lesson 3: Begin With Blink

Two 45-minute lessons or one 90-minute lesson

Materials

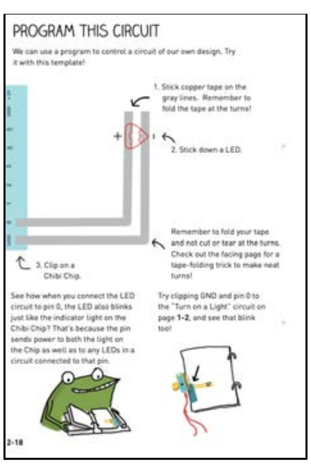
- ☐ 1 Circuit Sticker LED
- ☐ 9 inches conductive tape
- ☐ Chibi Chip, cable and programming device
- ☐ Blink Circuit template: Chibi Script: 2-12 to 2-14, MakeCode: 2-18 to 2-20

Resources

- **Lesson page numbers**: Chibi Script: 2-1 to 2-11, MakeCode: 2-1 to 2-17
- MakeCode Book Slides
- Programming Demo video
- Chapter 2 Walkthrough video

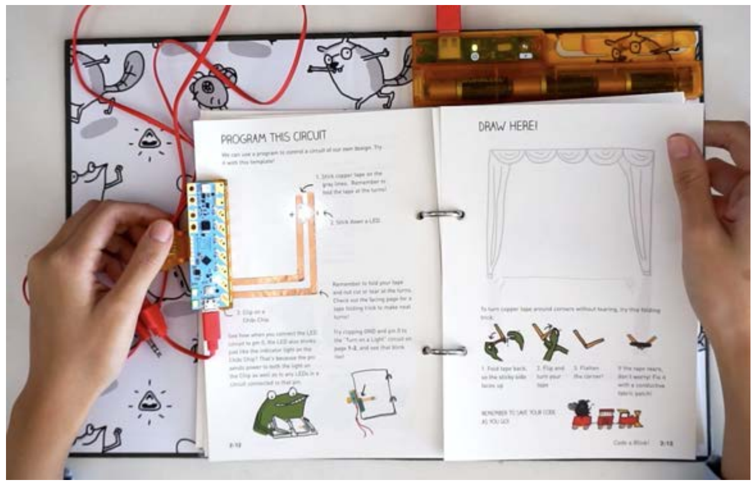
Inspiration

- Emergent Bilinguals by Ofelia García, Jo Anne Kleifgen, and Lorraine Falchi
- Program your Pages booklet by Nexmap



Lesson Overview

In this activity, students will learn how to program a blinking light with different patterns, and upload their code to the Chibi Chip.



Learning Objectives

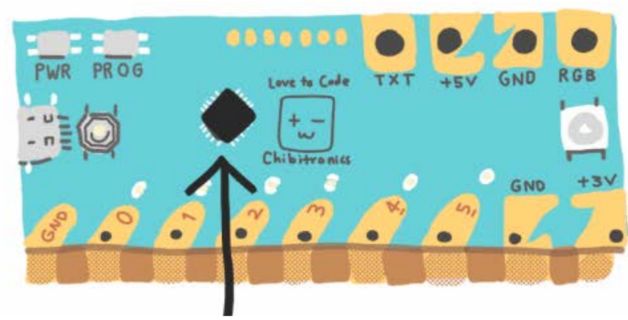
- Upload a program to the Chibi Chip
- Write a program that blinks an LED connected to the Chibi Chip with custom patterns
- Use the "on start" and "forever" structures to write code that runs once or runs repeatedly in a loop
- Express emotion and mood using light patterns

Vocabulary

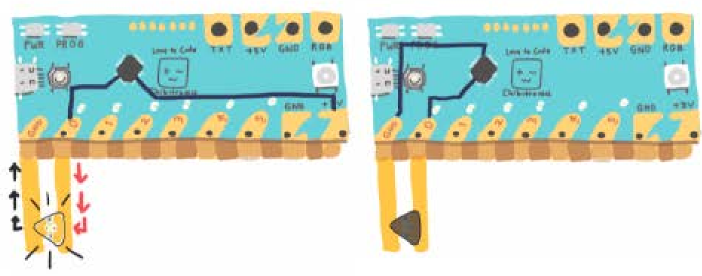
- **microcontroller**: a type of tiny computer used to control physical devices, everything from robots and coffee makers to electronic art pieces
- **program**: a sequence of instructions, or code, for a computer to follow
- **I/O pins**: connections on the Chibi Chip that can be switched from 0V (GND) to 3V, turning LEDs or other components on and off. I/O stands for input/output (more on inputs versus outputs in later lessons)
- **loop**: a code structure that runs the instructions within it repeatedly - either forever or until some condition is met

Background

How can we program the lights connected to our Chibi Chip? There is a little black diamond on the Chibi Chip called a **microcontroller** which can run instructions from a computer program. The microcontroller is connected to six pads on the Chibi Chip numbered 0 through 5. These numbered pins are called the **input/output (I/O) pins**.

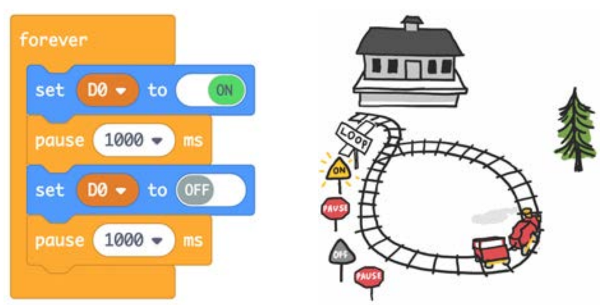


Unlike the +3V and GND pads, which are permanently wired, all the numbered pads can be switched between either +3V or GND by instructions in the **program**. There are tiny digital switches inside the microcontroller that can make and break these connections, enabling us to create cool blink patterns and many other dynamic or interactive effects.

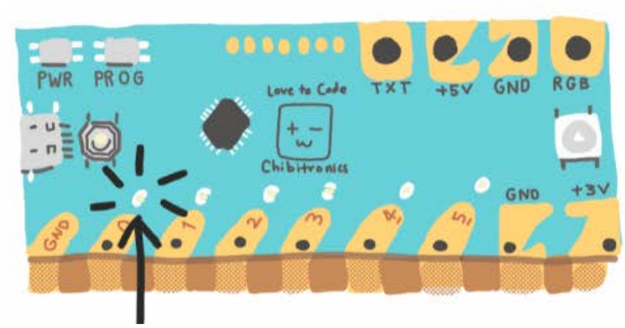


In the Microsoft MakeCode language, the code instructions to switch pads between +3V and GND are **set pin to ON** and **set pin to OFF**. When pin 0 is set to ON, it is connected internally to (+3V). When pin 0 is set to OFF, it is connected internally to (GND). This allows us to turn LEDs connected to the Chibi Chip on and off.

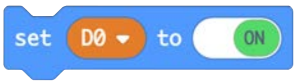
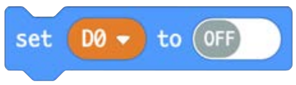
To write a program that creates a blinking pattern, two more blocks come in handy: **forever loop** and **pause**. The forever loop causes the code blocks inside to repeat indefinitely. The pause temporarily stops the program for the set amount, allowing us enough time to see the changes happen. Pause times are in milliseconds where 1 second = 1000 ms.



There is an indicator light built into the Chibi Chip for each numbered pin. These indicator lights let us know what a program is doing separately from the paper circuit the Chip is connected to. This is very handy for testing programs and debugging circuits!



Here is a summary of the new code "vocabulary" used in this activity

Microsoft MakeCode	Chibi Script	Arduino	What it does
	`on(pin)`	`digitalWrite(pin, HIGH)`	Turn LED on by connecting the I/O pin to +3V.
	`off(pin)`	`digitalWrite(pin, LOW)`	Turn LED off by connecting the I/O pin to GND.
	`pause(milliseconds)`	`delay(milliseconds)`	Do nothing for some number of milliseconds (there are 1000 milliseconds in 1 second). For example, leave a light on for a certain amount of time before turning it off.
n/a (happens automatically!)	`outputMode(pin)`	`pinMode(INPUT)`	set pin to be used as an input (eg. a switch or sensor)
	`void setup() { }`		The setup or "on start" function: everything in this block will run once at the start of the program, when the Chibi Chip is first powered on.
	`void loop() { }`		The loop function: everything in this block will run repeatedly after the setup / on start function finishes.

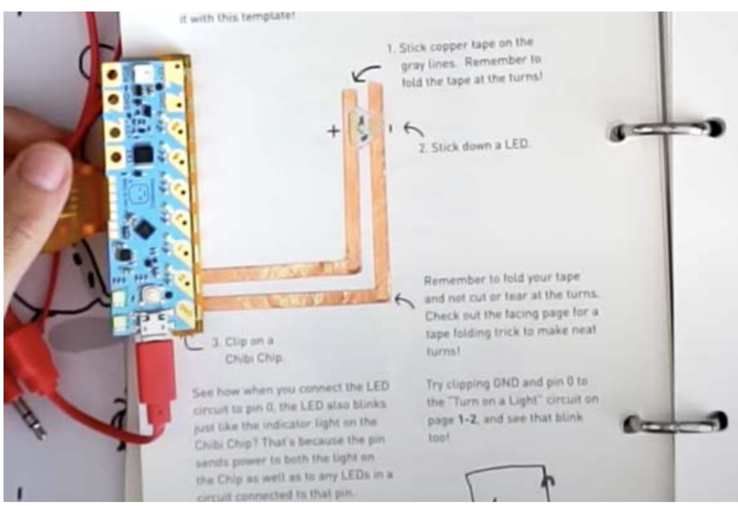
Teacher Preparation

1. For background, read lesson pages: Chibi Script: 2-1 to 2-11, MakeCode: 2-1 to 2-17
2. Build the LED circuit using the template as an example to show students
3. Test out a program upload on your own computer and if possible, on one of the computers that students will use. Troubleshoot any connection issues (see LTC Troubleshooting Guide)
   Try out the code exercises in this lesson
4. Print templates and prepare materials for students or teams

Lesson Sequence

1. Start with Art: Read the poem below with students (and optionally the original poem or a translation of your choice). Discuss: what words and phrases are used to describe the movement of light? What images or emotions do these evoke?

Under the trees light has dropped from the top of the sky, light like a green latticework of branches, shining on every leaf, drifting down like clean white sand. A cicada sends its sawing song high into the empty air. The world is a glass overflowing with water. "Ode to Enchanted Light" by Pablo Neruda, translated from Spanish by Ken Krabbenhoft	*La luz bajo los árboles, la luz del alto cielo. La luz verde enramada que fulgura en la hoja y cae como fresca arena blanca. Una cigarra eleva su son de aserradero sobre la transparencia. Es una copa llena de agua el mundo. "Oda a la luz encantada" de Pablo Neruda*

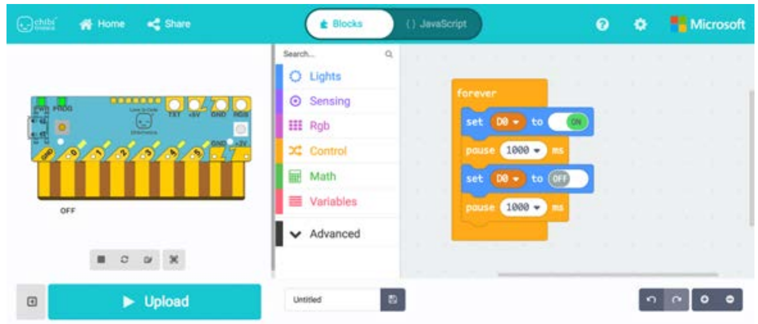


2. Demonstrate the blinking LED circuit. Tell students that they will be able to program their lights to blink and change in custom patterns of their own design.

Consider as a group: what are some different ways they can think of that their blinking light could tell a story, express an emotion or create a mood?

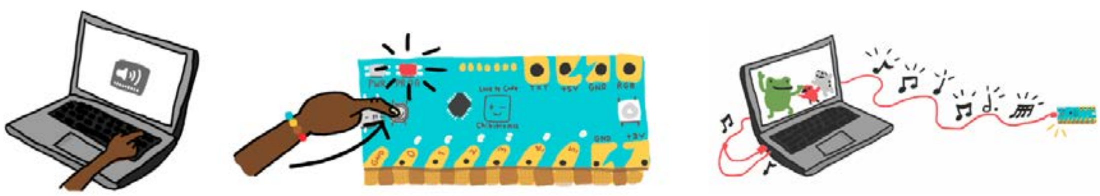
3. Build the circuit on the chapter 2 blink template. Remember to fold at the corners. Then clip on the Chibi Chip.

4. Visit **makecode.chibitronics.com** in a web browser, then load Love to Code -> Blinky from the home page. Notice the blinking light on pin 0 in the simulator. That's the code in action!



5. Follow the instructions at Uploading a Program to the Chibi Chip: first plug the cable into the Chip and then to a computer or other programming device. **Make sure the device audio is turned all the way up and is not muted.**

6. Press and hold the program button on the Chibi Chip for three seconds, then start the upload by clicking the **Upload** button in the Microsoft MakeCode interface.



7. Remix the code! Ask students to try:

1. Making the LED blink slower
2. Making the LED blink faster. What is the fastest it can go where the blink effect can still be seen?
3. Making the two pause times different from each other: what does the pattern look like when it stays on for a shorter time than it is off?
4. Creating a pattern that represents something in the real world, like a heartbeat or a flickering candle
5. Designing and programming their own custom blink pattern

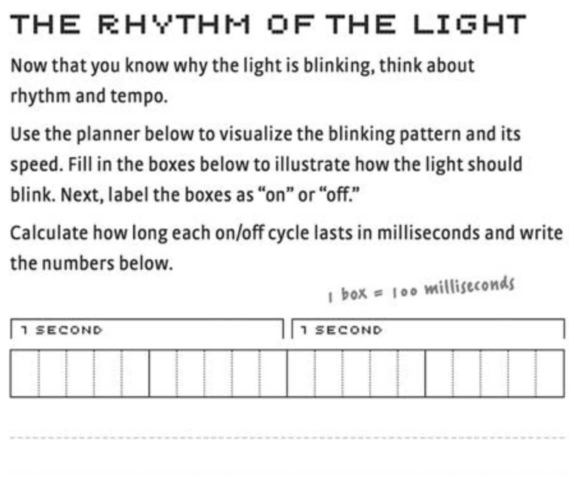
8. Illustrate the page so that their blinking LED tells a story. Some theme ideas:

a. Blink out a secret message (in morse code, binary, or something else they invent!)
b. Match the beat of a favorite song (see also Sketchbook Lesson 4: Blinking Slide Switch)
c. Create a scene from their neighborhood, or from a favorite book

Extensions and Adaptations

1. Use the prompt from the Illuminated Story activity with this one (a "mad libs" style prompt helping students come up with a story accompanied by light).
2. The **set level** block allows students to set light levels between ON and OFF to get different levels of brightness. It will be introduced in Lesson 8 along with other topics, but can be added as an optional extension to this lesson. See Illuminated Story activity for an example of introducing both **set ON/OFF** and **set level** in the same lesson.
3. Relating to the "start with art" poem: for students learning multiple languages (eg. emergent bilinguals or any student learning another language), discuss any differences they notice in the translation, drawing on multiple languages to reflect on the piece. Optionally, substitute a translation in any relevant language.

Inspiration


THE RHYTHM OF THE LIGHT

Now that you know why the light is blinking, think about rhythm and tempo.

Use the planner below to visualize the blinking pattern and its speed. Fill in the boxes below to illustrate how the light should blink. Next, label the boxes as "on" or "off."

Calculate how long each on/off cycle lasts in milliseconds and write the numbers below.

Jennifer Dick of NEXMAP created a sketch in her notebook that blinks the morse code for SOS using a microcontroller and LED. To plan out the blink timing and figure out the pause times to add to her program, she created this visual tool (pg. 11, *Hack Your Notebook, Program Your Pages, working with microcontrollers*) and shaded in the on/off pulses.

Lesson 4: Programming Multiple Pins

One 45-minute lesson

Materials

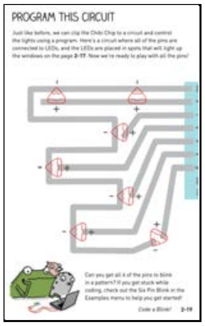
- [ ] 7 Circuit Sticker LEDs
- [ ] ~42 inches conductive tape
- [ ] Chibi Chip, cable, and programming device
- [ ] Multi-LED template:
  Chibi Script pg. 2-17 to 2-19
  MakeCode pg. 2-23 to 2-25

Resources

- **Lesson page numbers**:
  Chibi Script pg. 2-15 to 2-16, 2-20 to 2-21
  MakeCode pg. 2-21 to 2-22, 2-26 to 2-27
- MakeCode Book Slides
- Bring Light to Life Video

Inspiration

- Hells and Heavens by Beatrice Coron & interview
- Neighborhood & Community through Mythology
- Silhouette art by Kara Walker & interview
- TickyTown by KFai Steele
- Erin Riley's Blackout Poetry



Lesson Overview

In this lesson, students will learn to control multiple LEDs using the 6 input/output (I/O) pins on the Chibi Chip, and use this to create animated narratives by lighting up different images in sequence.

Learning Objectives

- Construct a circuit with multiple LEDs connected to different microcontroller pins
- Make different LEDs in the circuit turn on and off in custom patterns by programming multiple microcontroller pins
- Use animation sequences and silhouette "reveals" to narrate a story in time and space

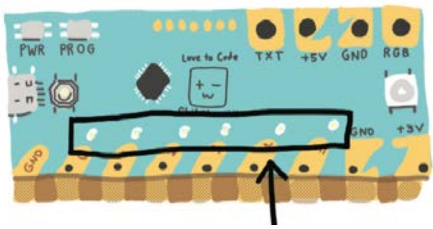
Vocabulary

- **narrative:** the representation in art of a connected sequence of events or experiences

Background

The Chibi Chip has 6 I/O pins numbered 0 through 5. Each can be controlled separately through code. To control a specific pin, choose its number from the orange dropdown menu in the block. The example on the right shows what this looks like for the "turn _ on/off" block.

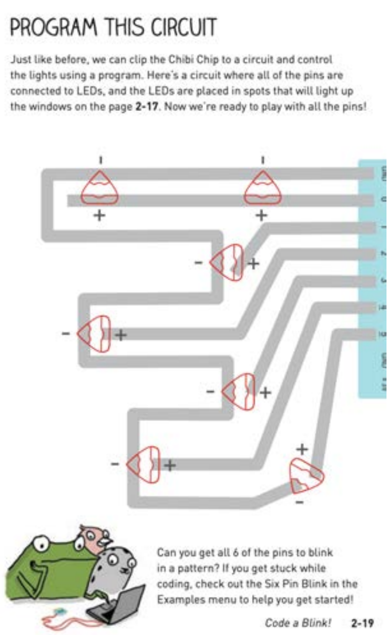
In this activity, students will practice writing code to turn on and off lights that are connected to different pins. They will learn to code for lights to change simultaneously as well as in sequence one after the other.



Troubleshooting tip: there is an indicator light built into the Chibi Chip above each numbered pin. These lights show which pins are on or off according to the code, even when the Chip is not yet connected to a paper circuit. This helps us troubleshoot code issues separately from circuit connection issues.

Teacher Preparation

1. Create a class demo: Build the multi-LED circuit and then add your own drawings or silhouettes to the back of the building illustration template.
2. Upload code to the demo. Use Love to Code -> Six Pin Blink for an example that lights all the LEDs one after the other. Try the student exercises in the lesson to practice blinking pins at the same time and one after the other. Make it your own!

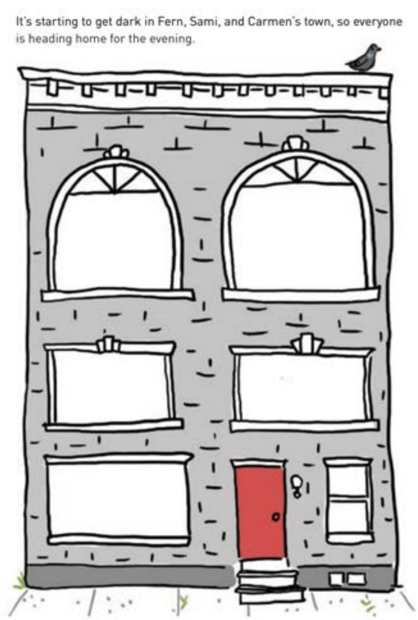


PROGRAM THIS CIRCUIT

Just like before, we can clip the Chibi Chip to a circuit and control the lights using a program. Here's a circuit where all of the pins are connected to LEDs, and the LEDs are placed in spots that will light up the windows on the page **2-17**. Now we're ready to play with all the pins!

Can you get all 6 of the pins to blink in a pattern? If you get stuck while coding, check out the Six Pin Blink in the Examples menu to help you get started!

Code a Blink! **2-19**



It's starting to get dark in Fern, Sami, and Carmen's town, so everyone is heading home for the evening.

Lesson Sequence

1. Start with Art: Share images from Hells and Heavens by Beatrice Coron (make sure to scroll through the image on the left side of the page!) and watch the artist explain her work. What scenes and characters do students notice? How does the artist tell her stories? Coron plays with light and shadow in her work but instead of paper circuits, she uses light shining through holes in the paper cuttings. How might the artist's techniques combine with paper circuitry to tell stories in new ways?

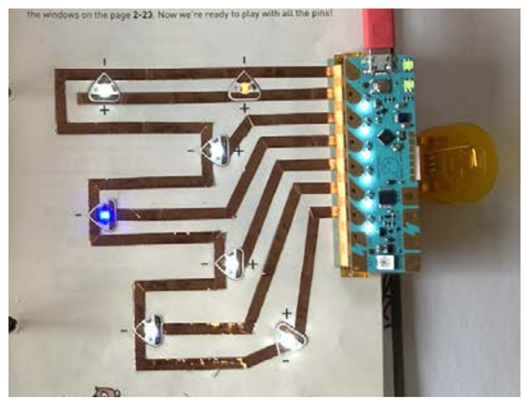
2. Demo the multi-LED circuit. Then Introduce the project theme, such as:

    a. Tell a story from history or from fiction. Students draw a person or scene in each window, then write code to animate each in sequence, showing a connected sequence of events (causation) or what different figures were doing at that moment in history (different perspectives).

    b. Create a visual autobiographical story. Each window shows the student doing an activity that is important to them, or that represents a window into their daily life.

    c. Tell the story of a community or neighborhood. Each window shows someone in the student's community (empathy / perspective taking). Suggested resource: Exploring Neighborhood and Community through Mythology

3. Put students in project groups (2-3 students) and give them time to brainstorm and sketch what they will create based on the project theme.



4. Using the conductive tape and LEDs, students build the multi-LED circuit on the template.

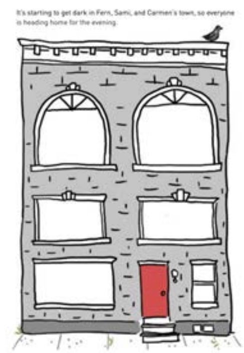
5. Ask students to label each LED with the pin number it is connected to. For example, the bottom right LED is connected to pin 5 on the Chibi Chip. This step builds understanding about the I/O connections from the microcontroller, and will also help students keep track of which LEDs they are programming.

6. Upload the code sequence on the right (pg. 2-21). This code blinks back and forth between pin 0 and pin 3. Ask students to add more pins to this sequence. Can they turn pins 0 through 5 on, one after the other? Remind them to save a copy of their code.

7. Now try the code at the top of pg. 2-22. This code blinks 0 and pin 3 together. Ask students to add more pins: can they make pins 0 and 5 blink at the same time?

8. Ask students to share their solutions to Step 6 and Step 7 with the group. There are multiple ways this code can be written! Some interesting differences to look for: turning LEDs on in a different order, pausing after turning an LED off vs. immediately turning the next LED on.

9. **Checking for understanding** Ask students: why do the 2 LEDs in the top row on the template always turn on and off at the same time, no matter what the code says? (Answer: the 2 LEDs in the top row are both physically connected to pin 0, so any code that controls pin 0 will activate both LEDs).



10. Students can now use their LED sequences to illuminate the building template. Ask students to draw or collage shapes on the back of the template that will only be revealed as the lights turn on.

11. Once they have created their illustrations, students code their light sequences to reveal the drawings behind each window. Encourage them to think creatively about the order and timing of the "reveals" of each window in order to tell a compelling story.

12. Students record a video narrating their sequence, or present it live to the group.

Extensions and Adaptations:

1. For an extra code challenge: experiment with multithreading (covered in Lesson 9) by using multiple forever loops to make light effects on different pins happen at the same time.

2. Experiment with how the same code and circuit can tell multiple stories by adding different illustrated overlays! For example, have students trade illustrations to see what new stories emerge or draw entirely new illustrations based on existing light patterns.

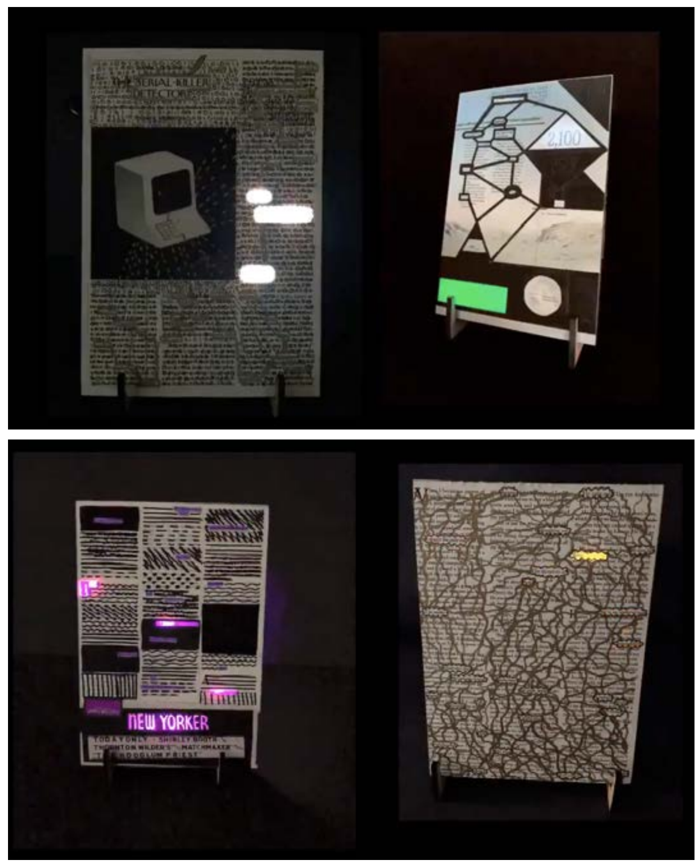
3. For more mature students (content warning: artworks include graphic violent and sexual imagery that may not be appropriate for younger students): Explore Kara Walker's work with silhouettes and watch this video of the artist describing the cut silhouette as a medium to speak about painful topics like racism, slavery and injustice. How does the artist use presence and absence, light and dark, to make her points? Compare and contrast Kara Walker's approach to Beatrice Coron's approach from the *Start with Art* at the beginning of this lesson. Notice the styles, themes, imagery and emotions portrayed in their works.

Inspiration

Art: K-Fai Steele; Photo: Asli Demir

The template in this activity was inspired by an artwork TickyTown by KFai Steele. This piece uses the "reveal" technique in a playful way to tell the story of a community of ticks living on a furry dog's back!

"Code in the Clouds," constructed for the Albuquerque Explora Museum by the Chibitronics team, uses the different pins on the Chibi Chip to light up hot air balloons in a cardboard sky.



Educator Erin Riley's students used paper circuits and multiple pins on the Chibi Chip to create beautiful blackout poetry pieces illuminating different words and elements in sequence.

Lesson 5: Design and Program a Circuit

Two 45-minute lessons or one 90-minute lesson

Materials

- ☐ 3 to 6 Circuit Sticker LEDs
- ☐ ~60 inches conductive tape
- ☐ If using copper tape, 4-5 fabric tape patches
- ☐ String, measuring tape, and/or rulers
- ☐ (optional) LTC stencil
- ☐ Bill of materials worksheet
- ☐ Circuit template:
  Chibi Script: 2-22 to 2-24
  MakeCode: 2-28 to 2-30

Resources

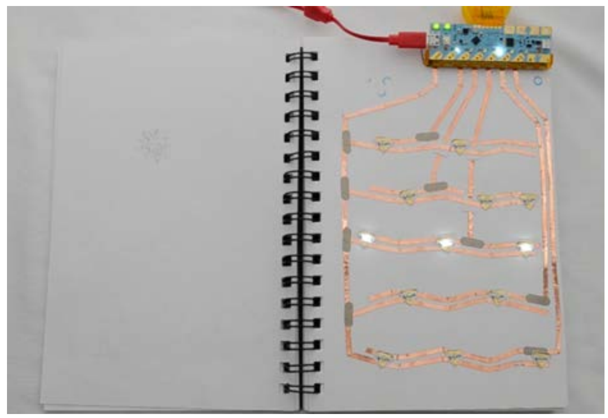
- **Lesson page numbers**:
  Chibi Script: 2-23
  MakeCode: 2-29
- MakeCode Book Slides
- Crosses and Ts with Copper Tape

Inspiration

- Quiet Invitation by Mary Uthuppuru and blog documenting process
- One Code, Many Projects

Lesson Overview

In this lesson, students will imagine and sketch a circuit layout of their own design, then build and troubleshoot their circuit. This lesson can be combined with one of the Featured Projects, so that students are working towards a project goal.



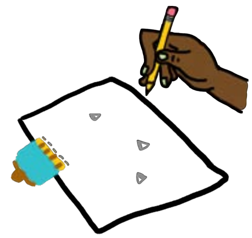
Learning Objectives

- Sketch, built, and troubleshoot a circuit of the student's own design
- Write a *bill of materials*, a list of the materials needed to build a particular circuit
- Measure and estimate the length of conductive tape needed in a circuit
- Optimize a design for artistic and technical goals

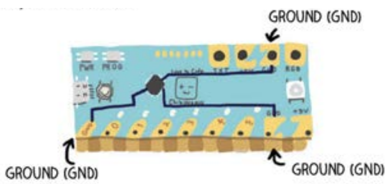
Vocabulary

- **circuit layout:** the design or plan for a circuit, usually a 2 dimensional "map" of components and connections between them
- **placement:** deciding where to place components on a circuit layout
- **routing:** deciding where to place circuit connections (such as wires or conductive tape) in order to electrically connect all components in the circuit
- **bill of materials (BOM)**: the list of materials needed to build a circuit. For a paper circuit, this includes the components (LEDs and Chibi Chip) and the total length of conductive tape needed

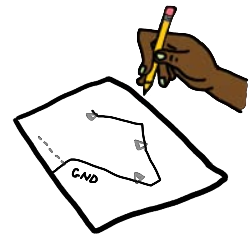
Background



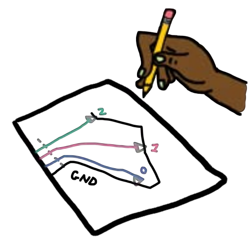
The multi-LED circuit in the previous lesson showed an example of how to connect LEDs to different I/O pins so that the LEDs can be programmed to light up separately or together. In this activity, students will apply this idea to a **circuit layout** of their own design. They will begin with component **placement**, deciding where they would like to place their LEDs on the page to light up different areas in their design. Next, they will work on **routing**, or figuring out how to connect the components to each other with conductive tape.



Each LED needs a GND connection connected to its pointed negative (-) side. Any of the GND pins on the Chibi Chip can be used interchangeably, and the same GND can be shared between all the LEDs in the circuit.

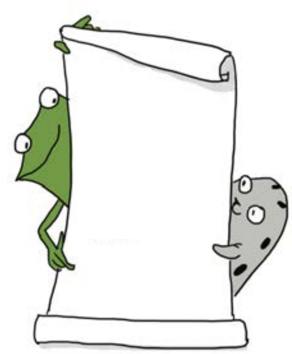


The positive (+) side of each LED also needs to be connected to any of the numbered I/O pins on the Chibi Chip. As a reminder from the previous lesson: LEDs that are connected to the same pin will always come on at the same time. Since the Chibi Chip has 6 programmable I/O pins, up to 6 separate groups of lights can be controlled with one Chibi Chip.



Once students have a first draft of their **circuit layout**, have students present their design to other students and receive feedback. This process is an opportunity to a) practice "science talk" in presenting their work, b) become learning resources for each other and practice constructive critique, and c) gain appreciation for different approaches and solutions (these circuits can be built in many different ways!)

Students will then create a **bill of materials** (or **BOM**) to request materials for their circuit, and engage in creative problem-solving around how to measure the length of conductive tape needed. This process is an opportunity to consider the use of materials in their circuit, and to practice planning ahead when creating a design or engineering project.



Students will see how their design choices impact use of material - for example, how different routing options for the same component placement can use different amounts of conductive tape. Using conductive tape as a decorative as well as functional element is a valid design goal for many circuits, so minimizing material use is not the emphasis. Instead, the goal is for students to build awareness of the many choices available in the design process and how these choices affect the fabrication process and outcome of their project. They can choose to optimize for different goals!

Teacher Preparation

Follow the lesson steps to sketch and build your own example circuit! To anticipate questions students might run into, make sure to include some T junctions and cross-overs in your design.

Lesson Sequence

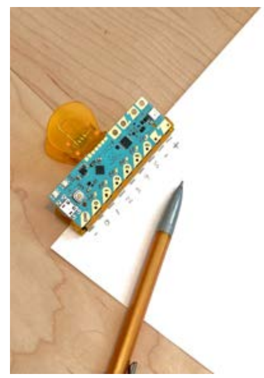
1. Start with Art: Watch the video of [Quiet Invitation](#) by Mary Uthuppuru, a paper circuit diorama that explores bioluminescence in the forest. Ask students to think about the artist's process: what do you think was her first step in making this project? What happened next? How would they (students) plan out a project like this? Then, share the artist's [own documentation](#) of this project from ideation to building out the finished piece.

2. Create project groups (2-3 students) and Introduce the project theme, such as an [accordion book](#) or scene from a [paper city](#). Ask students to write down: what will each LED in their circuit do?

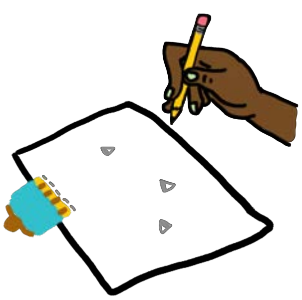
3. Students first decide on component placement, drawing where they will put their Chibi Chip and LEDs. They can use the stencil to mark the Chibi Chip connections, draw them from the Chip directly, or work from a printed template.

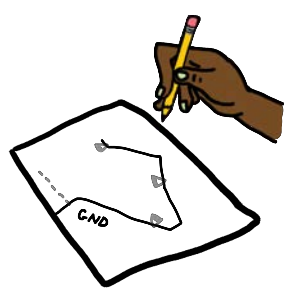
Printed template


Using the Chibi Chip stencil

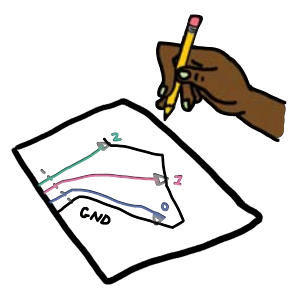

Using the Chibi Chip as a guide

4. Next, students will route the connections. One method is to begin by drawing a shared GND trace to each of the LEDs, then individual traces from the I/O pins to the LEDs. Make sure to label the LEDs with the pin number they are connected to!


1. Mark where the LEDs and Chibi Chip will be placed



2. Draw a connection from GND to the - side of each of the LEDs



3. Draw connections from the I/O pins to each of the LEDs

Tip: Color-coding connections makes circuits much easier to follow. We recommend black lines for GND and colors for each of the pins. Erasable colored pens are very helpful!

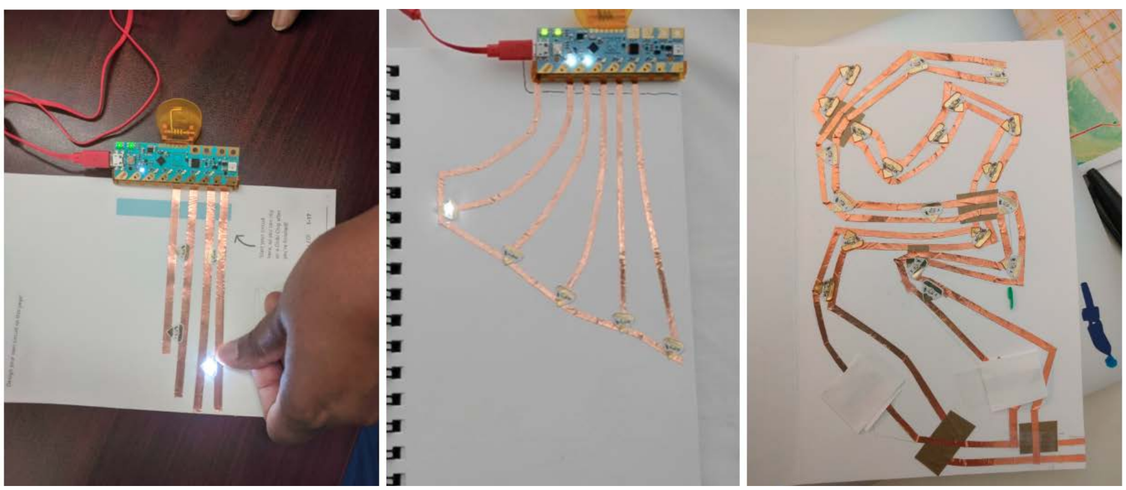
5. **Peer feedback**: in groups, students take turns explaining their circuits and giving each other feedback. Questions to consider:
    a. Does it look like this circuit will work the way the designer intended? If not, what changes would you suggest?
    b. How did the designer choose to lay out their circuit connections? What do you like about it? Is there anything you would do differently, and if so, why?

6. Circuit edits: students revise their circuits based on peer feedback.

7. Bill of materials: students write out their bill of materials, listing what they need for their circuit. Class brainstorm: how might they measure the length of conductive tape needed, given the measuring materials available? (could include string, flexible or rigid measuring tapes, rulers). How can they check if their measurement will definitely give them enough conductive tape to finish their circuit?

8. Students give their bill of materials to the teacher for approval. Teacher hands out materials to each student or team.

9. Students can now build and program their circuits. Make sure to include time for troubleshooting!

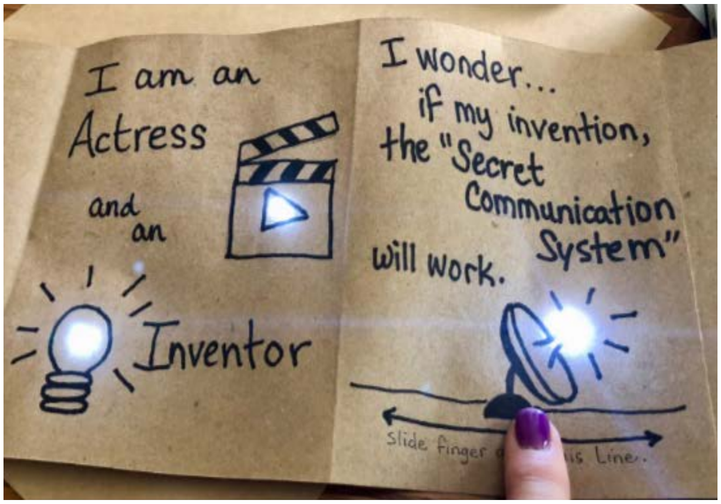


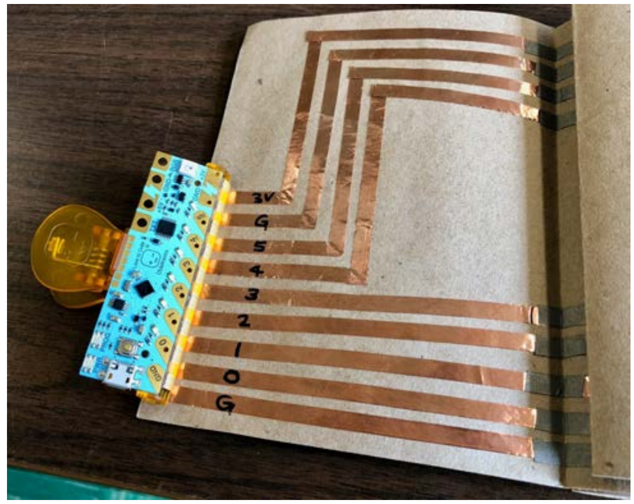
Example Chibi Chip Circuits

Extensions and Adaptations

1. Adjust the project complexity by choosing a maximum number of LEDs students can use. For example a project with 3 LEDs will be simpler to design and program than a project with 6 LEDs. If students want more LEDs for their design, ask them to show you that they can complete the simpler version before adding more, building up to a more complex circuit.
2. Mix up the code: just like students can place different illustrations over the same circuit to tell new stories (see Extensions and Adaptations from LTC Lesson 4: Programming Multiple Pins), students can also use different code with the same paper circuit to achieve new and surprising effects. Invite students to trade Chibi Chips and see how code from one project runs on a different project!

Inspiration





Accordion Book made by Barbara Liedahl. See the Accordion Book Featured Project to learn more!

Programmed paper cities by students and teachers. See the Paper City Featured Project for more guidance!

Lesson 6: Programming with a Switch

One 45-minute lesson

Materials

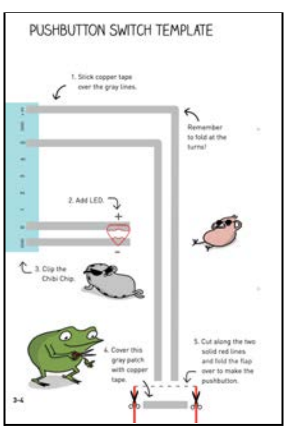
- [ ] 1 Circuit Sticker LED
- [ ] 21 inches conductive tape
- [ ] Chibi Chip, cable, and programming device
- [ ] Switch template:
  Chibi Script: 3-4 to 3-6,
  MakeCode: 3-4 to 3-6
- [ ] Scissors to cut switch flap

Resources

- Lesson page numbers:
  Chibi Script: 3-1 to 3-14, 3-36 to 3-38
  MakeCode: 3-1 to 3-15, 3-36 to 3-38
- MakeCode Book Slides
- Chapter 3 Walkthrough (part 1)

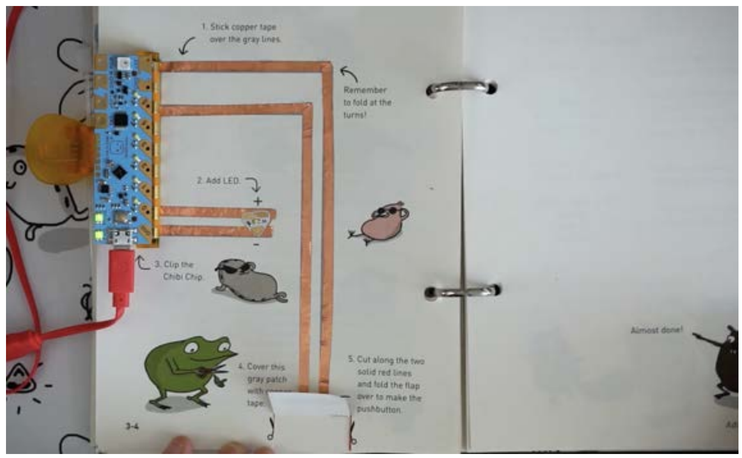
Inspiration

- Housefly by Arthur Ganson
- Garden Map by Nicole Catrett



Lesson Overview

In this lesson, students will learn about switches and build a circuit that responds when a paper switch is pressed or released. They will use code to create multiple switch behavior options for the same circuit, including a reversed switch (off when pressed), a trigger for a light sequence, and a toggle switch.



Learning Objectives

- Build and program a switch to control lights
- Use event-driven logic to trigger a light sequence when a switch is pressed
- Use a variable and conditional logic to program a switch that toggles lights on and off
- Create art that responds to audience interaction

Vocabulary

- **switch:** a mechanism that can close and open a connection in a circuit
- **event-driven**: code that runs in response to an event, such as a change in the state of a switch
- **variable**: a code construct that allows the program to keep track of and update a value over time
- **conditional**: a code construct that allows branching between multiple possible actions based on the answer to a question or comparison

Background

A **switch** is a gap in a circuit that can be connected and disconnected, turning parts of the circuit on or off. Stick conductive tape to a paper flap over a gap in the circuit to make a simple switch. When the flap is pressed, the circuit connects. The springiness of the paper flap keeps the switch open unless it is pressed.

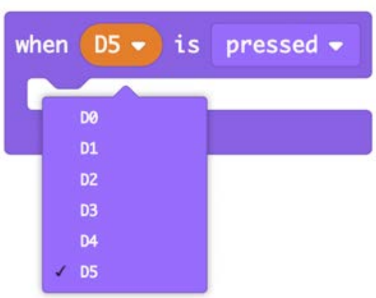
Without the Chibi Chip, a switch directly connects and disconnects power to a circuit, turning it on and off. When you add a Chibi Chip, you connect the switch to one of the I/O pins so that the Chip can sense whether it is pressed or not by measuring the voltage level. Beyond simply turning on and off a light with the switch, code allows you to trigger more complex actions when the switch is pressed.

How does this work? The input/output pins! When in input mode, each I/O pin can sense whether or not it is connected to +3V. When connected (the switch is pressed), certain parts of the code run, such as the blocks inside the special **event-driven** blocks in the table below.

In this Lesson students will learn multiple ways for their code to react to the press of a switch: a simple on/off, a reversed on/off, a trigger which runs a blink sequence, and a toggle which stays on or off each time the switch is pressed.

Here is a summary of the new code "vocabulary" used in this activity:

Microsoft MakeCode	Chibi Script	Arduino	What it does

	(similar but not equivalent)
	`void loop() {`
	`if(readLevel(5) == HIGH) {`
	`}`
	`pause(100);`
	`}`
		(similar but not equivalent)
		`void loop() {`
		`if(digitalRead(5) == LOW) {`
		`}`
		`delay(100);`
		`}`
			Respond when a pin is high or low, eg. with the press of a switch.
			
			The Microsoft MakeCode version here is **event-driven** and responds when the pin is changed from high to low or low to high. The Chibi Script and Arduino versions here are "**polling**" based, and continually check the state of the pin.
			
			For event-driven code on the Arduino, see: interrupts.

	(similar but not equivalent)
	`void loop() {`
	`if(readLevel(5) == LOW) {`
	`}`
	`pause(100);`
	`}`
		(similar but not equivalent)
		`void loop() {`
		`if(digitalRead(5) == LOW) {`
		`}`
		`delay(100);`
		`}`	

Teacher Preparation

1. Build the switch circuit using the pushbutton switch template. What turns on when the switch is activated? Make a creative demo
2. Try the code activities and challenges

Lesson Sequence

1. Start with Art: Watch the video Housefly by Arthur Ganson. What role does cause and effect play in this sculpture? How about rhythm and randomness? This artist combines engineering with whimsy in this mechanical sculpture to create a surprising and humorous effect. How might we create surprising and humorous interactions with paper circuitry?

2. Students build the pushbutton switch template circuit and connect a Chibi Chip

3. Use the explanations in the LTC book to introduce each code example, then try the code challenges below:

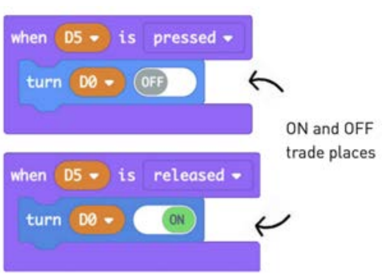
The code: | **Challenges to try:**

On/off

1. Turn a different LED (not pin 0) on or off when the switch is pressed
2. Turn two or more LEDs on when the switch is pressed and off when the switch is released. As students practice with the code, use the indicator LEDs on the Chibi Chip, rather than extending the paper circuit to save time and materials

---

Reversed on/off



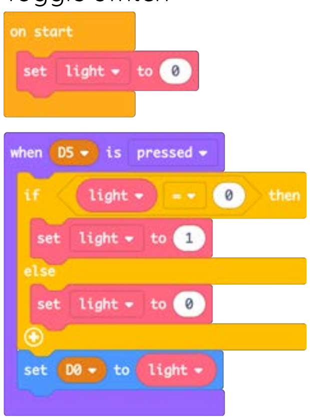
1. Add to the code so that it turns **on** pin 1 when pin 0 is **off**, and turns **off** pin 1 when pin 0 is **on**
2. What can you do with a circuit that turns off when pressed? Brainstorm as many ideas as you can!

The code: | **Challenges to try:**

Trigger switch

1. Create your own light sequence that is triggered by the switch
2. Trigger an entirely different light sequence when the switch is released
3. Consider: does the light sequence stop running immediately when the switch is released, or does it play to the end? Why does this happen?
4. Going further: trigger a sequence involving multiple pins, as in LTC lessons 4 and 5.

Toggle switch



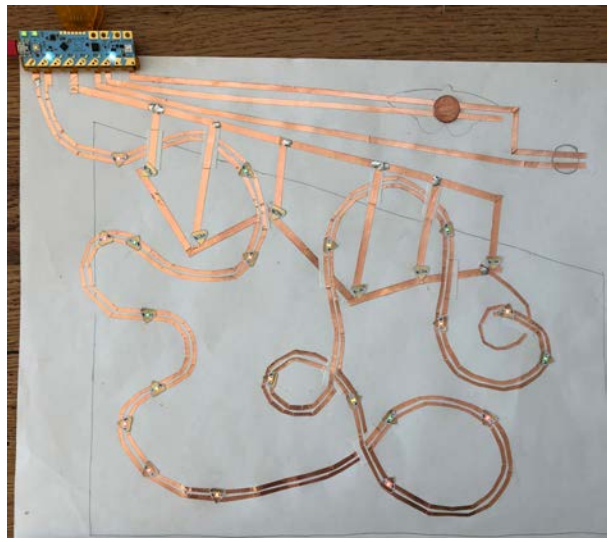
1. Toggle between multiple light "settings," where one press turns on several lights, and another press turns different lights on, or turns all the lights off. There are multiple ways to do this in code, so don't be afraid to experiment!
2. Turn different lights on one by one in sequence every time the switch is pressed? The first time the switch is pressed, pin 0 turns on. The next time, pin 1 turns on, and so on.

4. Apply these skills to a mini-project! Theme ideas:
   - Create traffic signals that respond to small vehicles running over a switch placed in the road, or other events in a [paper city](#)
   - Create a mini museum exhibit that activates when a button is pressed. The exhibit could show a demonstration (a scene in history, a science phenomenon) or a piece of interactive LED art
   - Create a paper model of something in the real world that is activated by a switch
   - See [Featured Projects](#): Paper City, Data Art, and Binary Counter for more switch project ideas

Extensions and Adaptations

- The LTC switch template pairs well with the art activity from Part 1 Lesson 2: Switches, Silhouettes, and Shadows
- For students with some prior programming experience, here are some additional switch coding challenges:
    - Trigger an action only if the switch has been held down for a certain amount of time (eg. a 3 second press activates a specific action)
    - Count the number of presses and use the count to change the output of the program (eg. blink lights faster or a different number of times)

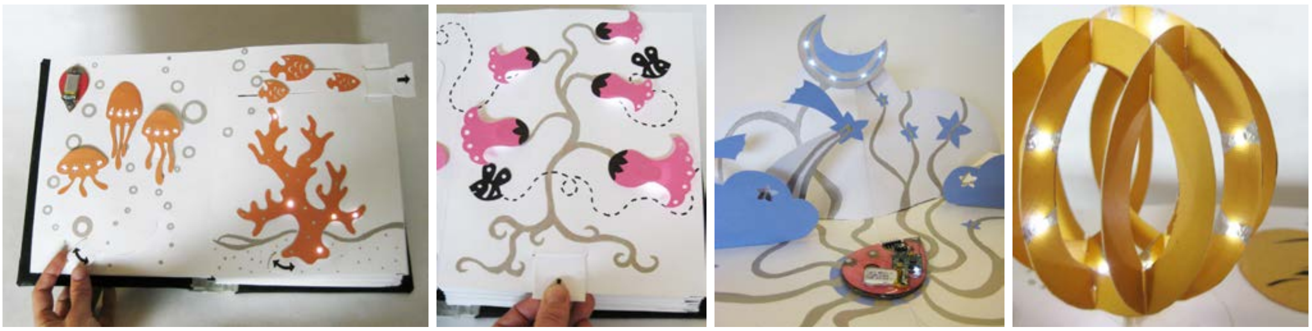
Inspiration



In this lovely map by Nicole Catrett of Wonderful Idea Co, one switch activates the path that butterflies take through a garden, and another switch reveals the path that humans take. Nicole says:

> *"To control the different circuits, I made two simple paper circuit switches. When you press one, a bit of copper tape bridges between +3V and one of the pins on the Chibi Clip. I've made paper circuits with switches before, but the really exciting bit here is after you make your circuit, you can change its behavior by programming it...*
>
> *...I decided to create a program that would make the butterfly circuit fade in and out like a butterfly fluttering around. When you connect the switch that controls the butterfly circuit, colored lights flash and fade like butterfly wings.*
>
> *There are so many opportunities to be expressive and creative with these paper circuit maps! There is the information you are mapping, the way that you illustrate it, the way you program it, how people interact with it . . . it really deepens the experience of creating a paper circuit, and provides lots of paths for exploration, depending on which bits you find interesting."*

Featured Art Technique: Paper Engineering



Electronic Popables by Jie Qi, Images by Leach Buechley

Paper engineering is the art of turning flat pieces of paper into shapes and structures that move and pop into three dimensions, like in interactive cards or pop-up books. Techniques range from simple lift-the flap interactions that reveal information underneath, to pull-tabs that slide shapes across the page, to complex 3D sculptures that magically pop-up and then fold flat when you turn the page.

Paper engineering mechanisms also turn out to be perfect for creating paper circuit switches and sensors! Below are artworks that blend traditional print, bookbinding and paper engineering techniques with paper circuits. How do the artists play with light in their pop-ups?

Pop-up Heart card by Colette Fu (left), Last Gods' Retreat artist book by Susan Lowdermilk (center and right)

To create your own pop-up paper circuits, like the card on the right, check out our tutorials on the [Chibitronics craft blog](#). These tutorials cover everything from basic "press here" paper circuits to pull-tabs, pop-ups and bookbinding structures. For more paper engineering mechanisms, explore [cutandfoldtemplates.com](#), a collection of templates created by Kelli Anderson. These make great resources for inspiration as you experiment with designing your own switches!

Pop-up card and paper circuit by Wei Wei Wang

Lesson 7: Design a Switch

Two 45 minute lessons or one 90-minute lesson

Materials

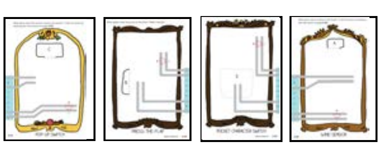
- ☐ 1 Circuit Sticker LED
- ☐ ~20 inches conductive tape for each switch
- ☐ Chibi Chip, cable, and programming device
- ☐ Drawing tools and paper
- ☐ Scissors
- ☐ Clear tape and glue stick
- ☐ Printed switch templates: Chibi Script: 3-22 to 3-34, MakeCode: 3-22 to 3-34
- ☐ Switch design worksheet

Resources

- Slide Deck
- Lesson page numbers: Chibi Script: 3-18 to 3-21, MakeCode: 3-18 to 3-21
- MakeCode Book Slides
- Chapter 3 Walkthrough

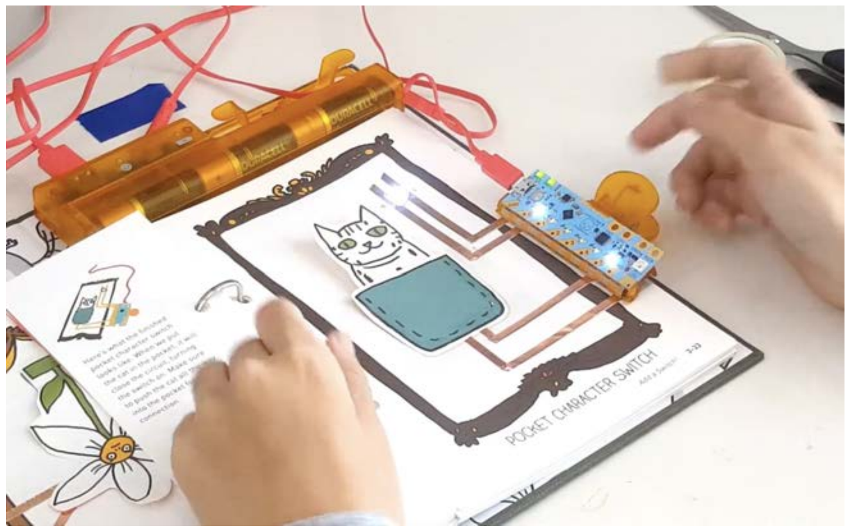
Inspiration

- Junkmail Collages by Aurora Robson & interview
- Caine's Arcade
- Reed Switches for magnetic switches
- Chia-Chi Wang's class
- Origami Switches by Michael Shannon
- Pop-up Book by Jie Qi
- Makey Makey Tutorials



Lesson Overview

IIn this lesson, students will create different types of paper switches, then learn to design their own.



Learning Objectives

- Build and personalize a variety of paper switches
- Brainstorm and prototype a switch of their own design
- Use interaction to model an idea

Vocabulary

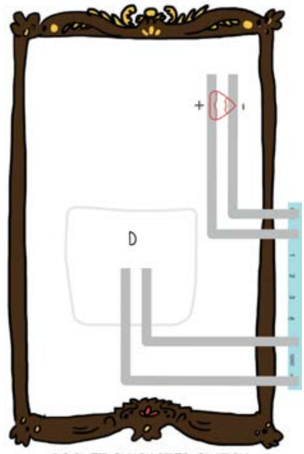
- **sense**: to detect or perceive something in the physical world
- **input**: information that enters a computer, such as a voltage level detected by the Chibi Chip
- **switch contact**: conductive parts in a circuit used to make contact when closing a switch
- **switch gap**: a break in a circuit path that can be closed by a switch
- **mechanism**: a system of parts that work together to do something (*switch mechanism*)

Background

As we saw in the previous lesson, a **switch** is a gap in a circuit that can be connected and disconnected, turning parts of the circuit on or off. The I/O pins on the Chibi Chip can read whether a switch is open or closed and trigger different actions every time the switch is pressed or released.

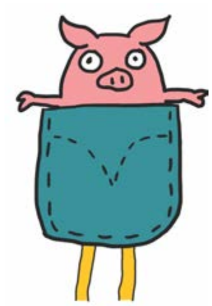
The previous lesson showed one way to make a paper switch, but we can get creative and make many variations using the same concept. Any paper **mechanism** that allows us to move a piece of conductive tape to open and close a circuit can act as a switch.

Each of the switch circuits in this lesson has an LED connected to GND and pin 0 and a switch, consisting of a conductive tape connection to +3V and one to pin 5. Each of the different types of switches works by connecting +3V to pin 5, as in the pocket character switch example shown on the right.



POCKET CHARACTER SWITCH

Press-the-Flap Switch
Use a simple flap of paper with conductive tape and a paper spacer to close a circuit anywhere.



Pocket Switch
A conductive piece on the back of a character closes a switch gap inside a paper pocket.

Wind-Sensing Switch
Make a flap with a thin stem, like a leaf, for a switch that closes a circuit when air presses it down.

Pop-Up Switch
Switches (and circuits) don't have to be flat! These flexible switches can stretch to close different switch gaps.

Troubleshooting tip: switch mechanisms require pressure to make a solid electrical connection. Pressure can come from a finger or hand (press the flap switch or pop-up switch), air (the wind sensing switch), the paper itself (the pocket switch), or some other part of the mechanism.

Switches that use paper to create pressure sometimes fail to make a good connection if there is not enough "spring" to the paper holding down the conductive tape. It helps to add extra paper thickness to the switch contact area and to make sure to firmly glue or tape down outer parts, such as the switch pocket.

Teacher Preparation

1. Watch the switch video to review the four switch mechanisms covered in the chapter.
2. Design and build your own switch as a class demo. Create your own illustration for one of the existing mechanisms, and/or create your own switch mechanism entirely!
3. Print all the switch templates:
   a. pop-up switch: Chibi Script: 3-22 to 3-24, MakeCode: 3-22 to 3-24
   b. press-the-flap: Chibi Script: 3-25 to 3-28, MakeCode: 3-25 to 3-28
   c. wind sensor: Chibi Script: 3-29 to 3-30, MakeCode: 3-29 to 3-30
   d. pocket character switch: Chibi Script: 3-31 to 3-33, MakeCode: 3-31 to 3-33
   e. make your own: Chibi Script: 3-34, MakeCode: 3-34

Lesson Sequence

1. Start with Art: Explore images of Aurora Robson's Junkmail Collages and watch the artist share her creative process. How does the artist choose her materials? How do these materials create a dialogue with the world outside the artwork?

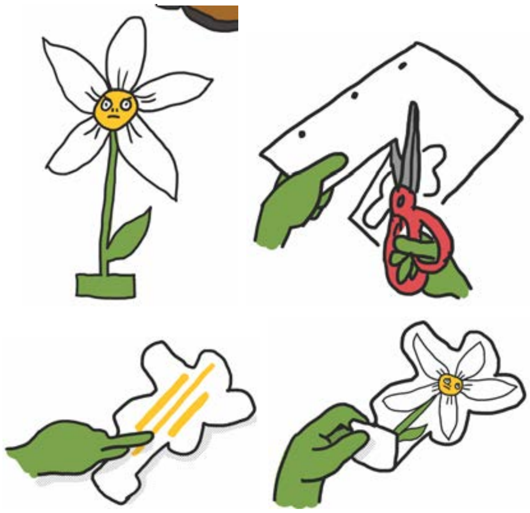
   In the previous lesson (LTC lesson 6) we explored direct cause and effect between different parts of a machine or paper circuit. Here the artist challenges us to think about larger structures of cause and effect – environmental, societal, ethical – and how our choices affect these systems. What systems of cause and effect are important to your students? How might they create interactive art to speak about these systems?

Wise Blood by Aurora Robson

2. **Warm-up**: Go around the room asking each student to answer: what is one thing they can sense right now (see, hear, smell, taste, feel...)? What knowledge allows them to interpret or make sense of this input, or information? What is one action they might take in response?

3. Introduce the switch activity: students will be making their own switches to detect something in the world around them.

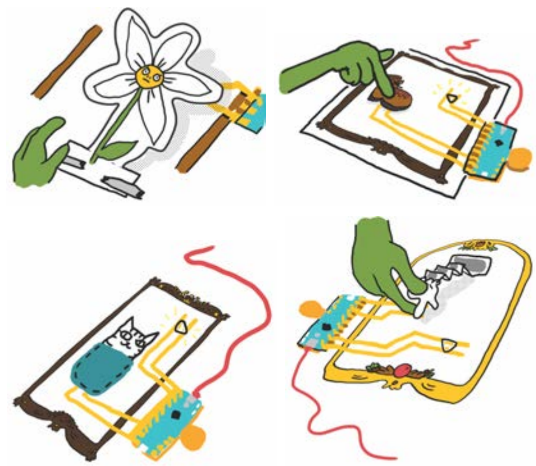
4. Divide students into groups of 4. These will be their "switch teams."



Assembling the wind sensing switch

5. **Lesson Part 1**: Show the switch video for students to see the 4 different switch types. Students will first build the switches on the templates to learn how they work before designing their own.

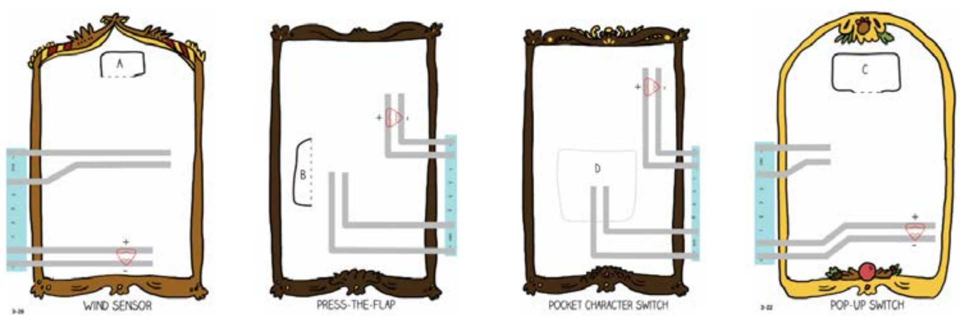
6. **Input**: Within their teams, each student builds one of the 4 switches following instructions from Love to Code Chapter 4. Encourage students to personalize the characters and objects on their switches, such as drawing their own character to place in the pocket of the pocket switch. They can also cut shapes out of magazines or old picture books.



Using the switches in a Chibi Chip Circuit

7. **Output**: Use the code from the previous lesson to map input (whether the switch is pressed or not) to output (what the LED does). What happens when the switch is pressed? Have students draw something of their choice to show the effect of the switch press.

8. **Switch gallery**: students go around the room to check out the switches that each team built!



9. **Lesson Part 2**: As a team, students brainstorm what they want to sense using a switch of their own design, then use the switch design worksheet to plan their design. Next, they prototype their designs.

   Note: it's ok to use circuits to make ***models*** of things in the real world. For example, a model of a "smart building" that activates shades when the sun gets bright doesn't need to detect the real sun, or activate real shades over the windows. Rather, it could use a switch to detect when a paper sun is moved over a papercraft building. LEDs in the building could then turn off to obscure the windows, demonstrating the shade effect.

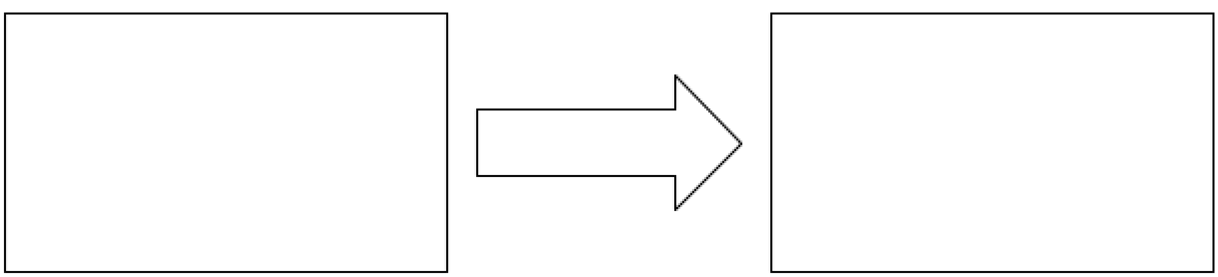
   The goal is to create a model that tells the story they have in mind. Think interactive posters, paper dioramas, and papercraft models! The following are some ideas for switches to help guide students:

a. **Pushpin switch**: sandwich a piece of paper between two conductors and place it on a corkboard or other pushpin-friendly surface. When a metal pushpin pokes through the layers, it will connect the conductors, closing the switch.
b. **Step/stomp switch**: a large press-the-flap switch that activates when someone steps on it. Make sure to include a spacer, such as foam tape or piece of corrugated cardboard, to hold the switch contacts apart unless it is actively pressed. You can think of this as a "person sensing switch," and use it to sense when someone enters the room or stands in a particular spot. Another variation: a sit/stand switch that senses when someone sits down in a chair.
c. **Window switch**: the switch contact touches a switch gap when you close the window.
d. **High-five switch**: a paper character closes a switch when it high-fives another paper character or a person!
e. **Rolling ball switch**: place the switch gap somewhere on a track that a ball will roll along. Wrap the ball in aluminum foil or another conductive material. When the ball reaches the switch gap it will close the circuit. Use multiple switches to track the path of the ball.
f. **Weight switch**: when enough weight is placed on a paper container, a conductor on the bottom of the container presses down on the switch gap.
g. **Moisture sensing switch:** run two strips of conductive tape over a sheet of plastic, such as a piece cut out of a yogurt lid, and dip them in water or wet soil. The water or moisture allows electricity to flow between the two strips, closing the switch gap. Be careful not to get any water on the Chibi Chip or its cable or you might cause a short circuit!

10. Class gallery walk: students show their switches in action!

Switch Design Worksheet

What does your switch sense, and what happens when the switch activates?



Input (cause): __________________ Output (effect):________________

How does your switch work? Draw it below, labeling the **switch contact** and the **switch gap**.

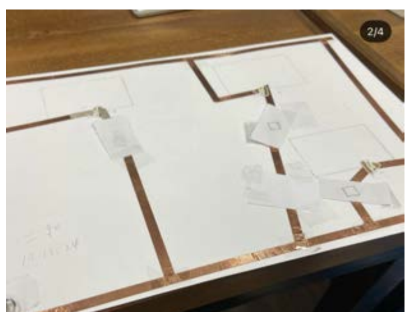
Extensions and Adaptations

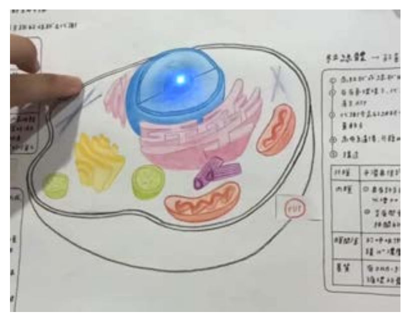
1. Theme ideas:
    a. "Levers of change": create an interactive poster or diorama that demonstrates an issue students care about and one way to address the issue
    b. "Smart home": build a model of a home that responds to its environment and/or people's actions in the home
    c. "Smart city": build a model of a city that responds to its environment and people's actions
    d. Sensing the natural world: create a model of a natural environment and measure changes such as wind, water flow, plants growing or animal behavior.
    e. Cardboard arcade: inspired by Caine's Arcade, build arcade games from paper and cardboard! These could have a subject-area theme, such as a science, math, or language arts topic.

2. **Reed switches** close the circuit when a magnet is brought near. While these are store-bought switches, rather than DIY ones, they make great "magic wand" style effects in papercraft creations. Read more about how to use reed switches here.

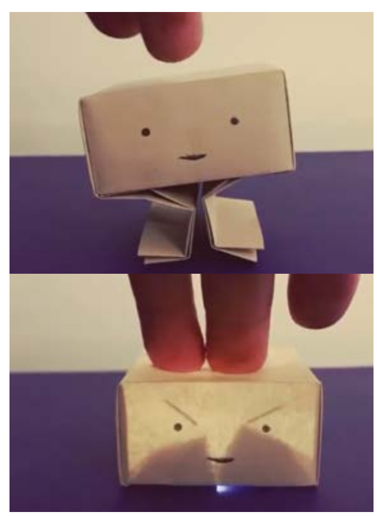
Inspiration

1. These sliding switches by Chia-Chi Wang's students (circuitcard on Instagram) use metal brads in clever ways to close switches as viewers move different parts of the paper creations.





2. This interactive origami robot by Michael Shannon (right) uses a switch attached to the folds of the origami!
3. Revisit Electronic Popables by Jie Qi to see a variety of paper switches and mechanisms in action.
4. Check out the Makey Makey tutorial pages for many great examples of DIY switches that also work with Chibi Chips.
5. Check out videos of "Rube Goldberg Machines" for sensor ideas. These often use mechanical motion rather than sensing electricity, but the mechanisms can spark inspiration. For example, detecting a rolling object that hits another object when it reaches the bottom of a ramp.



Lesson 8: Fading and While Loops

One 45 minute lesson

Materials

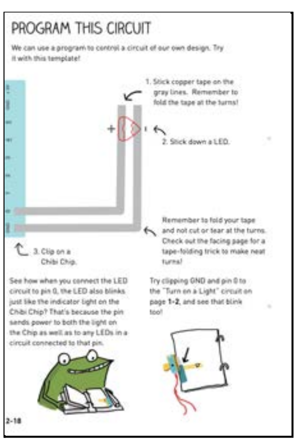
- [ ] Chibi Chip, cable, and programming device
- [ ] Completed circuit from the Lesson 3 activity, or any previous circuit that has an LED connected to pin 0

Resources

- **Lesson page numbers**:
  Chibi Script: 4-1 to 4-11, 4-24 to 4-25
  MakeCode: 4-1 to 4-11, 4-24 to 4-25
- MakeCode Book Slides
- Video: Chapter 4 Walkthrough (first minute)

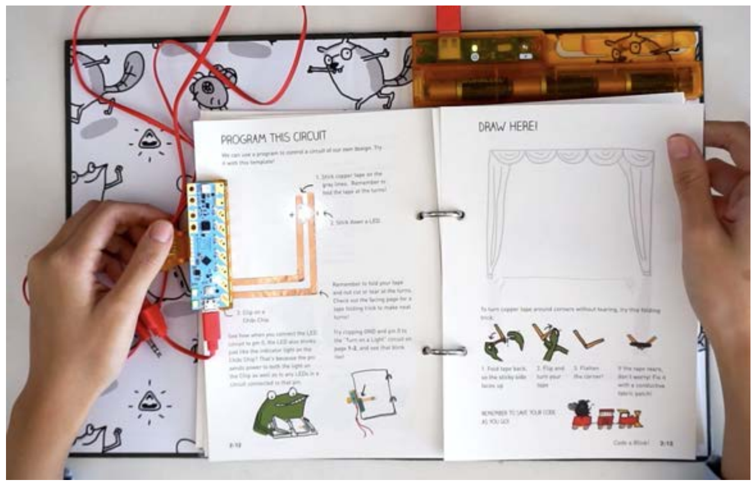
Inspiration

- The Ice Book by Davy and Kristin Mcguire
- Illuminated Pop-up Cards by Erin Riley



Lesson Overview

In this lesson, students will use analog output, loops, conditionals, and variables to create gradual fade in and fade out effects with their LEDs.



Learning Objectives

- Use **analog output** with **PWM** (pulse width modulation) to set different brightness levels on the I/O pins
- Use a **variable** to track and update the current brightness level of an LED
- Use a **while loop** and **comparison operator** to smoothly fade in and out an LED
- Create mood and express emotion using animated light patterns and lighting effects

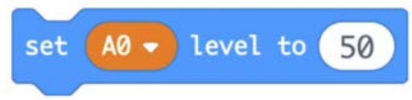
Vocabulary

- **fade out**: to gradually *decrease* in intensity
- **fade in**: to gradually *increase* in intensity
- **analog**: a signal that varies on a continuous scale.
- **PWM (pulse width modulation)**: a technique to quickly switch between ON and OFF to create the effect of different brightness levels.

Background

In previous lessons, we turned LEDs on or off to create different patterns. Beyond fully ON and OFF, we can also use the **set level** block to dim them to intermediate brightness levels between 0 and 100.

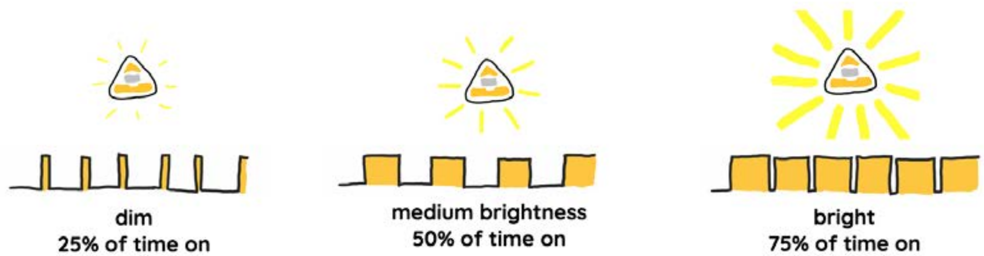
Notice that the dropdown for **set level** has an A in front of the pin number, rather than a D. This is because it uses the **analog output** functionality of the pin, rather than digital (D) On/OFF output.



Analog output is when the effect is somewhere in between fully ON and fully OFF. Behind the scenes, it uses something called **pulse width modulation (PWM)** to simulate different voltage (brightness) levels.

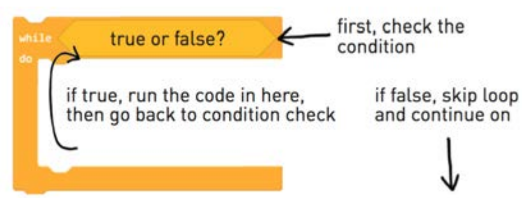
To make the light look like it is partially on, the Chibi Chip actually blinks the light on and off extremely quickly, around 400 times a second. This is so fast that our eyes blur the rapid blinking so it seems like the LED is shining at a constant, but dimmer, light level. The fast speed makes a choppy change appear smooth!

The brightness of the light depends on how much of the time the light spends ON vs. OFF. This ratio is called the duty cycle and is expressed as a percentage. When we use the set level block, the number (0-100) specifies the duty cycle percentage.

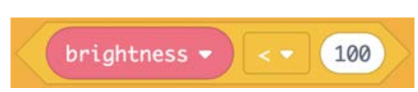


To create fading effects, set the LED level to gradually increase or decrease between 0 and 100. The amount of change determines how smoothly the light fades. For example fading by increments of 10 will look choppy compared to fading in increments of 1.

Rather than writing many lines of code for every single step in a fade, we can use the **while loop**, **variable** and **comparison** blocks. Code inside the while loop runs repeatedly as long as the condition is true. The variable is the current status and the comparison checks whether the current status meets the condition.



For example, to fade in and out, the while loop can increase the *brightness* (variable) of the light with each loop and check whether it has reached maximum *brightness* of 100 (condition). If so, exit the first while loop and in a second while loop, decrease the *brightness* until it reaches the minimum *brightness* of 0.



Here is a summary of the new code "vocabulary" used in this activity

Microsoft MakeCode	Chibi Script	Arduino	What it does
set A0 level to 50	`setLevel(pin, value)`	`analogWrite(pin, value)`	Use PWM (pulse width modulation) to set level of brightness between 0 and 100.
while / do	`while(condition) { }`		while loop: check if condition is true; if so, run code; loop until condition is false.
Make a Variable...	`int brightness;`		create, or *initialize*, a variable
brightness	`brightness`		reference the variable
set brightness to 0	`brightness = 0;`		set the variable to a specific value
brightness < 100	`brightness < 100`		comparison operator that outputs a true or false value
change brightness by 5	`brightness += 5;`		Add to the current value of a variable

Teacher Preparation

1. Try the PWM exercise: wave the Chibi Chip back and forth when it is set to different brightness levels and notice the different effects.

2. Build the Love to Code -> Fade with While Loop exercise from scratch (drag the blocks from the code block area based on the screenshot of the code). This example has more blocks-inside-other-blocks than previous examples, so building it will help you anticipate issues students might run into. Tip: to construct the conditional statement, make sure to drag the new code blocks to the left side of the input box. Make sure to carefully check the direction of the greater than / less than operator.

Lesson Sequence

1. Start with Art: Watch The Ice Book by Davy and Kristin Mcguire and observe how light is used to bring life to the paper theater. Have students take a few minutes of quiet writing time to imagine a scene from their own memories, writing down what the light looks and feels like in this scene. Is it warm or cool? Stable, or does it flicker? How does the light change? What effect does the light have on objects in the scene? What feeling does this scene give them?

2. Discuss: What kind of light effects do students know how to create with code, and what do they have questions about? What ideas do they have for adding other kinds of light effects? Consider not only code, but also using light-diffusing paper, silhouettes showing through the page, and other inventive applications of materials.

3. Introduce the **set level** block.

4. Ask students to play with the example code by setting pin 0 to different brightness levels to create their own patterns. Can they create the effect of a flickering candle or a glitchy neon sign?

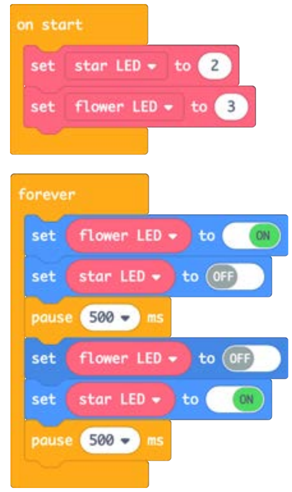
5. Seeing PWM in action: wave the Chibi Chip back and forth at each of these different levels. Sketch the light pattern you see for each one in the corresponding box.

set A0 level to 0	set A0 level to 25	set A0 level to 50	set A0 level to 75	set A0 level to 100

6. What if we wanted the LEDs to fade more smoothly? Have students try to make their LEDs change brightness as smoothly as possible, then share their versions with the group
7. Introduce the **while loop** as a way to make their code shorter! Upload Love to Code -> Fade with While Loop to try it out.
8. Try these code challenges:
    a. Fade the LED more slowly
    b. Fade the LED more quickly
    c. Move the fading effect to a different I/O pin
    d. Change the program so that it starts by fading out the LED, and then fades it in (hint: swap the two while loops, and update the starting value of the variable)

Extensions and Adaptations

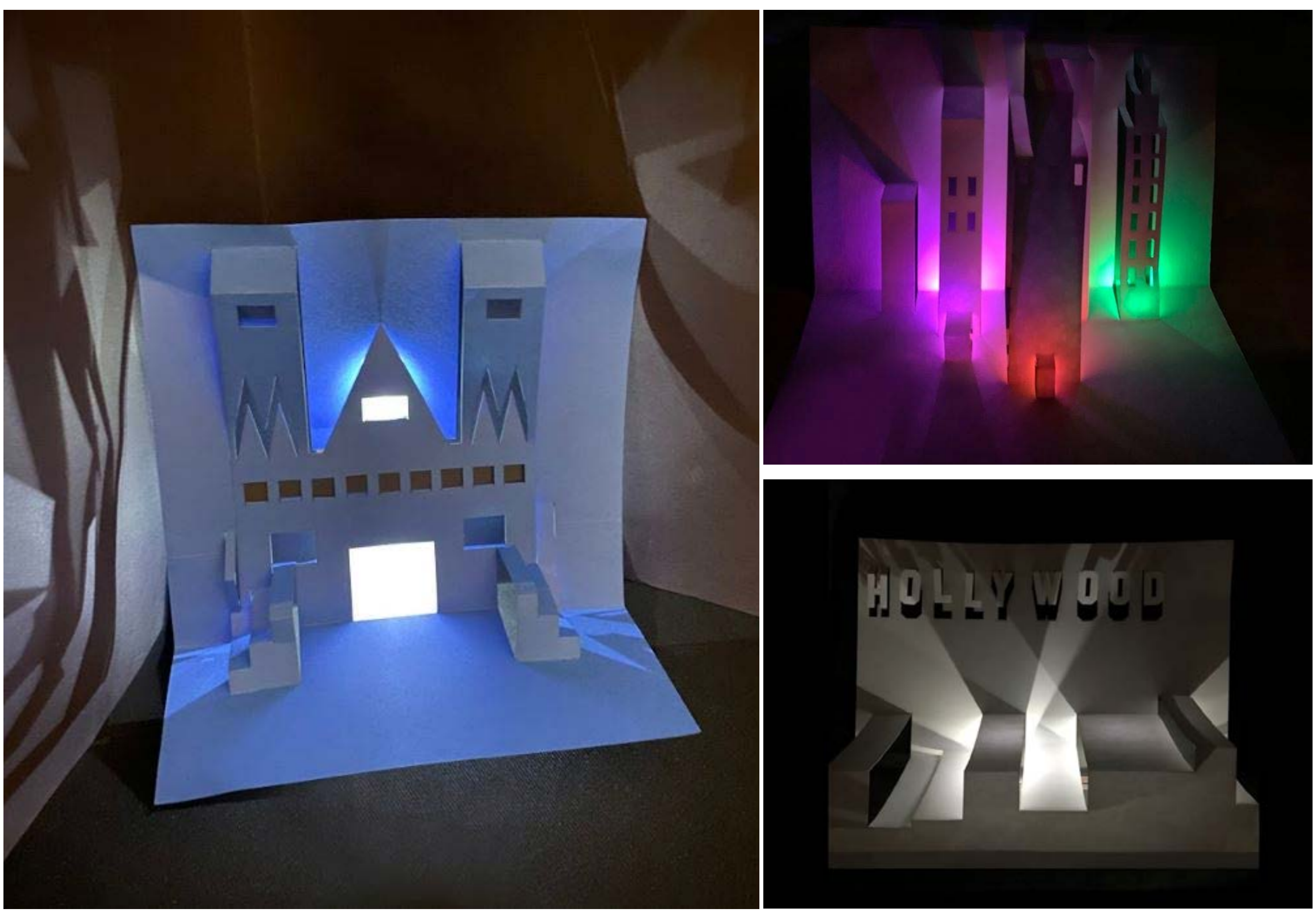
Variable naming and code readability: Based on Chibi Script pages 3-15 to 3-17 or MakeCode pages 3-16 to 3-17, discuss variable naming choices as a class. Why was the variable in the fade code called "brightness," and what are some other names that could have been chosen?



Return to a previous project and ask students to "clean up" their code using variables and comments to make it as clear as possible to someone else. Then swap code with another student or team. The new team should make a change to their code ("remix" the project). Discuss as a group: what made it easier or harder to modify others' code?

Inspiration

Fading effects on different pins can enhance paper shadows and silhouettes. For example, we think these stunning pop-up cards by educator Erin Riley would pair wonderfully with lights that fade and change.



Lesson 9: Multithreading

One 45 minute lesson

Materials

- [ ] Chibi Chip, cable, and programming device
- [ ] Circuit from LTC Lesson 4 or Lesson 5, or build a new one using Chibi Script: 4-18 to 4-23, MakeCode: 4-18 to 4-23

Resources

- Lesson page numbers: Chibi Script: 4-12 to 4-17, MakeCode: 4-12 to 4-17
- MakeCode book slides
- Chapter 4 Walkthrough (starts after first minute)

Inspiration

- STOMP performance
- Mars Lander map by Corinne Okada Takara

MAKE A SCENE

You've learned so much! Now use your coding chops to help Fern and friends design some light-up outfits for the parade.

You can make a scene bigger by using conductive fabric patches to connect between two pages. Try it now!

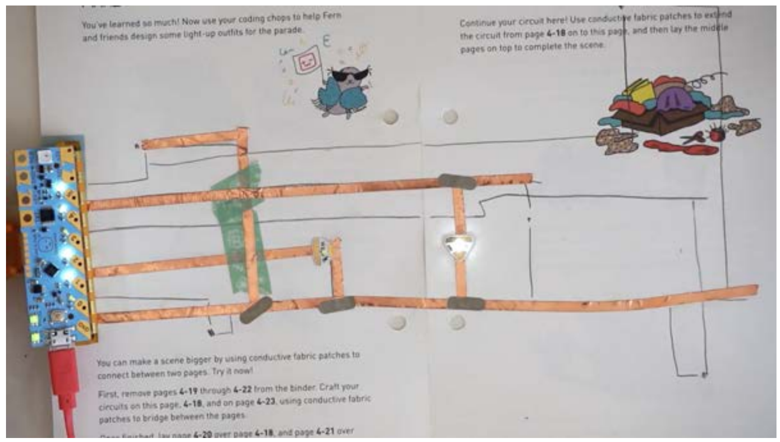
First, remove pages **4-19** through **4-22** from the binder. Craft your circuits on this page, **4-18**, and on page **4-23**, using conductive fabric patches to bridge between the pages.

Once finished, lay page **4-20** over page **4-18**, and page **4-21** over page **4-23**. The lights will shine through the parade!

4-18

Lesson Overview

In this lesson, students will learn to use the concept of multithreading to program different behaviors on each I/O pin.



Learning Objectives

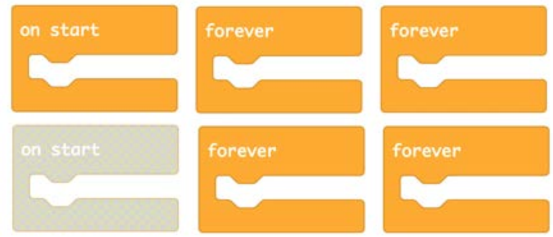
- Use multithreading to make pins run different code simultaneously and independently
- Avoid race conditions by writing code with instructions that do not conflict with instructions for other pins
- Combine independent behaviors to create a coordinated, cohesive whole

Vocabulary

- **multithreading**: running multiple pieces of code at the same time
- **thread**: a piece of code that runs on its own in sequence
- **race condition**: when different threads try to work with the same resource (such as a pin or a variable) and their instructions can collide!
- **choreography**: arrangement of actions leading up to an event, such as the steps and sequences in a dance

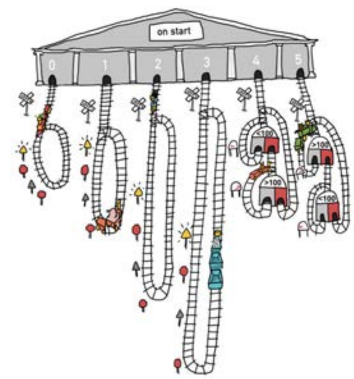
Background

So far, the programs we've written have a single **thread** of execution: that means they do one thing at a time in one sequence. If we wanted multiple pins to do different things simultaneously, we had to carefully interweave the instructions inside the forever loop. Many microcontrollers can only work this way.



We can have multiple forever *loops, but only one* on start!

However, with **multithreading** we can run multiple threads of code at the same time without worrying about interweaving code! In Microsoft MakeCode, it looks like this: multiple forever loops running simultaneously, each running their own code sequence.



Different threads are like trains on different tracks.

One thing to be aware of when working with multiple threads is **race conditions**. These happen when multiple threads try to work with the same resource, such as sending a signal to a pin or changing the value of a variable. Their instructions can collide!

Collisions can occur when different threads try to work with the same resource, such as a pin.

A good rule of thumb is to use different variables and pins in each thread. For example, pin 0 would have its own thread and no other threads would try to tell it what to do. In the multithreading code example, the variables *brightness4* and *brightness5* keep track of the brightness of pins 4 and 5, and each run in their own threads.

Be aware that the MakeCode simulator does not always run the threads with the same timing as the physical Chibi Chip. If things look slightly different in the browser than on the Chip, try tinkering with the pause times.

All this may sound a little complicated, but to get started: just try adding more forever loops and see what happens!

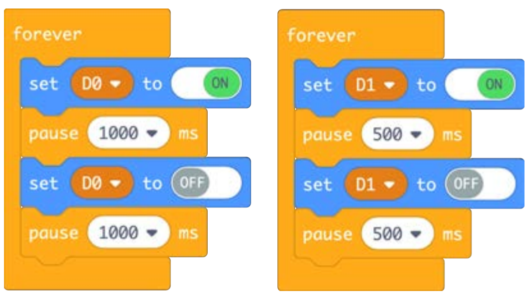
The code might run a little differently in the MakeCode simulator than on the physical Chibi Chip; timing is a difficult job!

Teacher Preparation

1. Read the lesson overview in the LTC book Chibi Script: 4-18 to 4-23, MakeCode: 4-18 to 4-23
2. Try the following code challenges, keeping an eye out for issues that students might run into

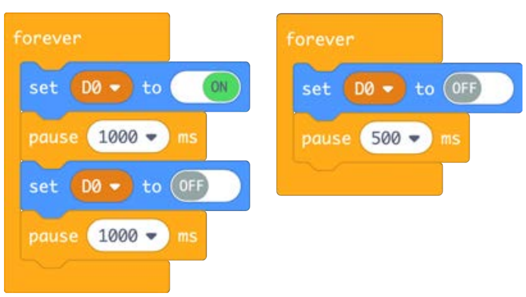
Lesson Sequence

1. Start with Art: As a class, watch a performance from STOMP. What is each performer doing individually? How do these different actions come together to create the piece? Introduce the concept of multithreading: each thread will control one LED, so different actions can happen in their circuit project at the same time.
2. In this activity, students can design a new circuit or use a circuit they have already created. The circuit should have at least one LED connected to each I/O pin, such as the circuits created in Lesson 4 and Lesson 5. If students are building a new circuit, try using this activity as a start toward a project such as a Paper City or Accordion Book.
3. Introduce the following code exercises:

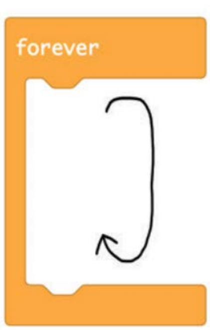
<table>
<tr><th>The code</th><th>Challenge to try</th></tr>
<tr><td>
</td><td>This code uses two forever loops to blink pin 0 and pin 1 at different rates. Try:

1. Mix up the rhythm! Play with the blink speed of pin 0 and pin 1

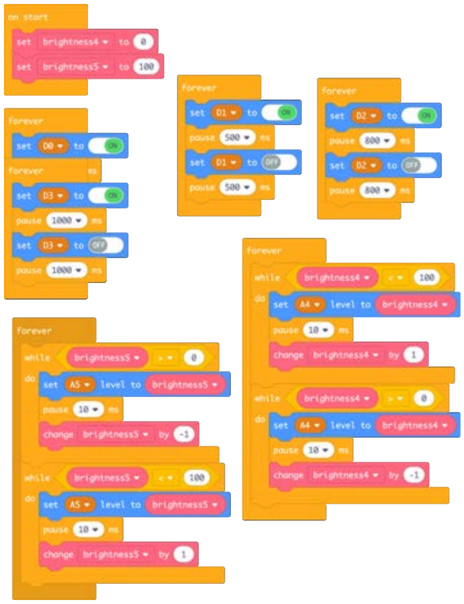
2. Add a third LED that blinks at a different rate than the first two

3. Add any parts of the fade program from LTC Lesson 8 that you need to add a fourth LED that fades gradually in and out as the other LEDs blink</td></tr>
<tr><td>
</td><td>What happens when two threads try to send directions to the same LED? Look at the code and write down a prediction about what you think will happen. Then try running it.

1. What happens to the LED on pin 0? Can you explain it?

2. Does the same effect happen on the physical Chibi Chip as in the simulator? What do you notice?</td></tr>
<tr><td>
</td><td>Write a program to turn LED 0 on, then LED 1, then LED 2, and then turn them off in sequence. How many forever loops (threads) do you need?

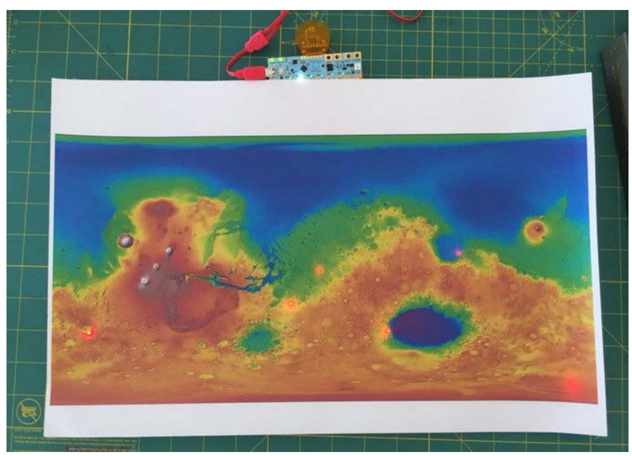
Tip: multithreading is most useful when you want each LED to do something independent and unrelated to the others, and their timing does not depend on each other. If you'd like your LEDs to turn on one after the other, or something else where their behavior is interconnected, using a single thread will work best.</td></tr>
</table>

The code	Challenge to try
	Check out the Love to Code -> Basic Multithreading example. Read the code and try to predict what each LED will do. Then try it out in the simulator. Finally, make it your own! Use multithreading to program your circuit such that each LED "marches to the beat of its own drummer." For example, if using the template from Lesson 4, each scene in the window can show its own light pattern.

Extensions and Adaptations

Multithreaded programs are a great opportunity for students to practice collaborating on code! Each student can be responsible for the code for one pin in a shared group project. Start by testing the code separately using the simulator and then combine the code into one program. Encourage students to allocate plenty of time to combining programs and troubleshooting any issues that may arise. Remind students to discuss their plan along the way with each other to make sure the separate threads will work together without collisions.

Inspiration



Corinne Okada Takara uses multiple pins on the Chibi Chip to map Mars lander attempts ("blue for future attempts, red for fails, white for successes"). Multithreading could be used to give each lander its own distinct blink or fade pattern, adding another channel through which to tell its story!

Lesson 10: *Love to Code* Light Sensor Part 1

One 60-minute lesson

Materials

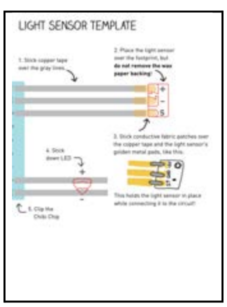
- [ ] 1 LED Circuit Sticker
- [ ] 1 Light Sensor Sticker
- [ ] 17 inches conductive tape
- [ ] 3 conductive fabric patches
- [ ] Chibi Chip, cable, and programming device
- [ ] Light sensor template: Chibi Script: LS-4 to LS-6*

Resources

- Light Sensor Chapter
- Lesson page numbers: Chibi Script: LS-2 to LS-3, LS-7 to LS-10, LS-11, LS-24

Inspiration

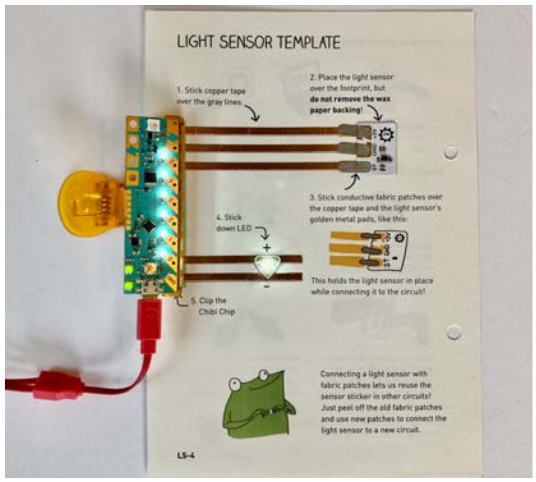
- Lightweeds by Simon Heijdens



*Note: the *Love to Code* Light Sensor Chapter is written for Chibi Script (text based code) but the concepts behind it apply to either language. The lesson following covers the Microsoft MakeCode version.

Lesson Overview

In this lesson, students will use the Chibi Chip to read the light level detected by a **light sensor** and use the sensor readings to control the brightness of an LED.



Learning Objectives

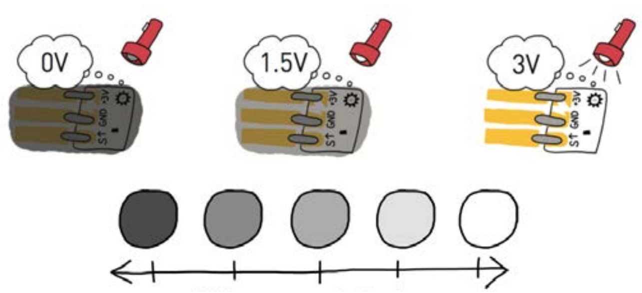
- Build a light sensor paper circuit
- Use thresholds (high/low) to make decisions in code based on light sensor readings
- Use analog input (read level) to read light levels and map it to the brightness or dimness of an LED
- Create art that responds to environmental conditions

Vocabulary

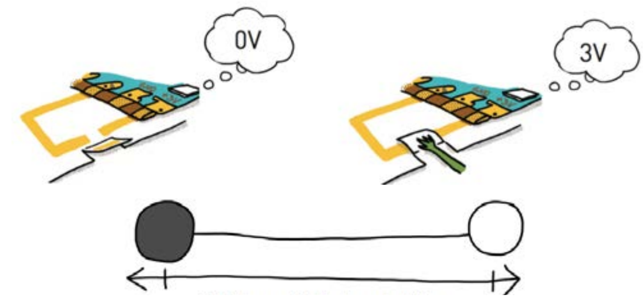
- **light sensor**: a component that measures the ambient light level
- **analog input:** read an input voltage level that varies on a continuous scale
- **digital input**: read an input voltage level that is either high or low, on or off, no values in between
- **environmental sensing**: the science of using sensors to measure environmental conditions, such as rainfall quantity, air quality, soil moisture, and many other things.

Background

The Chibitronics Light Sensor sticker contains a small electronic device that measures the ambient light level and turns it into a voltage. The Chibi Chip reads this voltage as an input on an I/O pin, similar to how it reads a switch.



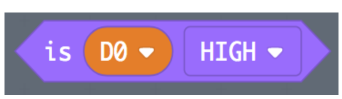
Light Sensor sees "shade of gray"



Switch sees only black (OFF) and white (ON)

However unlike a switch, which can only sense fully ON and fully OFF, a light sensor senses light levels in between. One way to think about this is that a switch only sees black and white, while a light sensor can see black, white and shades of gray in between.

The light sensor sticker has three connection pads: GND and 3V to power the light sensor, and S (**signal**) which outputs the brightness detected as a voltage level between 0 and 3V. The Chibi Chip can either read these as "in between" analog values or treat them as a simple ON/OFF using halfway (1.5V) as the threshold.



The **is (pin) high/low** block uses **digital input**: it turns the light level value into a simple on or off, bright or dim depending on whether the reading is above or below 1.5V.

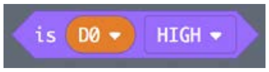
The **read level** block uses **analog input**: it gives a brightness reading ranging between 0 and 100. You can think of it as 0% brightness (for 0V) to 100% brightness (for 3V).

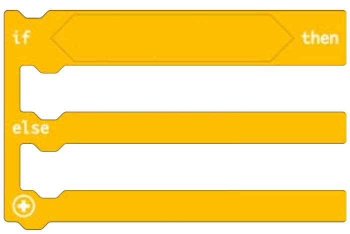
Teacher Preparation

1. Read *Love to Code* Light Sensor Chapter pages LS-2 to LS-3, LS-7 to LS-10, and the first paragraph of LS-11, and LS-24.

2. Build the light sensor circuit as a class example and try the code exercises in this lesson, while considering challenges students might run into.

Here is a summary of the main code "vocabulary" used in this activity

Microsoft MakeCode	Chibi Script	Arduino	What it does
	`read(pin)`	`digitalRead(pin)`	Sense whether pin is high (on) or low (off). Use this to read whether a switch is pressed or not, or as a threshold with light sensors.
	`readLevel(pin)`	`analogRead(pin)`	Read the voltage level between 0-3V. Returns a number between 0 and 100 based on the reading. Use this to read sensor values, such as light sensors.
	`100 - readLevel(pin)`	`100 - analogRead(pin)`	Math operator to perform addition, subtraction, etc.

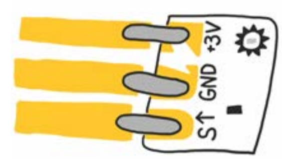
	`if(condition) {`
	`}`
	`else {`
	`}`
			if else statement (conditional statement)
			
			check if condition is true, if so run code inside the *if* block. Otherwise, run code inside the *else* block.

Lesson Sequence

1. Start with Art: Watch the video of [Lightweeds](#) by Simon Heijdens. In what ways does the artwork respond to the environment? How does the artist use data to tell a story? While data is often shown as charts and graphs, this work demonstrates how representing information in imaginative and interactive ways helps the audience connect more deeply with the data.

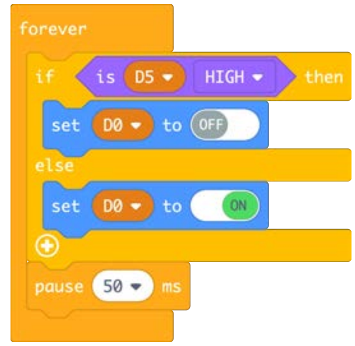
   How might students use paper circuits to express data in surprising and captivating ways? Note: one approach is to show data indirectly with metaphors rather than through literal depictions.

2. Introduce the light sensor. Show students that the little bump inside the sun shape is the sensor itself. Class brainstorm: what are situations where it is useful to know the light level in a room or outside? Write these ideas down!



3. Build the light sensor circuit. Instead of sticking the light sensor permanently to the page, leave the paper backing on. Place (don't stick!) the light sensor over the copper tape and use three conductive fabric patches to stick it in place. This way students can reuse the light sensor sticker in future projects!

4. Upload the basic light sensor example code (shown on the right). When you cover the light sensor (the little bump inside the sun shape) making it sense dark, pin 0 will turn on. Likewise, if it's exposed to light, pin 0 will turn off.



5. Ask students to test the light sensor with different light levels. Try covering the light sensor with their hands, shining a light at it (for example with a computer or phone screen), placing it under their desks, and moving to different areas of the classroom.

   Try this code challenge: can they reverse the effect to make the LED turn *on* when the light sensor detects bright light, and *off* when the light sensor detects that the ambient light is dim? When might this be useful?

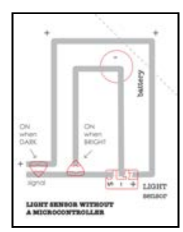
6. Next, upload the fade with light sensor example code. This example controls the brightness of the LED gradually based on the light level. The brighter the ambient light level, the brighter the LED.

   Try this code challenge: can they reverse the effect to make the LED get gradually brighter the dimmer the light level detected? Here is one solution that uses a math operator:

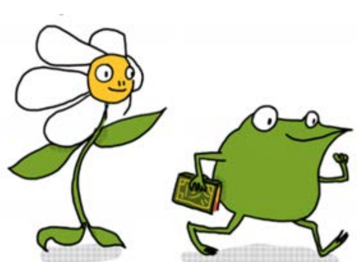
7. Go back to the ideas collected in the class brainstorm. Ask students (individually or in groups of 2) to choose one of the ideas and build a prototype that shows the idea in action. If students are working towards a unit project, put these ideas in that context. For example, if they are building a paper city, ask them to prototype something that happens in their "smart city" when the light level changes.

Extensions and Adaptations

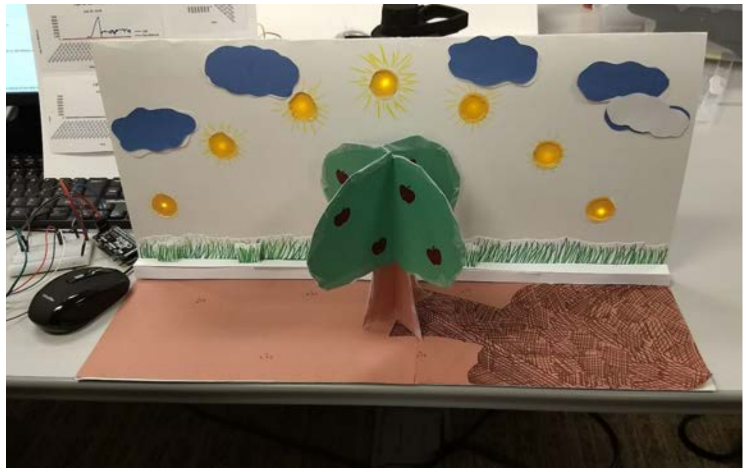
1. Make a battery powered light sensor circuit that controls the brightness of an LED directly, without a microcontroller! Use this template.



2. Turn your classroom into a mobile nature tech lab! Take students outside to try their light sensors in a school garden or nature area. Bring phones as programming devices and rechargeable USB power banks to power their Chibi Chips. What kinds of nature-related art and/or science projects can they imagine creating with light sensor circuits?



Inspiration



Students in the summer *Code at TACC* program at the Texas Advanced Computing Center learned to place sensors in nature to record environmental conditions, then built paper circuit dioramas to help tell the story of their data as they gave their project presentations. Notice the soil moisture sensor made from copper tape, clear plastic, and alligator clips!

Lesson 11: *Love to Code* Light Sensor Part 2

One 60-minute lesson

Materials

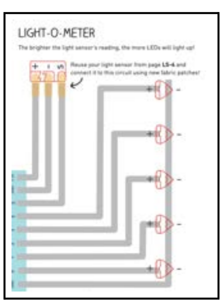
- ☐ 7-10 LED Circuit Stickers
- ☐ 1 Light Sensor Sticker
- ☐ 50 inches conductive tape
- ☐ 3 conductive fabric patches
- ☐ Chibi Chip, cable, and programming device
- ☐ Light-O-Meter Template: Chibi Script: LS-12 to LS-14, LS-20 to LS-22*

Resources

- **Lesson page numbers**: Chibi Script: LS-11, LS-15 to LS-19
- Slide Deck
- [Light Sensor Chapter]

Inspiration

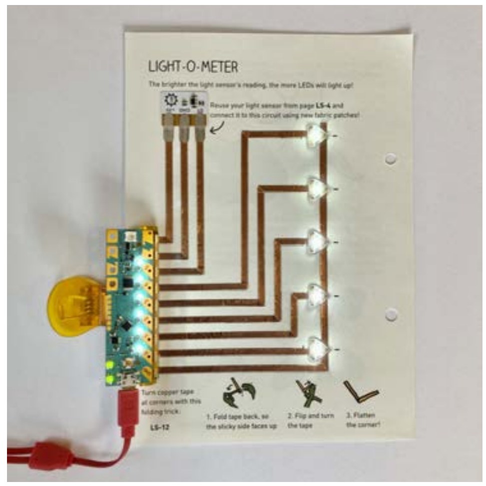
- [Dear Data] by Giorgia Lupi and Stefanie Posavec
- [Data Visualization Postcards]
- [*Tidal Notebook*] by Natalie Freed



*Note: the *Love to Code* Light Sensor Chapter is written for Chibi Script (text based code), but the concepts behind it apply to either language.

Lesson Overview

In this lesson, students will build a "Light-O-Meter" which maps live light sensor readings to a bar graph made from 5 LEDs. The brighter the light, the more LEDs will turn on.



Learning Objectives

- Build a light sensor paper circuit
- Use analog input (read level) to read the light level and map readings to a "light meter" readout
- Adjust (*calibrate*) sensor thresholds in code to account for ambient light conditions
- Create art based on sensor data

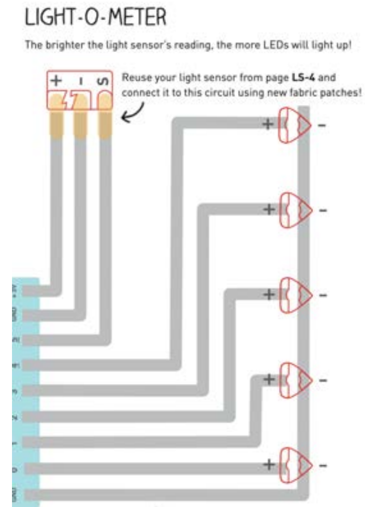
Vocabulary

- **calibrate:** to adjust sensor values taking into account ambient conditions for a more useful or accurate result
- **threshold**: a "cutoff" value, where an effect might happen if the sensor reading is over or under that value
- **data art**: an art form based on responding to or communicating meaning related to different types of data

Background

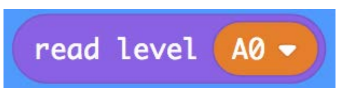
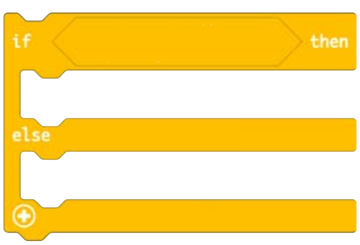
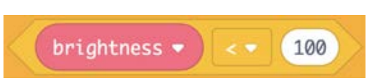
The "light-o-meter" in this lesson expands the possibilities for expressing analog values. Rather than changing the brightness of a single LED, the meter maps light sensor readings to a graph made from 5 LEDs. The graph animates to show the real-time sensor reading: the brighter the light, the more LEDs turn on (the taller the "bar" of the graph).

This circuit is a jumping off point for many other data visualization and data art approaches. The LEDs do not need to be in a straight line or even map one-to-one to the sensor reading. Instead, encourage students to put data into a context and create visualizations that also tell stories about the data.



For example, in the inspiration section, one art piece uses an arc of LEDs to show the current temperature, with different LED colors to show very cold and very hot days. Another art piece uses rows of LEDs connected to different IO pins to show ocean waves moving, varying the number of rows that light up to show the current tide level.

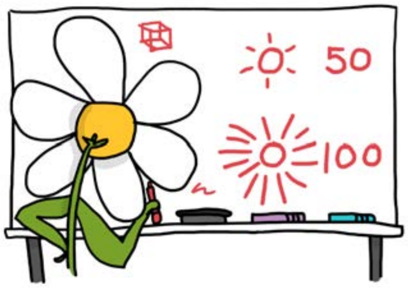
Here is a summary of the main code "vocabulary" used in this activity:

Microsoft MakeCode	Chibi Script	Arduino	What it does
	`readLevel(pin)`	`analogRead(pin)`	Read the voltage level between 0-3V and return a number between 0 and 100 based on the reading. You can use this to read sensor values, such as a light sensor.
	`if(condition) { } else { }`		if else statement (conditional statement) Check if condition is true, if so run code inside the *if* block. Otherwise, run code inside the *else* block.
	`brightness < 100`		Comparison operator that outputs a true or false value

Teacher Preparation

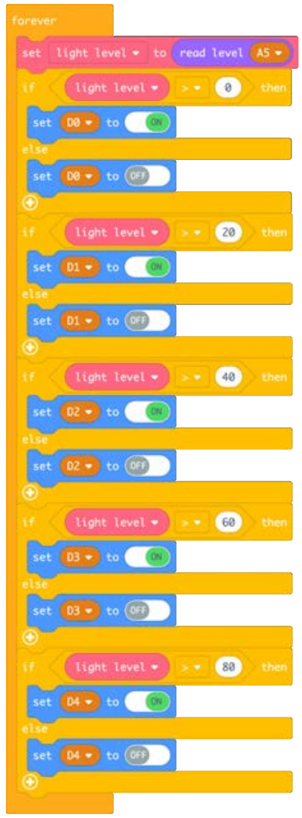
1. Read *Love to Code* Light Sensor Chapter pages Chibi Script: LS-11, LS-15 to LS-19.
2. Build the Light-O-Meter circuit and try the code exercises in this lesson, while considering challenges students might run into.

Lesson Sequence



1. Start with Art: Watch the video of [Dear Data] by Giorgia Lupi and Stefanie Posavec and explore their [data visualization postcards]. How does the process of collecting and visualizing data affect the artists' relationships to themselves, to each other and to data itself? This work demonstrates how we can learn not only from the finished data, but also through the process of noticing, documenting and sharing data.

   Paper circuits allow us to not only collect information through sensors, but also display data through light, animation and interactivity. How might we create new forms of data through paper circuits, and use it to tell new stories?



2. Build the Light-o-Meter circuit. As in the previous lesson (LTC Lesson 10), use conductive fabric tape patches to connect the light sensor sticker in a removable way. Next, upload the Light-O-Meter example code, shown on the right.

3. Code challenge 1: **calibrate**! Experiment with threshold values to a Light-O-Meter that is sensitive to the full range of brightness values in its environment. Start by holding a hand over the sensor, then raising the hand slowly away. The light meter should show all the LEDs off at the darkest point (with the hand covering sensor) and all the LEDs on at the brightest point. If this is not the case, adjust the **threshold** values (which start out set to 0, 20, 40, 60, and 80).

4. Code challenge 2: change the code so that the circuit turns into a "Dark-O-Meter," with more LEDs lighting up in the meter the darker it gets. Tip for students: pay close attention to the direction of the comparison operators (**<** and **>**), and talk through the logic one line of code at a time if they get stuck.

Extensions and Adaptations

1. The Light-O-Meter maps nicely to a bar graph or time series graph! Use the Light-O-Meter to track light levels over time in a particular location. For example, set up the Light-O-Meters in the classroom and record an entry on a graph at the start of class every day.

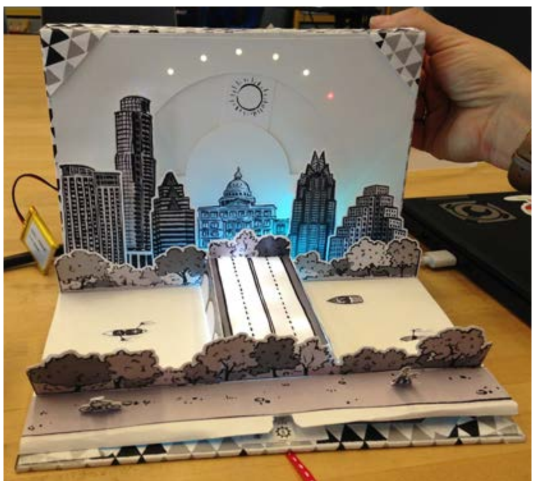
2. The **map** code block is another way that students can map a sensor value to an output. Encourage students to experiment with this block for an extra coding challenge.

3. The idea of sensor sensitivity and calibration has a connection to technological equity issues. When engineers design sensors to respond to people, they often create these systems without accounting for differences between individuals, reflecting and amplifying existing inequities.

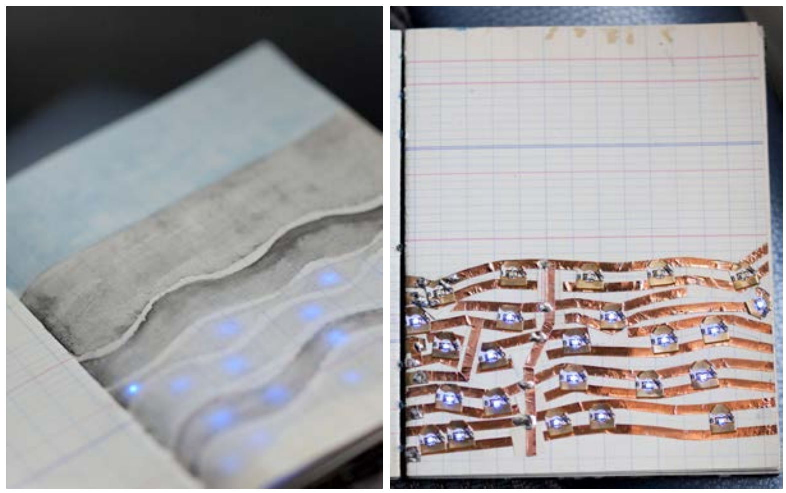
   For example, many voice recognition systems (which use data from sound sensors) are trained with men's voices, and don't recognize the voices of women, children, or people with accents from other languages as accurately. Another example is that sensors often respond more accurately to lighter skin than darker skin such as the automatic soap dispensers in bathrooms which use a light sensor. This is a bigger issue in facial recognition systems used by law enforcement, which often misread faces with darker skin.

   Ask students: how would they address equity when designing projects that use light sensors? In other words, how will they make sure their design works for everyone?

Inspiration



The *Austin Data Dashboard* pop-up book by Natalie Freed incorporates a Chibitronics light sensor. When the book detects that it is dark, LEDs turn on to show silhouettes of bats that live under the Congress Avenue bridge. Similar to the Light-O-Meter, temperature displays as an arc of LEDs across the sky.



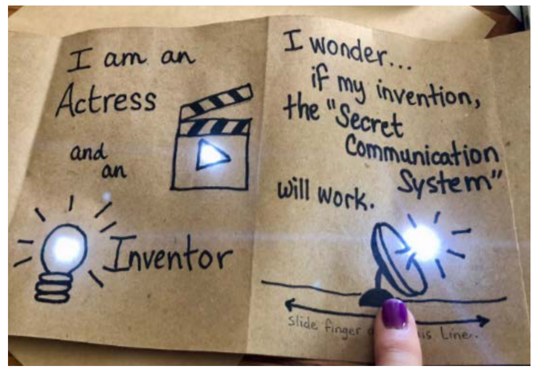
The *Tidal Notebook* by Natalie Freed is an artist book that shows the tide level using animating rows of LEDs that rise and fall like ocean waves. The circuit connections are similar to the Light-O-Meter, but with multiple LEDs per I/O pin turning on and off together.

Featured Projects

This section features some of our favorite "tried and true" projects that we have taught in classrooms and during workshops. They blend skills and topics covered throughout this guide and are designed to be open-ended so that you can adapt the project to subjects and themes of your choice. We hope these provide helpful inspiration for you to design your own projects as well!

Project 1: Paper Circuit Card

Project 2: Accordion Books

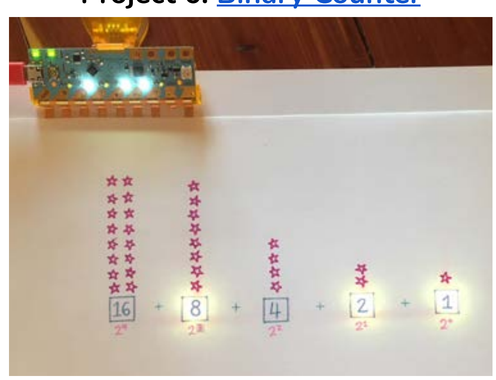


Project 3: Paper Circuit Mural

Project 4: Paper City

Project 5: Data Art

Project 6: Binary Counter



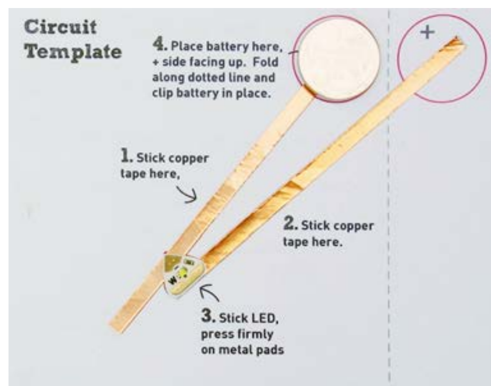
Featured Project 1: Paper Circuit Card

Overview: Create the most basic paper circuit: two short straight lines of copper tape with no turns or corners, one LED and one battery. This little card is quick, simple and can be completed in less than 5 minutes by beginners!

Paper Circuit Cards make a great introductory activity to get students acquainted with the materials of paper circuits. It's also good for make-and-take activities and drop-in events where time and resources are limited.

Theme Ideas

- Create a light-up name tag. Tie a loop of ribbon through the card to make it wearable like a necklace!
- Illuminate Yourself: Use the LED light to highlight one part of your identity
- Light Up Someone's Day: Create a simple greeting card for someone you care about!
- Class Portrait: Have students create light-up self-portraits and tape them pieced together on the wall to share out

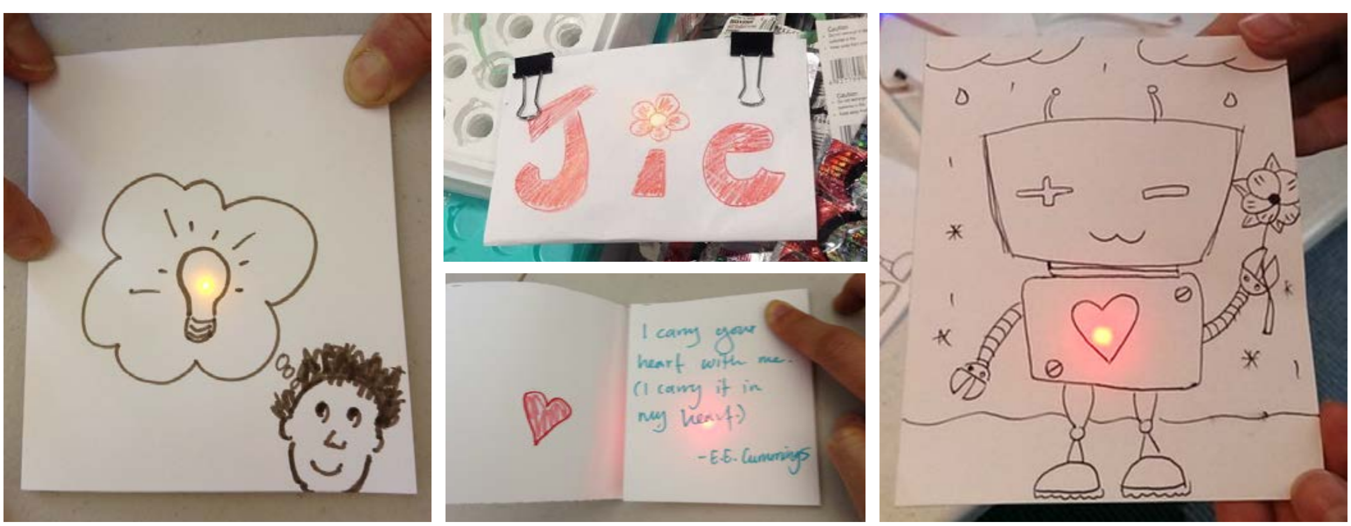


Prior Knowledge: no prior knowledge needed!

Resources

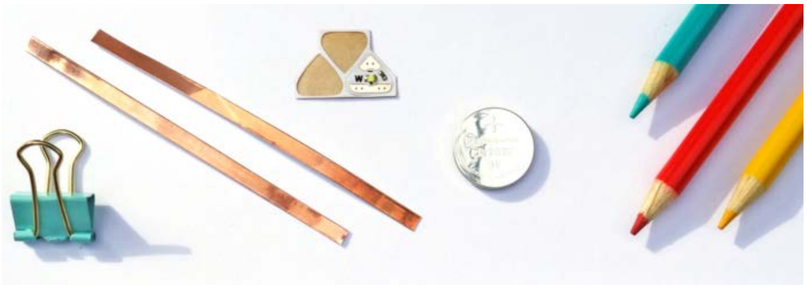
- Circuit Card Template
- Detailed tutorial page
- One-page tutorial summary on next page

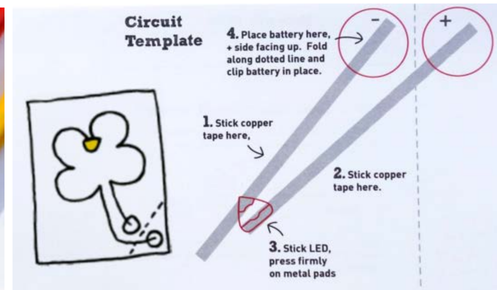
Inspiration



Make-and-Take Paper Circuit Cards from various Chibitronics workshops

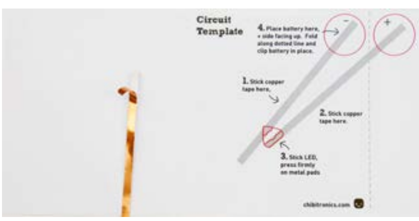
How to Make a Paper Circuit Card



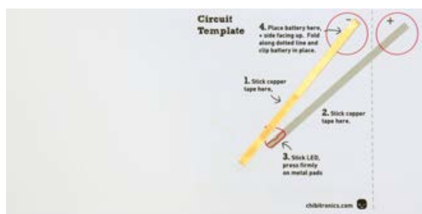


1. Gather your materials! You will need:

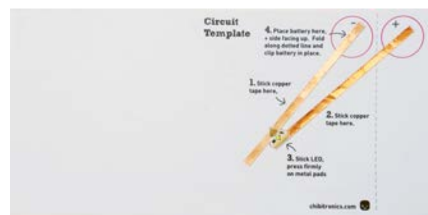
- 1 x Paper Circuit Card template
- 1 x CR2032 3V coin cell battery
- 1 x Circuit Sticker LED
- 1 x small binder clip
- 2 x 4 in (10cm) pieces of conductive tape
- Art materials of your choice, such as colored pencils, watercolors, or collage materials



2. Take one of the pieces of copper tape and peel back some (but not all!) of the paper backing to get it started.

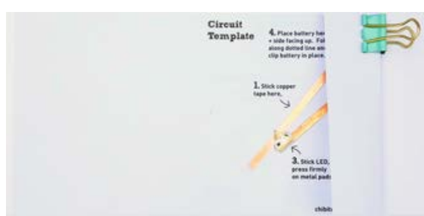


3. Run copper tape over both of the gray lines, gradually peeling back the paper backing as you go. Make sure the two copper tape strips do not touch!



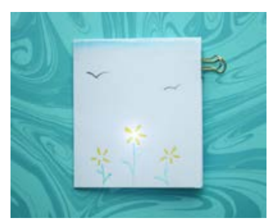
4. Stick your LED sticker over the outline and press it down for a count of 5. To achieve the best connection, avoid touching the adhesive with your fingers.

5. Place your battery + side up on top of the circle marked – . This way, when you fold the flap over, the positive side of the battery will make contact with the copper tape connected to the positive side of your LED.



6. Fold the flap over along the dotted lines, then hold it in place with a binder clip. Your LED should turn on!

If it doesn't, no worries! Check out these troubleshooting tips.



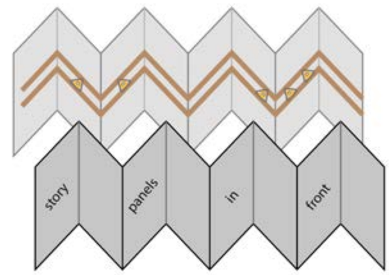
7. Fold the left half of your template over to the right so that it covers the circuit and your light shines through the paper. Now you can illustrate the blank page and use your LED to tell a story or illuminate your artwork!

Featured Project 2: Accordion Books

Overview: Create an artist book with a layer of hidden electronics. LEDs shine through each page of the book, illuminating a story. The lights can react to switches and sensors on different pages, and can optionally be programmed with a Chibi Chip.

Theme Ideas

- Write an "I Am" Poem about an inventor, book character, or another historical or fictional figure
- Create a learning journal about a unit project, adding one page at a time, then illuminate the "aha" moments
- Tell the story of an imagined or real travel journey written in the language of that country (for world language classes)



Prior Knowledge: measuring, cutting, parallel LED circuits, switches. Optional: any level of Chibi Chip programming.

Accordion book created with templates (which can be placed in any order!) by Jill Dawson

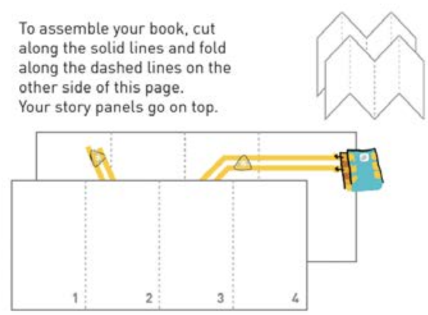
Resources

Coin cell battery-powered books

- Accordion Book Tutorial at Chibitronics by Jill Dawson
- Classroom Accordion Book Tutorial slides by Barbara Liedahl

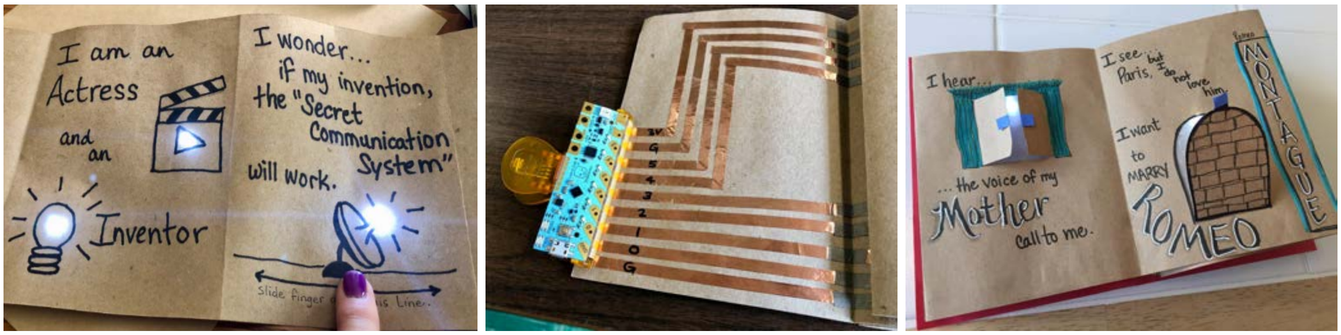
Chibi Chip-based books (with coding!)

- Mini accordion book template (a programmable mini-zine using one sheet of paper)



Inspiration

- Journey through the creation of an accordion book, "I Am Juliet" by Barbara Liedahl
- Presentation slides: Physical Computing, Storytelling, and Arts Integration
- Electronic Popables by Jie Qi: paper circuit pop up spreads as artist book inspiration



Interactive Accordion Books based on I Am poems by Barbara Liedahl

Chibi Chip Accordion book with copper tape and conductive fabric tape patches by Barbara Liedahl

Featured Project 3: Paper Circuit Mural

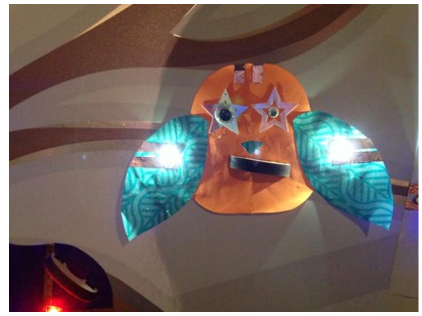
Overview: Create a collaborative large-scale paper circuit artwork in which students each contribute a smaller circuit, such as an LED circuit, that attaches to a larger background mural. The background mural has traces that are connected to power and optionally a Chibi Chip. When students attach their smaller circuit, it turns on and becomes part of the larger circuit.

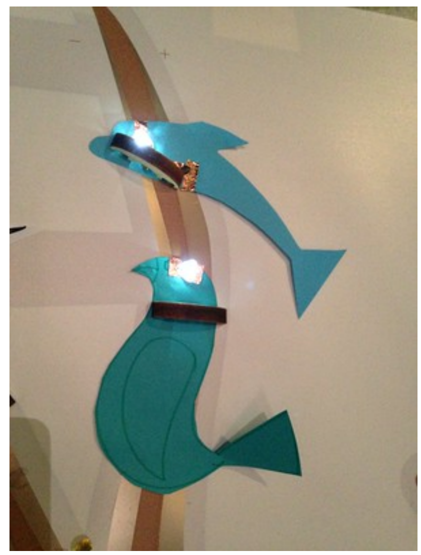
Theme Ideas

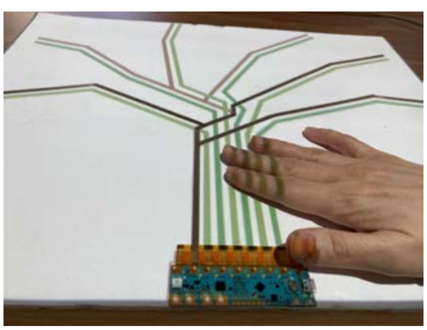
- Create a "Circuitree" where the background traces form the trunk and branches of a tree and students contribute leaves, flowers, fruit and anything else (real or imagined!) to fill out the branches
- Imagine a setting, such as outer space, under the sea, or a scene from a novel, and use circuitry to draw out this setting as a backdrop. Students contribute their small circuit elements, such as drawings, characters or words, to fill in the scene.
- Create a circuit timeline where each student contributes a light-up/interactive event for the timeline

Prior Knowledge: parallel LED circuits. *Optional:* any level of Chibi Chip programming.

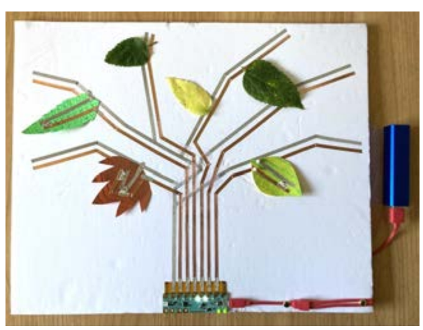
Teacher Preparation: You can prepare the traces ahead of time on a wall-mounted board such as foam core board or a sturdy sheet of paper, then show students how to add their individual circuits to the mural. In the example below, the traces create a tree, to which students can add their own individual glowing leaf designs.



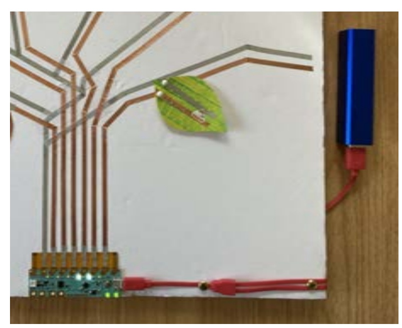




The circuit was created on a large piece of foam core board using a digital design and a projector to guide placement. The circuit can of course also be sketched out in pencil

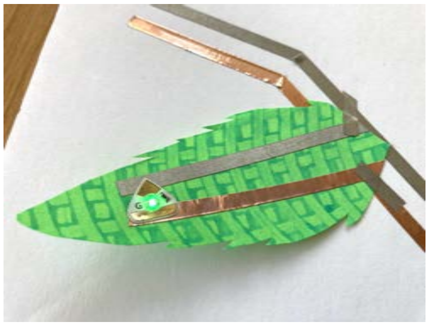


To help keep track of connections, conductive fabric tape was used for GND and copper tape for I/O pin traces. All are affixed to the Chibi Chip with conductive fabric tape

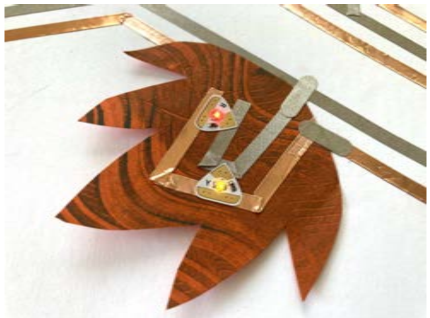


Chibi Chip circuits can be powered by rechargeable USB phone chargers. The cheap ones are better, they don't auto shut off when a low current draw is detected

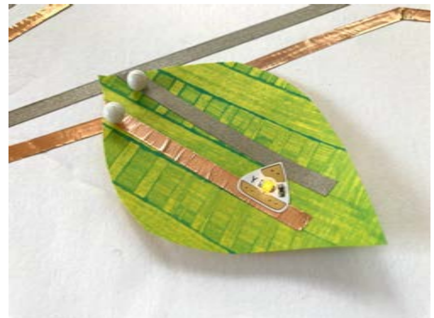
There are many ways for participants to attach their circuits to the mural! A few options:



Small pieces of conductive fabric tape placed on top connect corresponding traces



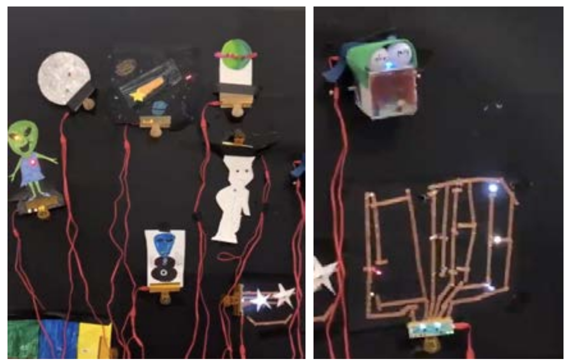
Conductive fabric tape patches (same material but pre-cut for ease of use)



Metal pushpins (the type in photo are called map pins) pressed through both traces

Inspiration

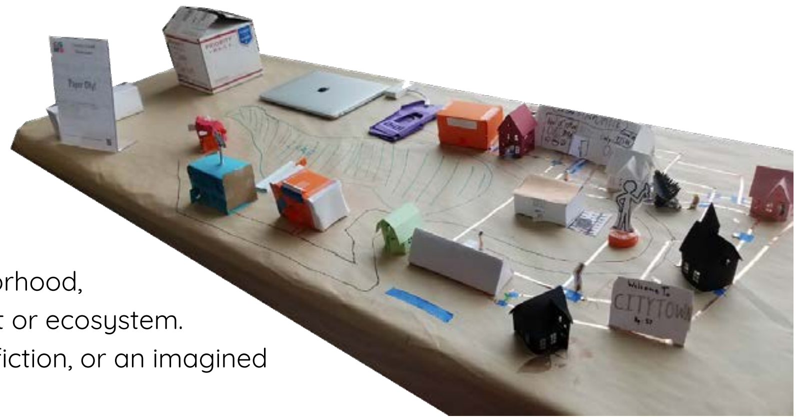
Wonderful Idea Co created an undersea-themed collaborative paper circuit mural at Maker Faire



Educator @MrsBissonSF and her students created an "intergalactic dance party" mural together!

Circuitree Mural from Making@Siggraph 2015 made with Chibitronics, Agic and Conductak

Featured Project 4: Paper City



Overview: Students work together to collaboratively design and build a "paper city," running power to buildings, signs, roads, and everything they need to showcase the story of the city.

Theme Ideas

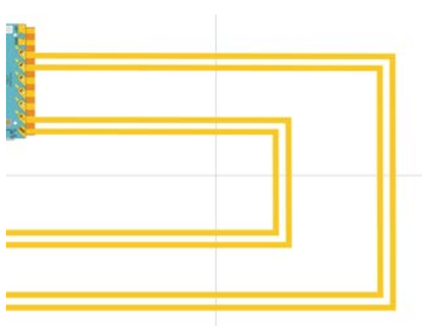
- A "paper city" can also be a neighborhood, a community, a natural environment or ecosystem. It can be a real place, a place from fiction, or an imagined future place.

- Some prompts and questions for paper city designs:
  - *What's the story behind your city?*
  - *What are the needs of the people in this city?*
  - *What makes it a good place to live? Ideal for whom and not ideal for whom else?*
  - *What conventions or rules make this city ideal?*
  - *What requires power, and what powers the city?*
  - *How does this city connect to the outside world?*

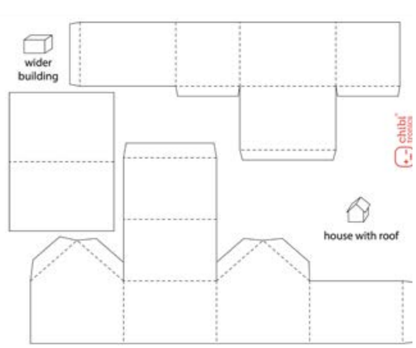
Prior Knowledge: parallel LED circuits. Optional: any level of Chibi Chip programming.

Resources

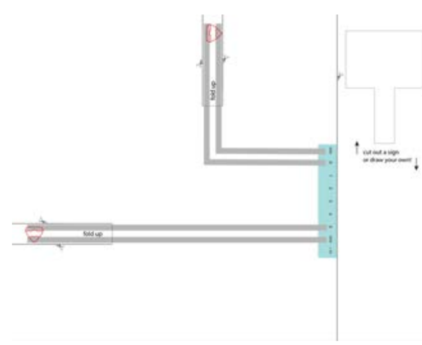
- Paper city cut & fold templates
- Presentation slides: Introducing...A Paper City!
- Signals & Signs Template



Print and cut out city "footprints" that students or teams can build separately, then reassemble to collaboratively build their city. Add more I/O pins as needed.



Print out these starting points for paper buildings, then cut and fold to make 3-dimensional shapes. Add windows, doors, cutouts, and extend the basic shapes.



Add pop-up signage that responds to events in the city. Ideas: a lamp post that shows weather forecasts, a sign that makes drivers happier when stuck in traffic jams, a park sculpture.

Inspiration

Students in a library makerspace co-designing their paper cities

Paper city programmed and powered by Chibi Chip I/O pins

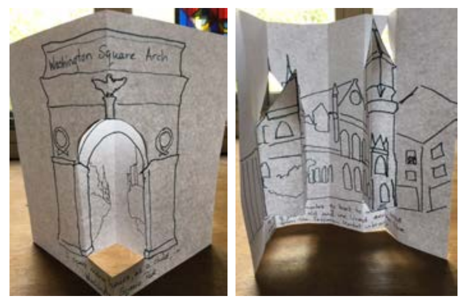
1900s Paper City with Chibi Chip by educator Holly Manswell, 2021

"New paper circuit experts add stars behind mountains, streetlights behind houses, lights inside houses, and luminescent sea creatures beyond the beach. Their lights are then controlled by a light sensor that turns lights on as the sun sets and the day becomes night. Fourth graders who had learned to create circuits the year before used a lesson or two from the Love to Code book, and began building a city where they could program lights, motors, microphones, and sensors." - Susan Brown

Paper cities created by educators:

Lance Newman

Taylor Peterson



Joanna Tankel

In the My Neighborhood Project in the Hack Your Notebook Series by NEXMAP, students create mini-notebooks with pops ups and paper circuits telling the stories of their neighborhoods and communities.

Featured Project 5: Data Art

Overview: Use paper circuits to create illuminated data visualizations or artistic ways to represent information. These can range in complexity from a single LED highlighting a point of interest on a map or graph, to multiple programmed LEDs and other outputs that respond to switch or sensor input.

Theme Ideas:

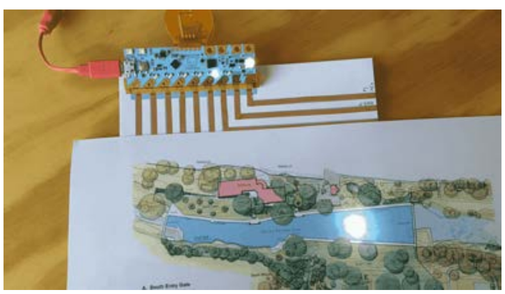
- Highlight points of interest on a map, such as a historical map, a local area map, or a map of students' communities. To make the visualization interactive, add one or more switches to reveal different information when each is pressed.
- Use an LED fading in or fading out at periodic intervals to show the frequency of an event in the world that impacts students.
- Collect data from students' school or home communities using a survey created by students. Students then design data art pieces to help tell the story of what they learned

Prior Knowledge: parallel circuits, switches, optionally Chibi Chip programming

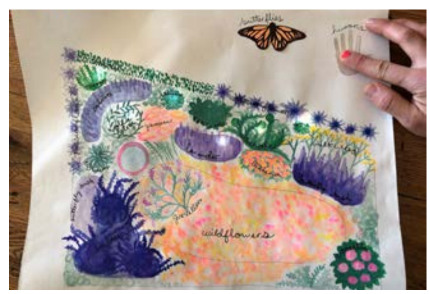
Resources

- Open Data, Open Minds Project from NEXMAP
- Mapping and Data Visualization with Paper Circuits from Wonderful Idea Co.
- WWII Circuit Map by Jacquelyn Nickey

Inspiration

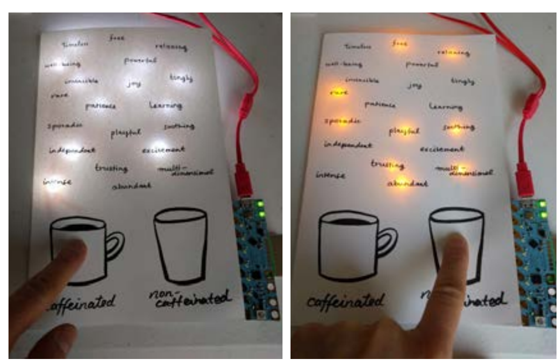


LEDs under a local map show the speed of water flow as it changes over the course of a season. Natalie Freed with NEXMAP Open Data, Open Minds



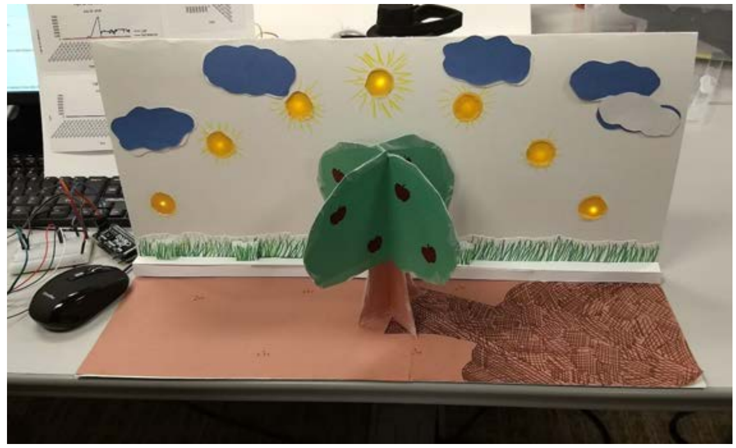
Garden Map showing butterfly and human routes by Nicole Catrett of Wonderful Idea Co.

WWII Circuit Map by Jacquelyn Nickey

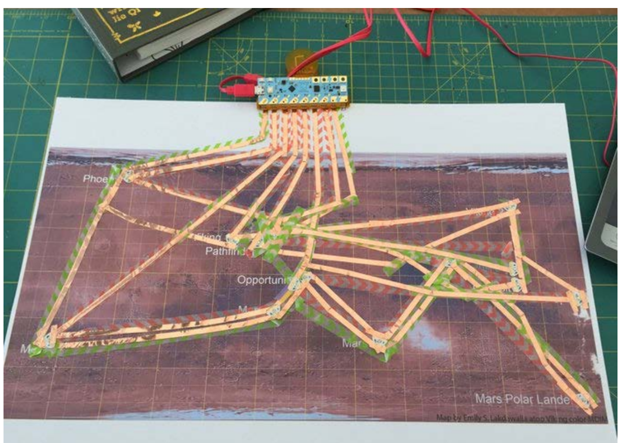


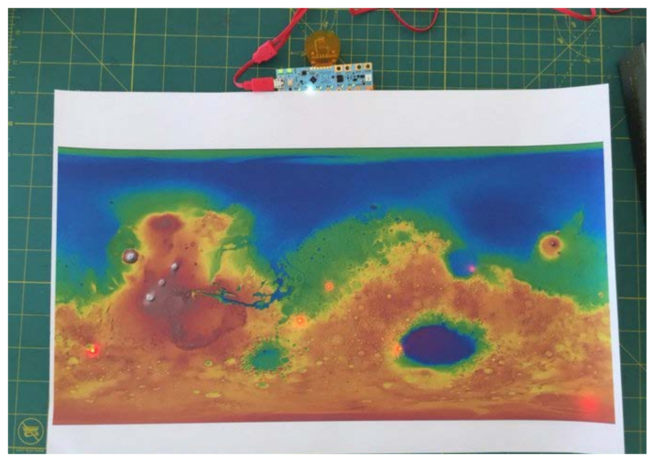
"Your Creative Place" survey visualization, Natalie Freed with NEXMAP Open Data, Open Minds

Students in the summer *Code at TACC* program at the Texas Advanced Computing Center learned to place sensors in nature to record environmental conditions, then built paper circuit dioramas to help tell the story of their data as they gave their project presentations.



Corinne Okada Takara used multiple pins on the Chibi Chip to map Mars lander attempts ("blue for future attempts, red for fails, white for successes").





10th grade students in the Rhode Island Nurses Institute Middle College High School Program created paper circuit visualizations alongside Tableau workbooks to showcase investigations of health care data.

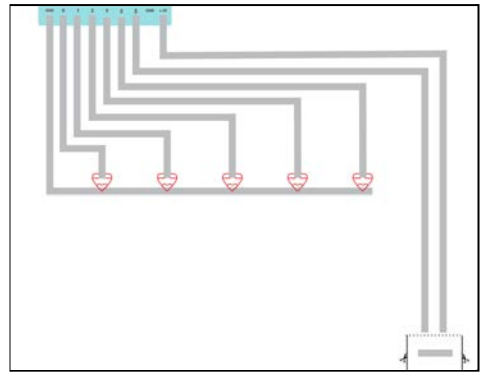
"Calculations and decisions about how to contextualize information so it could be read in an output and interaction on paper – a blinking LED and a switch, say – turned into useful exercises at reverse engineering a kind of word problem.

How shall I use a light to render a mortality rate for a given region? What's my blink rate for what period of time? What's the division and arithmetic I need to get a number and an output that's meaningful?'"

-*Civic Switchboard Case Study*

Featured Project 6: Binary Counter

Overview: Build a personalized "binary counter" using 5 LEDs to represent a 5-bit binary number. The LEDs represent either an off (0) or on (1) state. A paper circuit switch increments the binary number by 1 each time it is pressed.

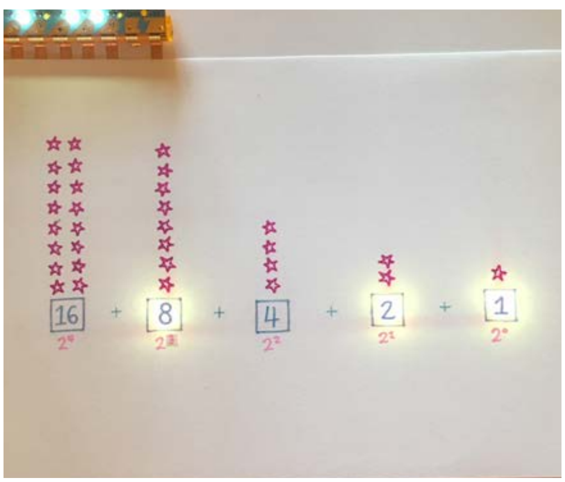


Template (for students to customize!)

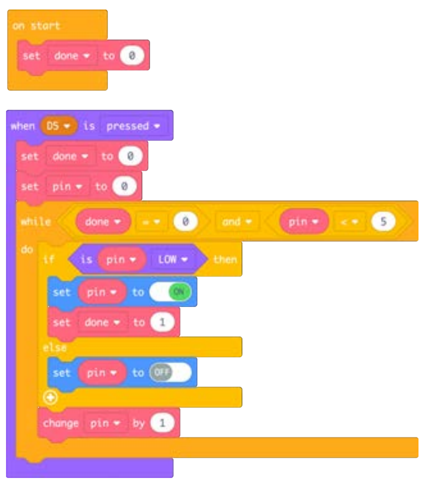
Theme Ideas:

- Create a counter to measure something important to you, such as the habit tracker featured below. Create a display of your own design.
- Hide a message in art. Design a circuit and overlay to disguise a secret number in an art piece. The LEDs can be placed anywhere on the design. Create a guide explaining how to decode it.
- Create binary birthday cakes with 5 candles that can be either on or off, displaying the age in binary. Students could make birthday cakes for a historical figure or a person who is important to them.

Prior Knowledge: LTC Lessons 1 through 7 (copper tape and LED circuits, simple switches, programming multiple LEDs, loops, conditionals, variable). Or LTC lessons 1-3, then jump in using the example code below. Before the circuit building, go over how binary numbers work, and practice translating numbers from binary to decimal and back. You can also discuss what happens when binary numbers overflow.



Binary counter project showing binary 01011, which is the number 11 in decimal



Starting point code

Binary "30 day habit tracker" by Kathy Tran

Resources:

- Example code using Microsoft MakeCode
- Printable template
- Binary Numbers at CS Unplugged
- Binary Piano: a nifty printable for learning to work with binary numbers

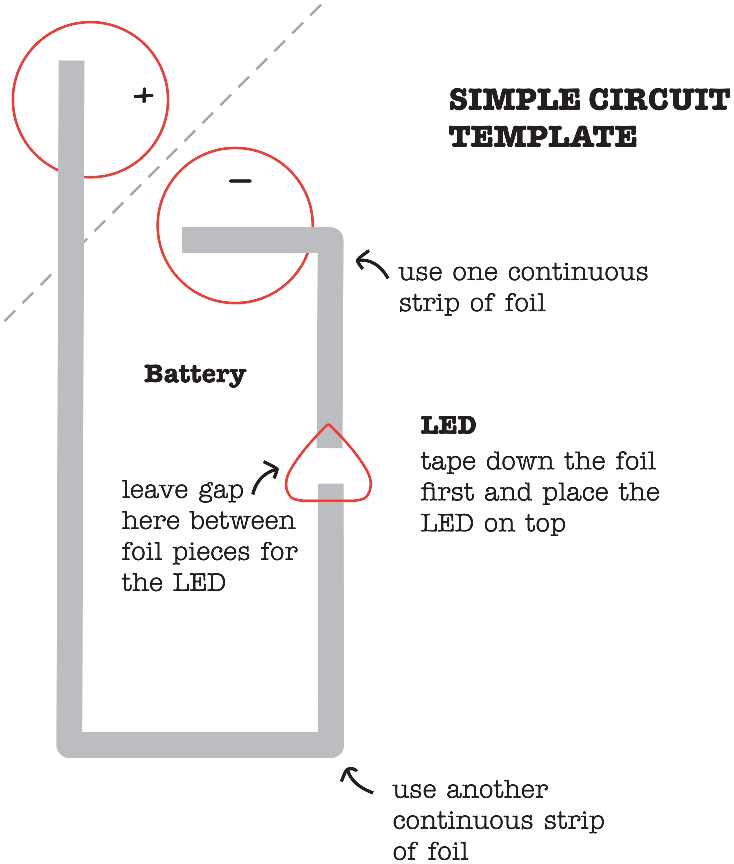
Appendix A: Sample Rubric

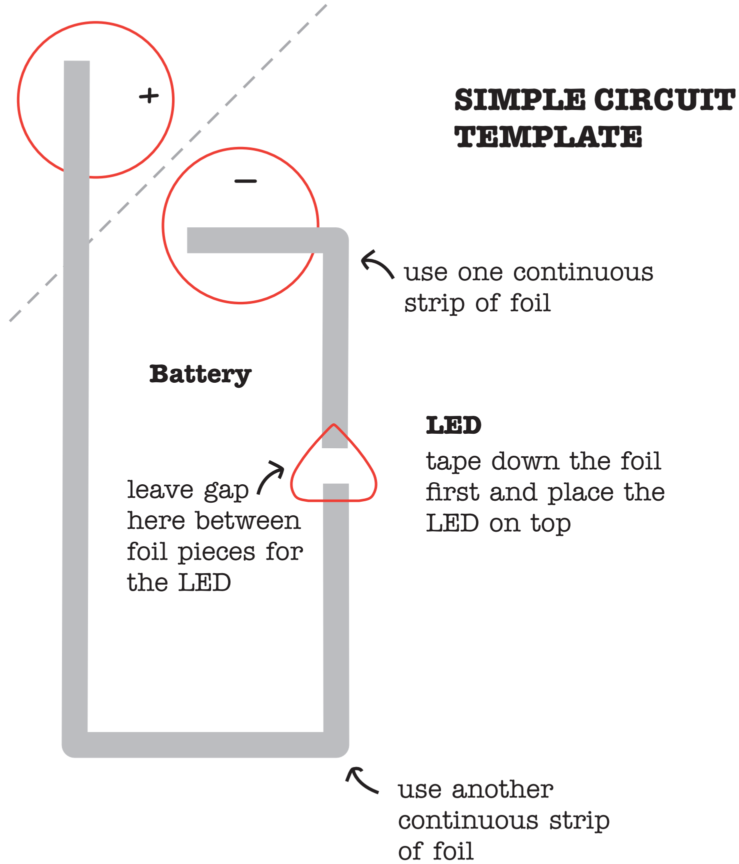
This sample rubric can be adapted for use in different projects. Consider: what are your goals for the lesson, and what are you hoping to assess?

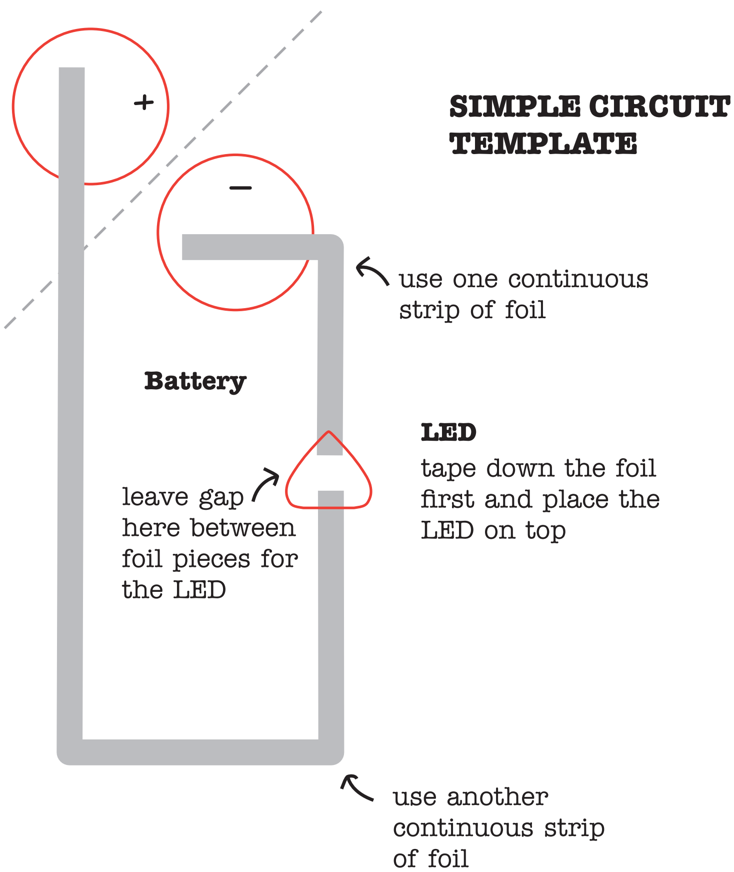
	Exemplary	Proficient	Emerging
Circuit Design and Building	Circuit functions consistently and incorporates multiple LEDs and a switch. Circuit differs from template examples, demonstrating understanding of circuit design concepts.	Circuit functions all or most of the time. Circuit incorporates a switch. Circuit does not differ significantly from template examples.	Circuit does not work or works inconsistently. Circuit does not incorporate a switch.
Project Reflection & Engineering Design Process 5 steps of the engineering design process: understand the need, brainstorm and design, plan, create, and improve.	In project planning worksheet, project construction, and final reflection (verbally answered questions), students engage in each of the 5 steps of the engineering design process.	Most or all of the steps are present, but may be missing some depth.	Missing some steps of the process, such as not considering multiple ideas in brainstorming step.
Creative / artistic elements of project	Project construction shows attention to detail and craftsmanship. Design contains expressive elements and evidence of originality. Form is clearly connected to function.	Project construction shows some attention to detail. Design contains some expressive elements, but they do not appear clearly connected to the function of the design.	Project construction is messy or poorly executed. Design is lacking in originality.

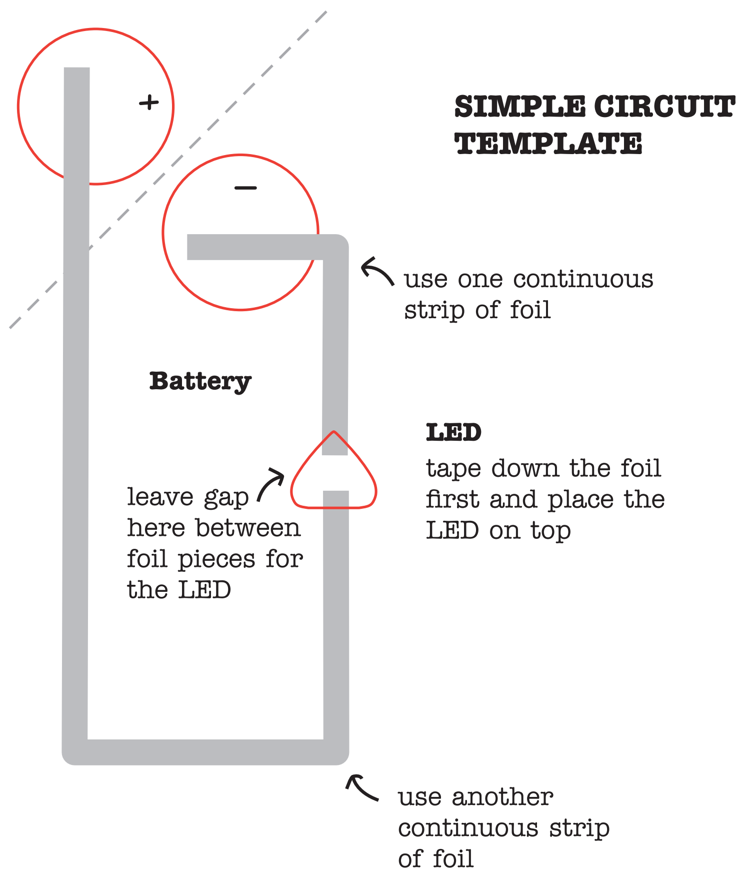
Appendix B: Printable Templates

This section contains the core printable templates for each lesson activity. Templates are arranged in the order that they appear in this guide. We hope you and your students enjoy these activities!

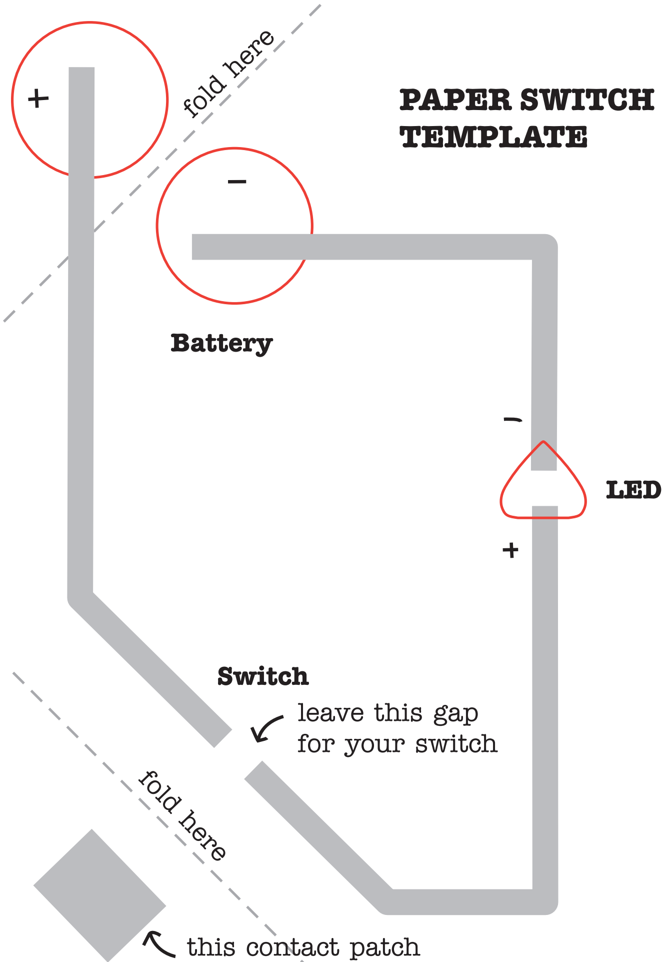

SIMPLE CIRCUIT TEMPLATE
+
–
use one continuous strip of foil
Battery
LED
tape down the foil first and place the LED on top
leave gap here between foil pieces for the LED
use another continuous strip of foil


SIMPLE CIRCUIT TEMPLATE
+
–
use one continuous strip of foil
Battery
LED
tape down the foil first and place the LED on top
leave gap here between foil pieces for the LED
use another continuous strip of foil

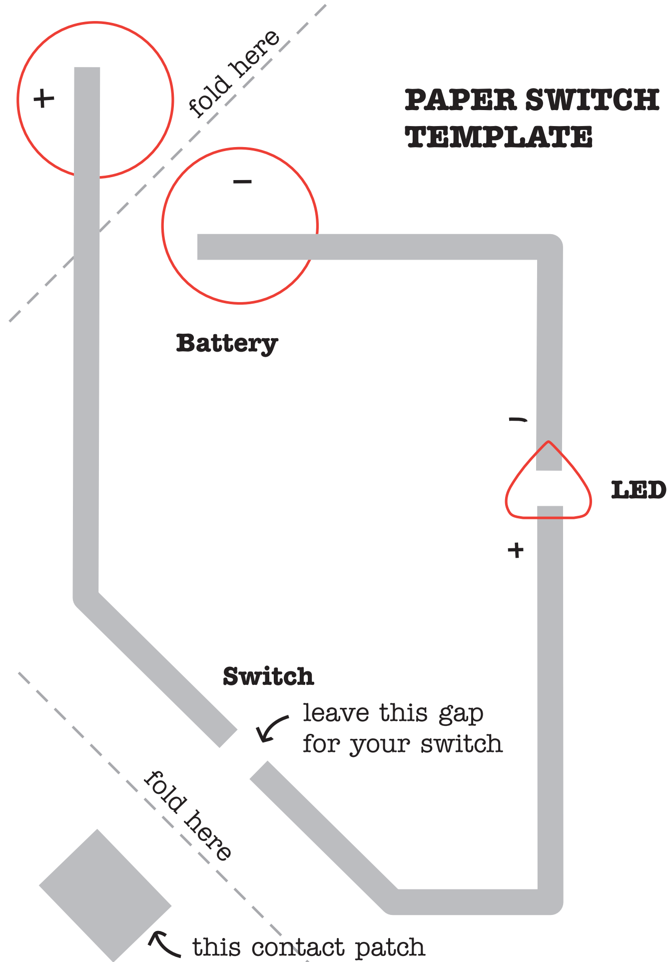

SIMPLE CIRCUIT TEMPLATE
+
–
use one continuous strip of foil
Battery
LED
tape down the foil first and place the LED on top
leave gap here between foil pieces for the LED
use another continuous strip of foil


SIMPLE CIRCUIT TEMPLATE
+
–
use one continuous strip of foil
Battery
LED
tape down the foil first and place the LED on top
leave gap here between foil pieces for the LED
use another continuous strip of foil

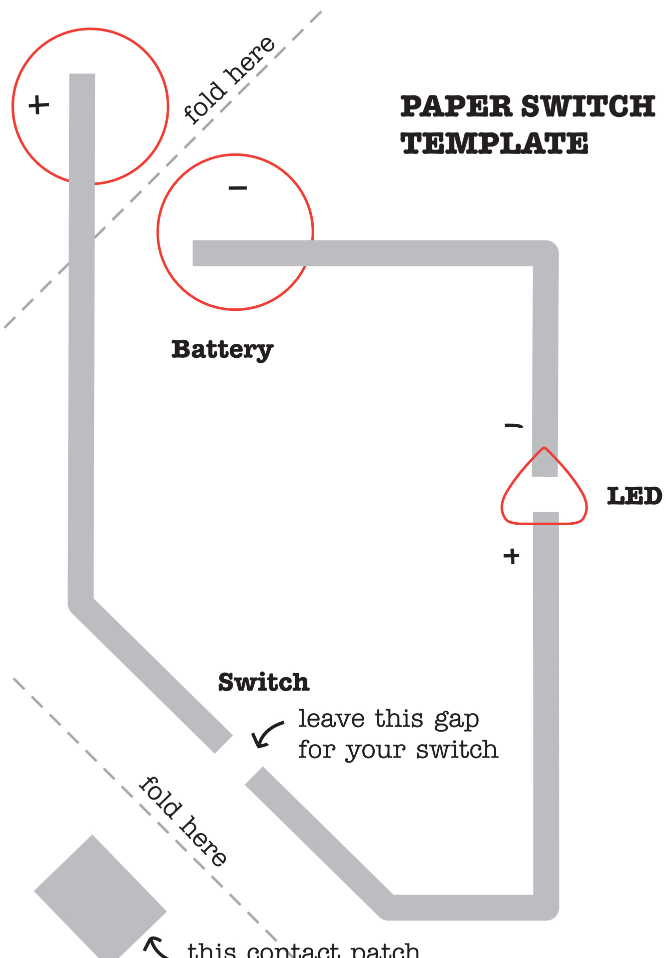
PAPER SWITCH TEMPLATE



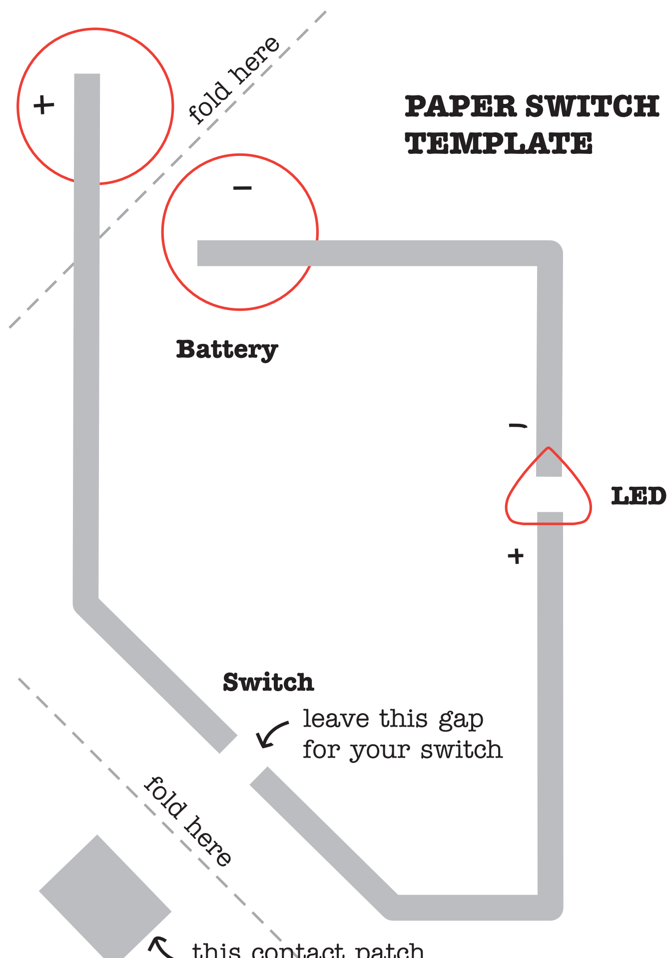
PAPER SWITCH TEMPLATE



PAPER SWITCH TEMPLATE

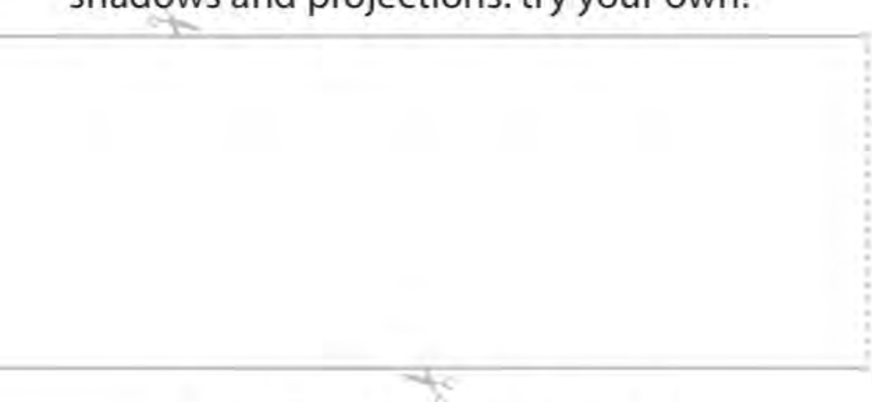


PAPER SWITCH TEMPLATE



shadows: fold up, hold LED over cutouts

shadows and projections: try your own!



try some shapes or letters!

pencil (top)
pen (bottom)

white text weight
paper cutout

white cardstock
paper cutout

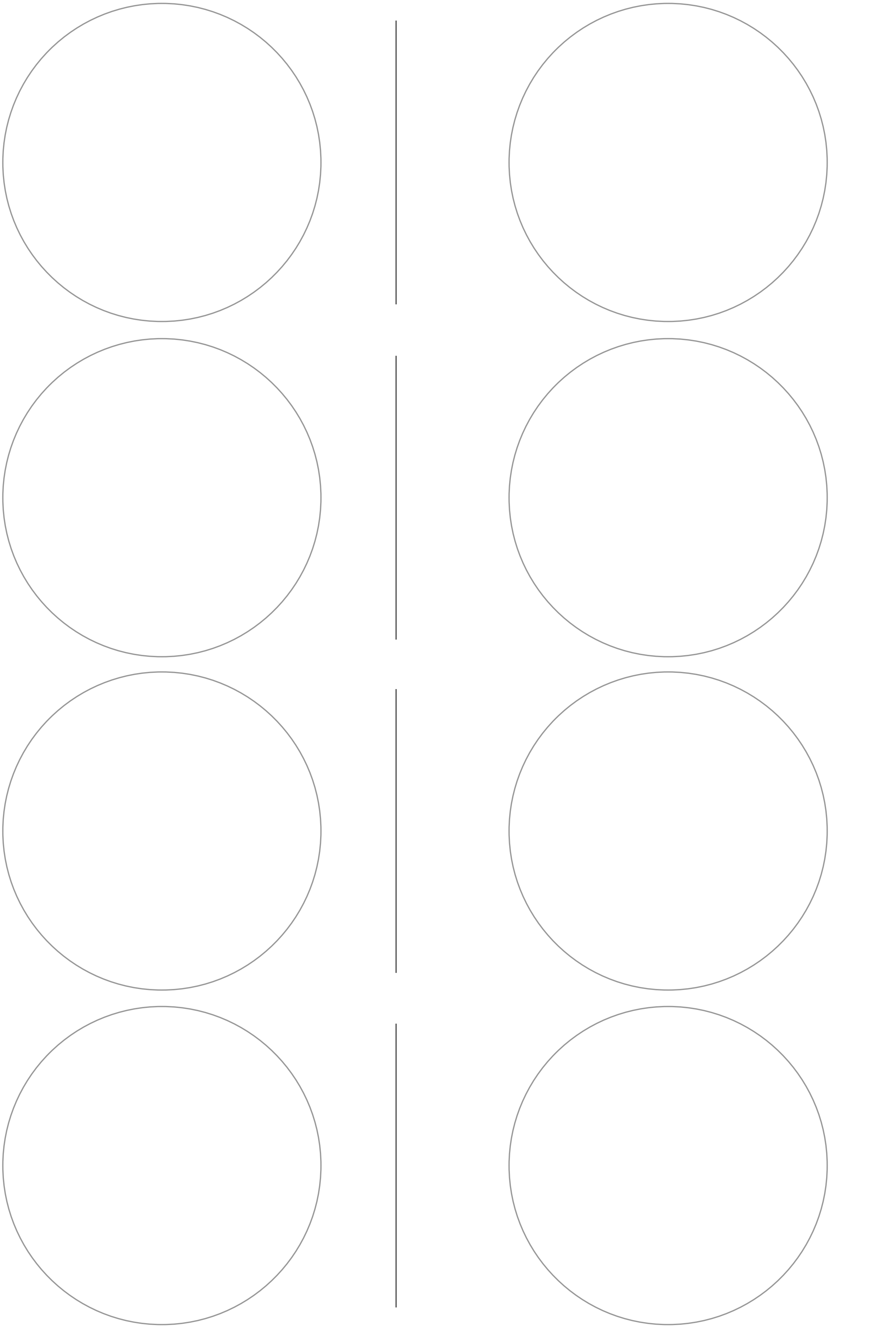
dark paper cutout

colored tissue paper

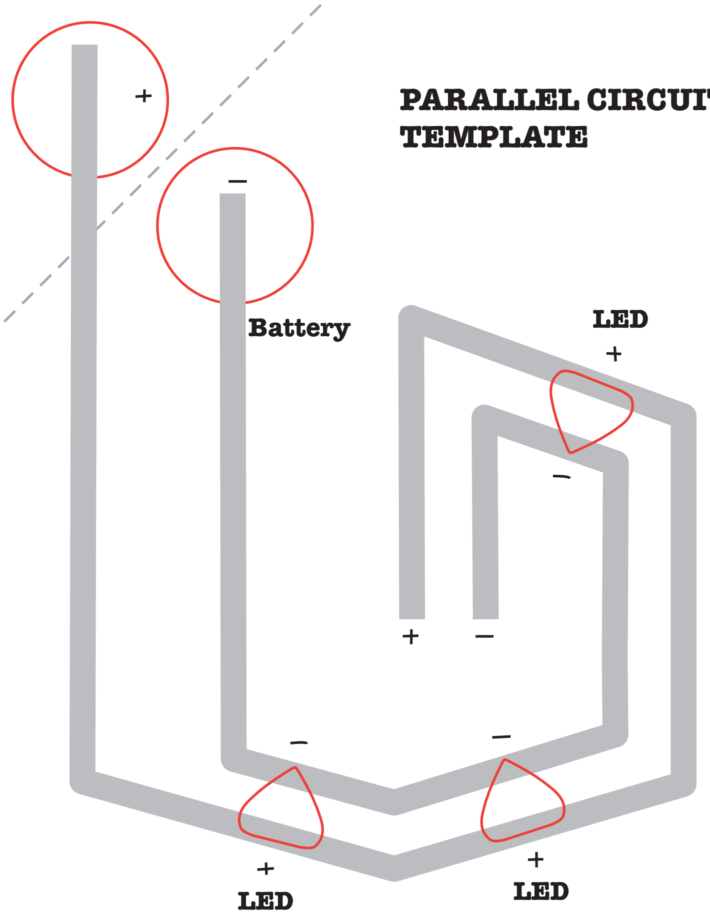
colored tissue paper
with cardstock

transparency plastic
with Sharpie marker

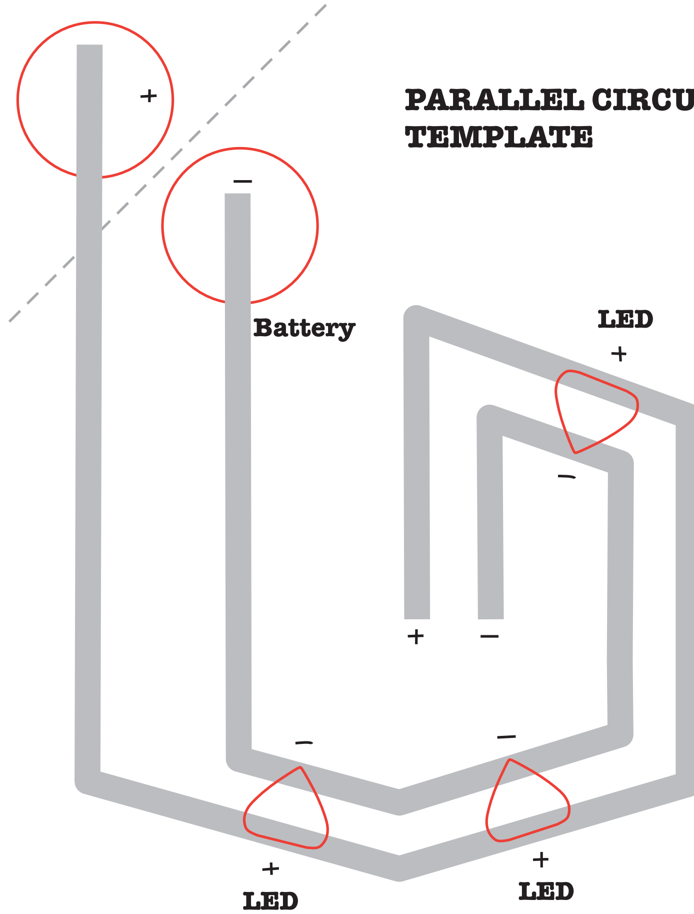
transparency plastic,
Sharpie, & cardstock



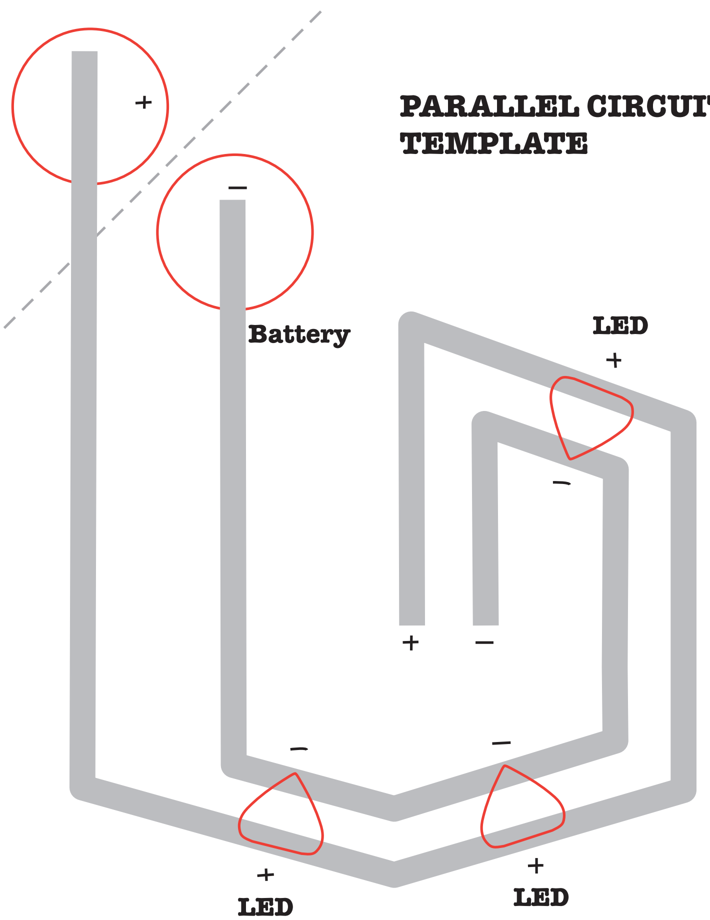
PARALLEL CIRCUIT TEMPLATE



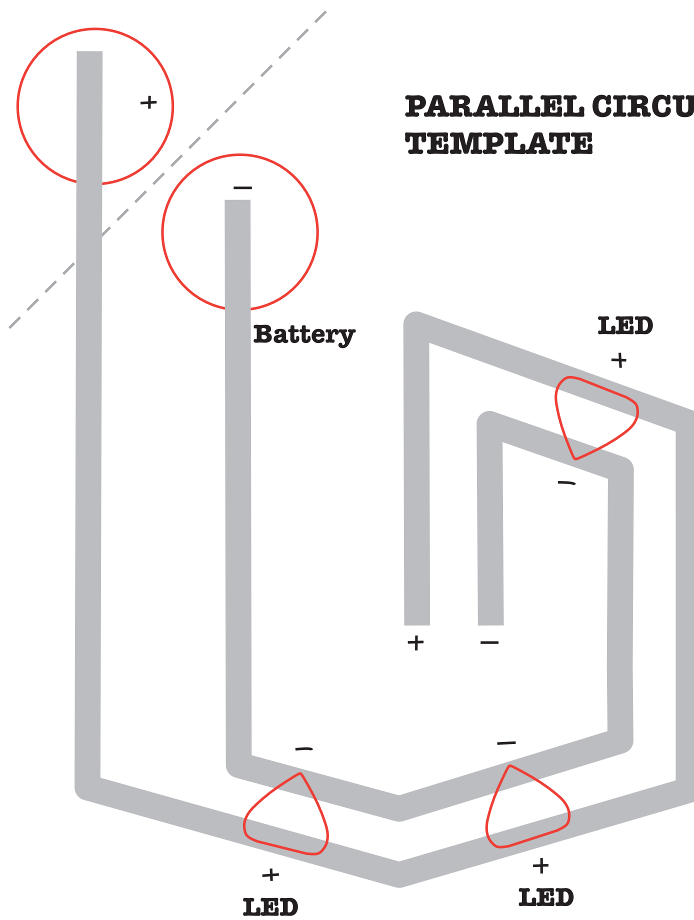
PARALLEL CIRCUIT TEMPLATE

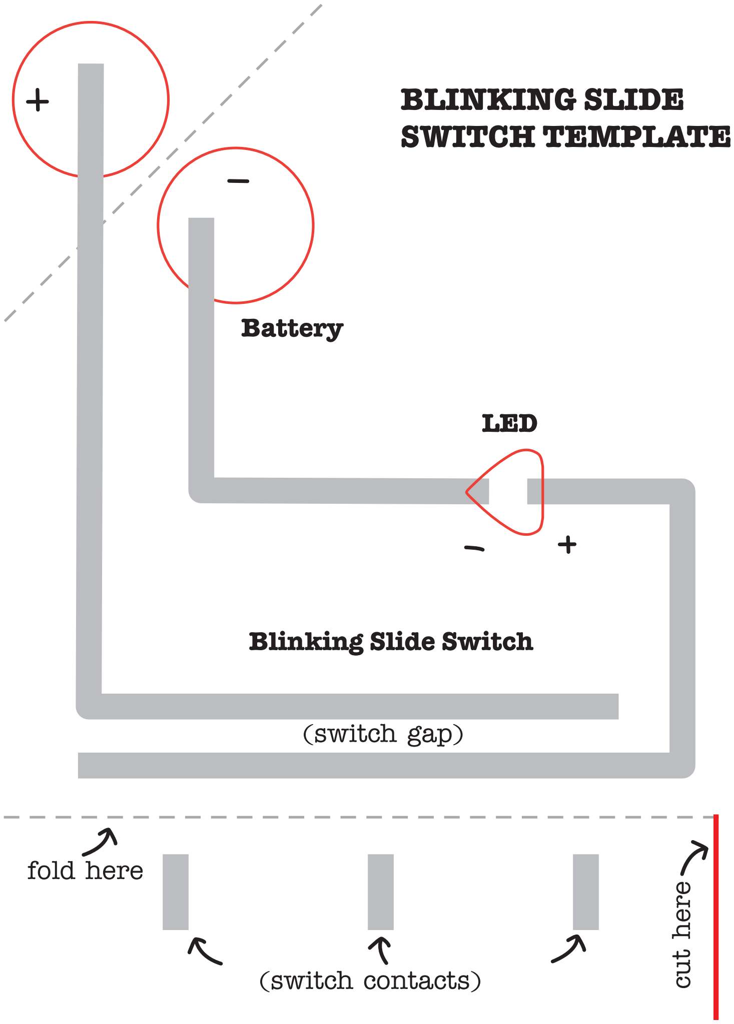


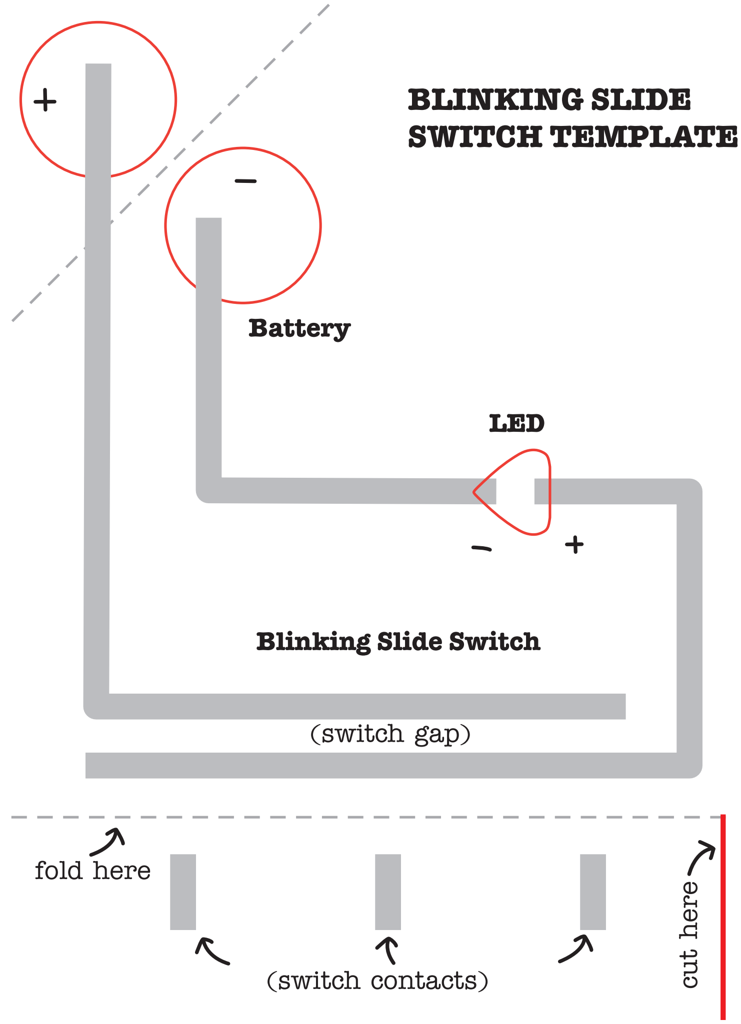
PARALLEL CIRCUIT TEMPLATE

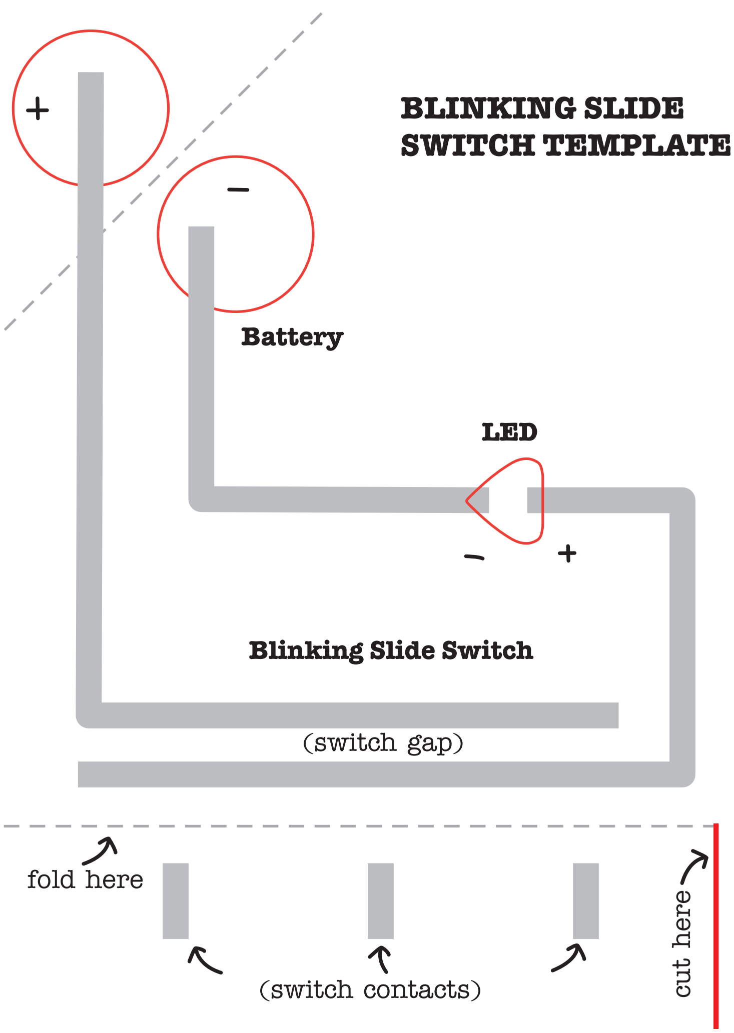


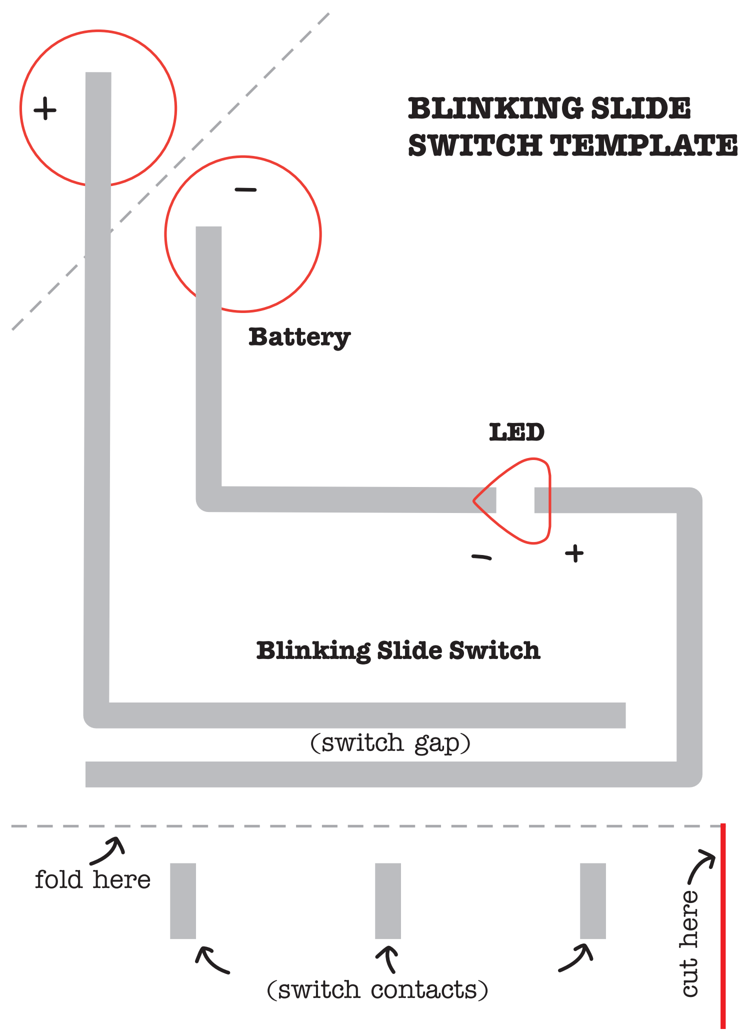
PARALLEL CIRCUIT TEMPLATE




BLINKING SLIDE SWITCH TEMPLATE
+
–
Battery
LED
–
+
Blinking Slide Switch
(switch gap)
fold here
cut here
(switch contacts)


BLINKING SLIDE SWITCH TEMPLATE
+
–
Battery
LED
–
+
Blinking Slide Switch
(switch gap)
fold here
cut here
(switch contacts)

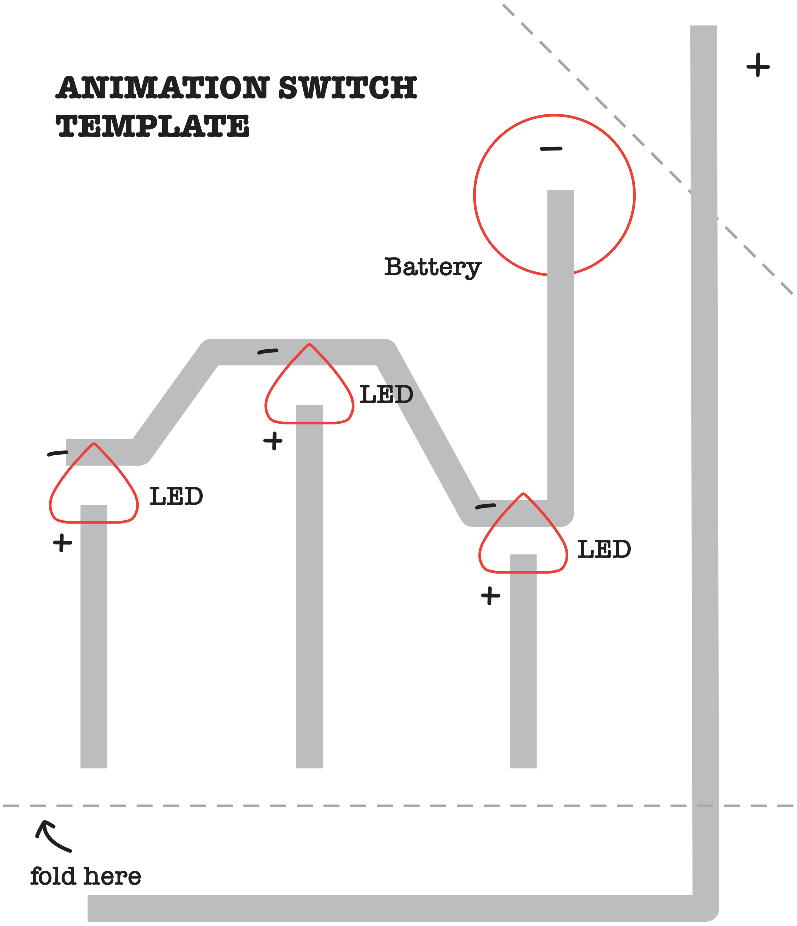

BLINKING SLIDE SWITCH TEMPLATE
+
–
Battery
LED
–
+
Blinking Slide Switch
(switch gap)
fold here
cut here
(switch contacts)


BLINKING SLIDE SWITCH TEMPLATE
+
–
Battery
LED
–
+
Blinking Slide Switch
(switch gap)
fold here
cut here
(switch contacts)

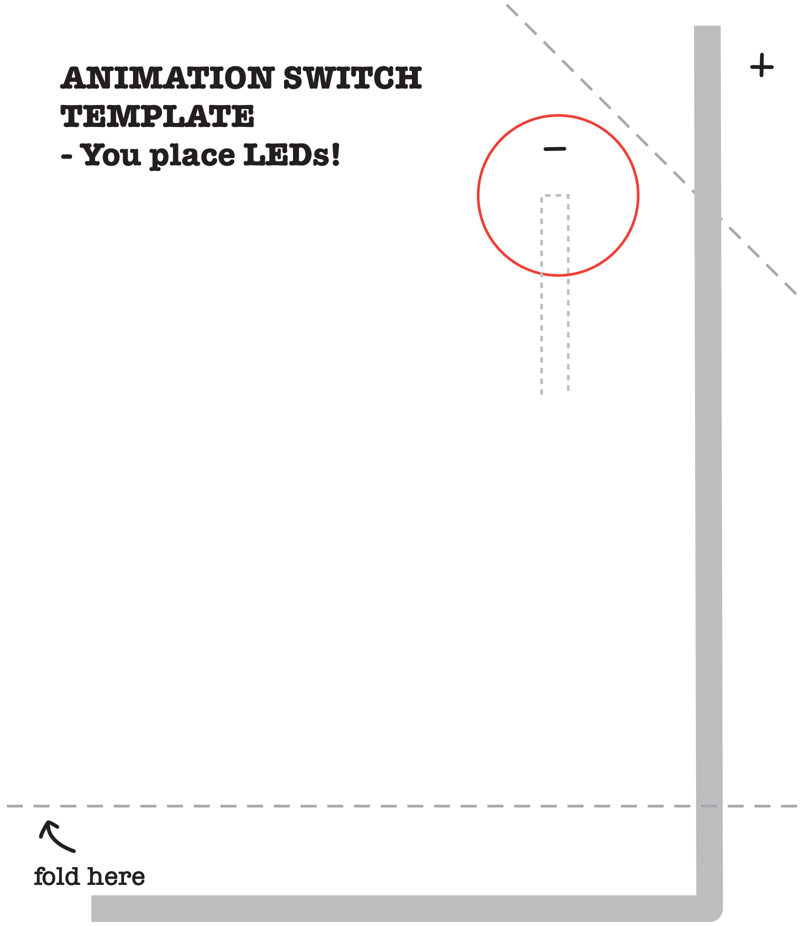
BLINKING SLIDE SWITCH TEMPLATE (WIDE)

Switch contacts: use conductive tape to create a sequence of ON/OFF blinks that will “play” as you run your finger across the page.
Tip: glue or tape a rectangle of cardstock here to slightly separate the two sides of the card when your finger is not pressing.

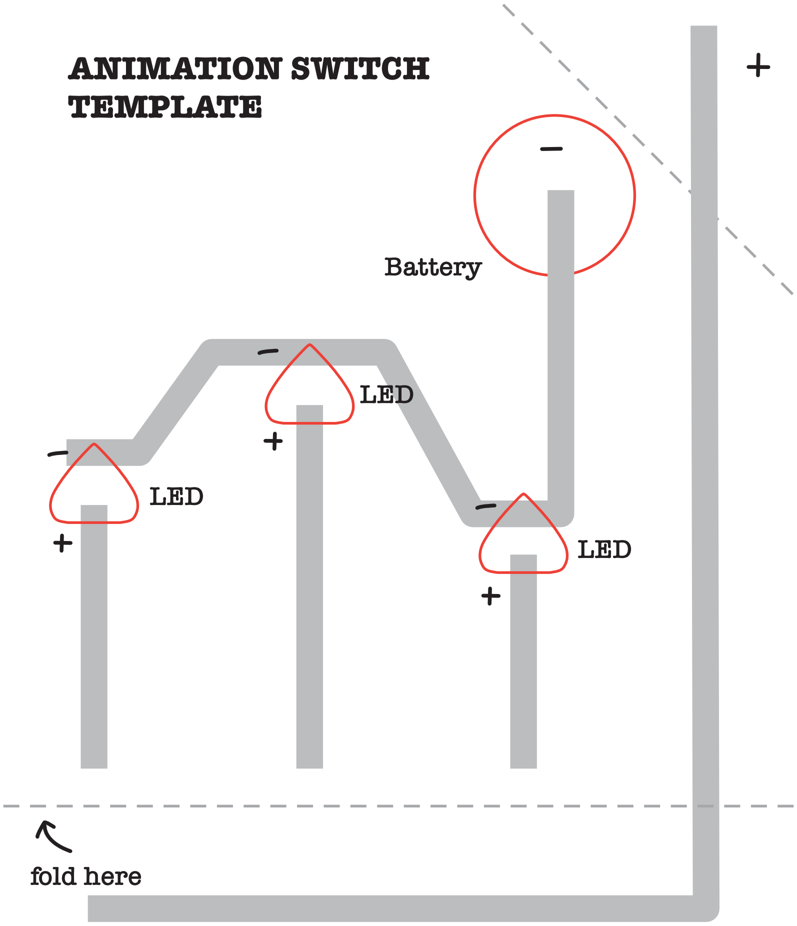
ANIMATION SWITCH TEMPLATE



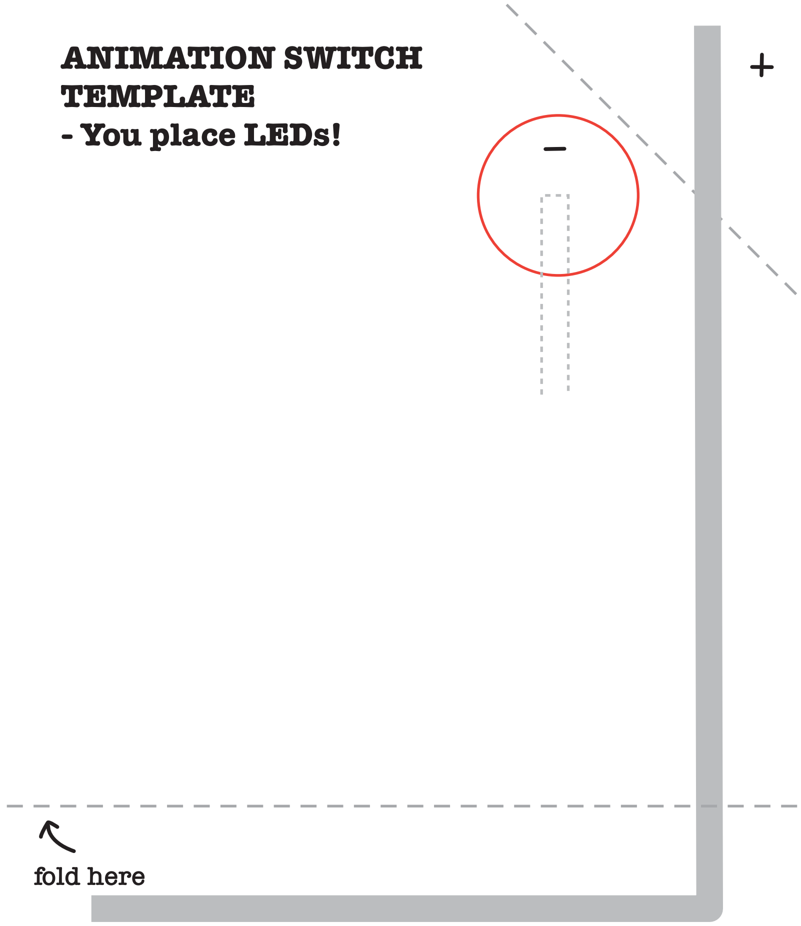
ANIMATION SWITCH TEMPLATE - You place LEDs!



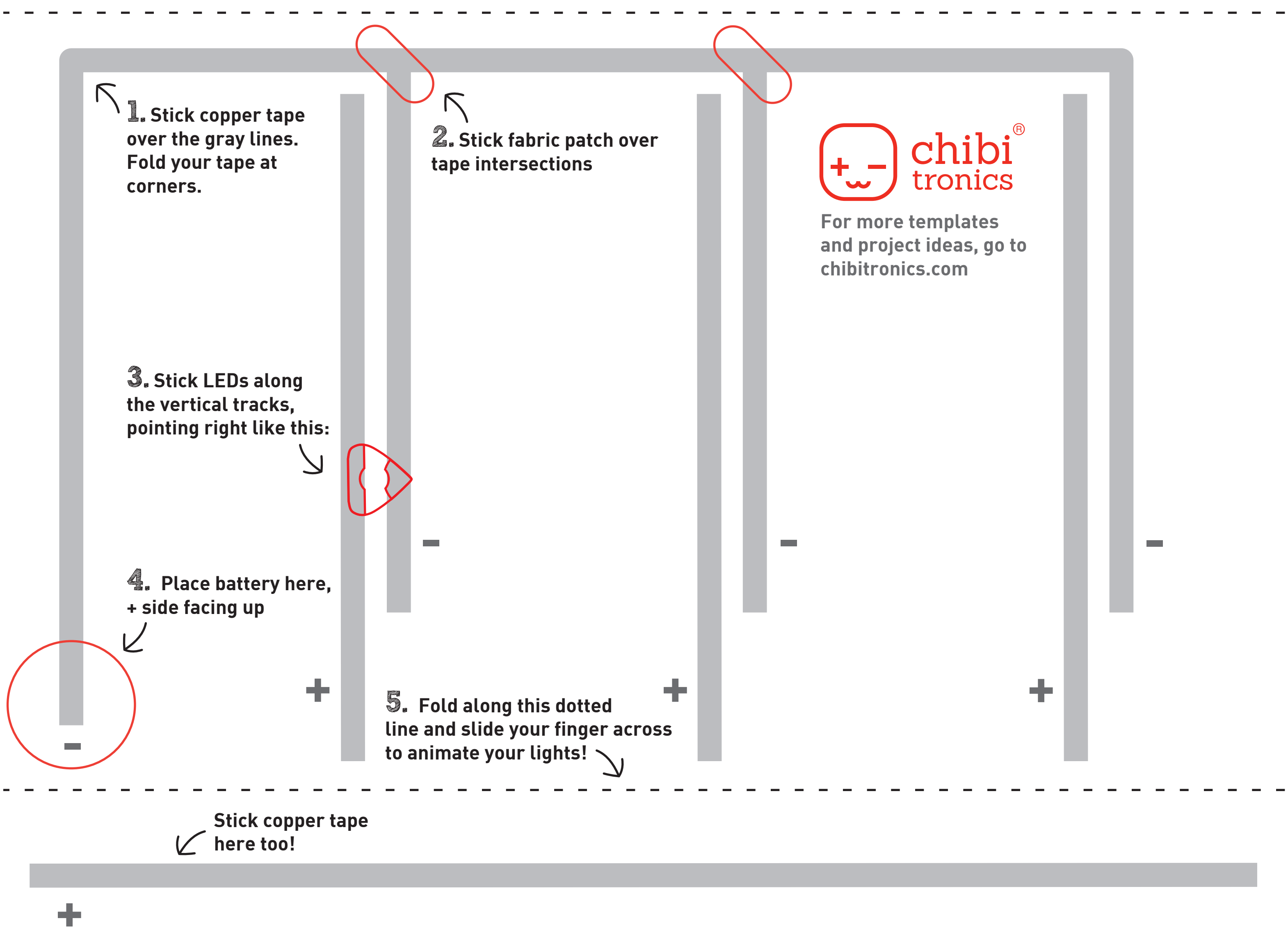
ANIMATION SWITCH TEMPLATE



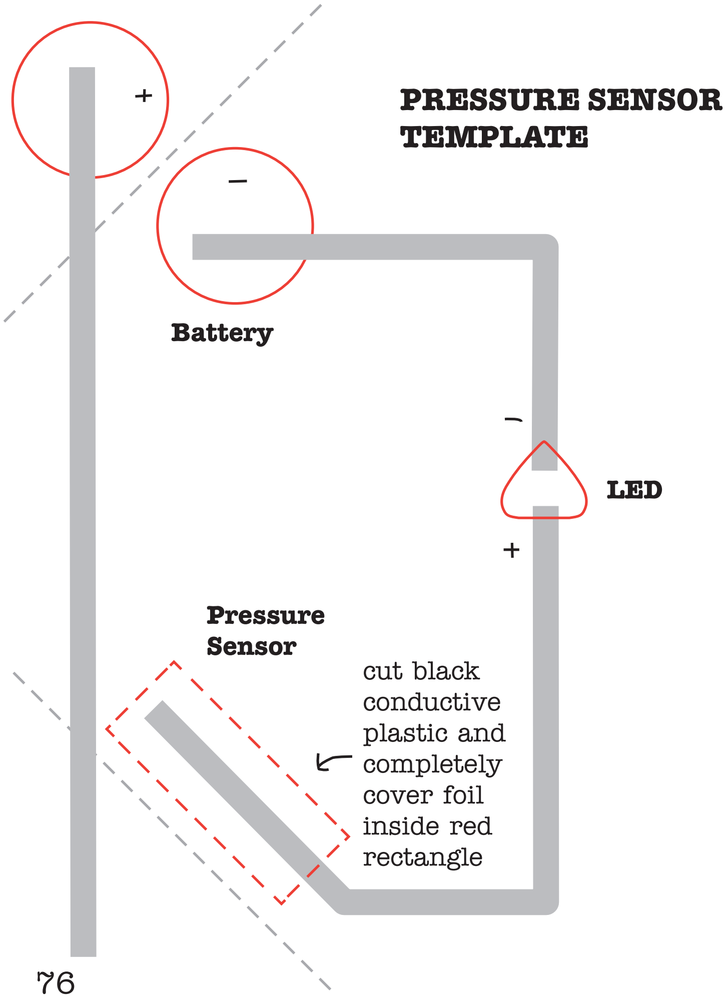
ANIMATION SWITCH TEMPLATE - You place LEDs!



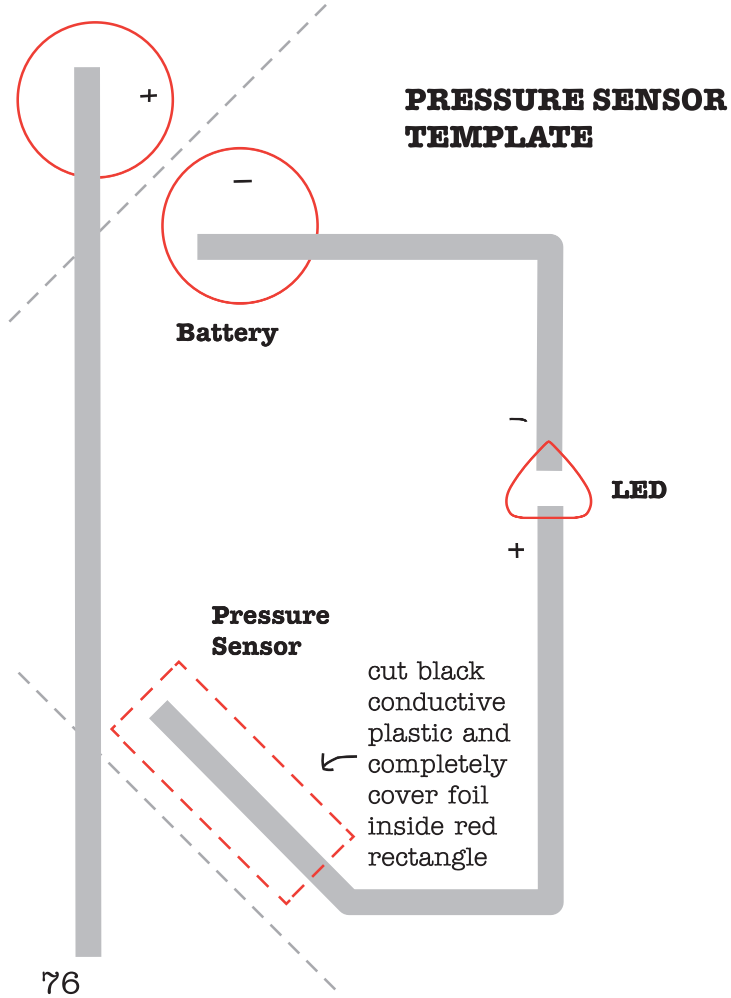
ANIMATING SWITCH TEMPLATE (WIDE)



PRESSURE SENSOR TEMPLATE



PRESSURE SENSOR TEMPLATE



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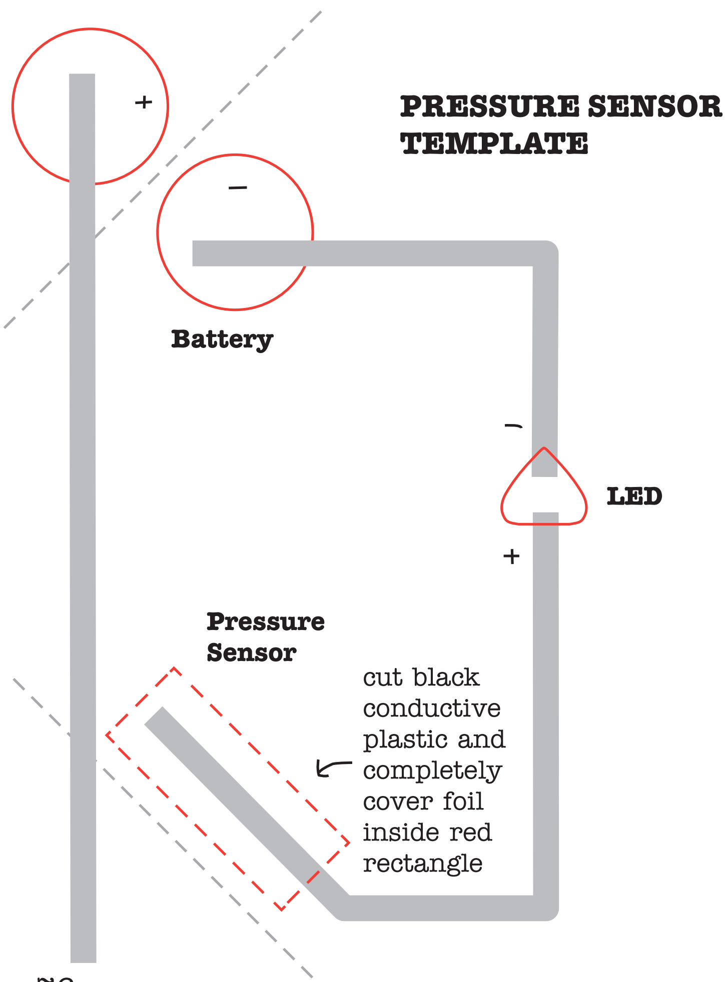
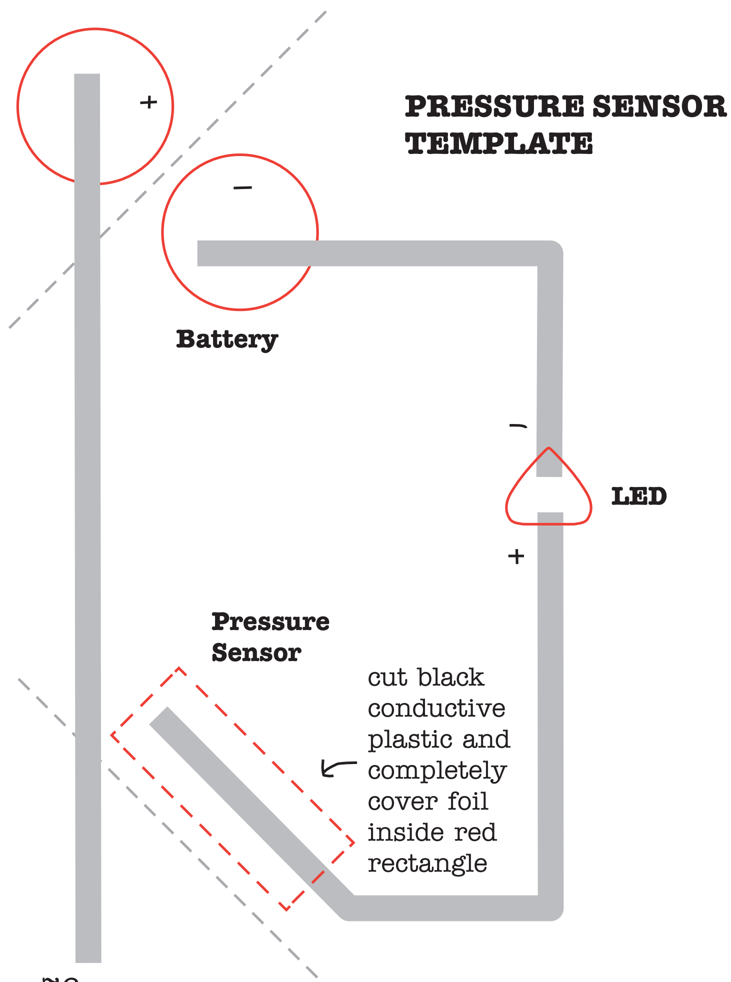
PRESSURE SENSOR TEMPLATE



76

PRESSURE SENSOR TEMPLATE



76

Story Starter

Write a story starter for another team.

Who **is in the scene?**

A ________________(adjective) ________________________ (identity)

and a ________________(adjective) ________________________ (identity)

Examples: *a grumpy pirate and a tired toddler. A curious librarian and a tall detective.*

What **is in the scene?**

A ________________(adjective) ________________________ (object)

and a ________________(adjective) ________________________ (light source)

Examples: *a damp shoe and a flickering neon light. A wobbly shelf and a cloudy moon.*

Illustration

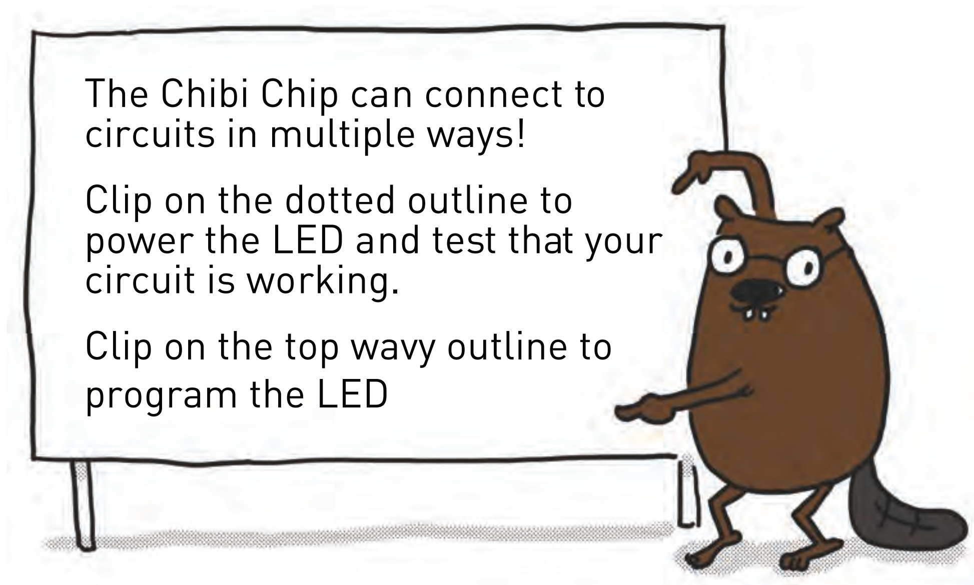
Show us the scene! Use drawings and your programmable light to show us what is happening to your characters. Lay this page over your circuit page and illustrate it below:

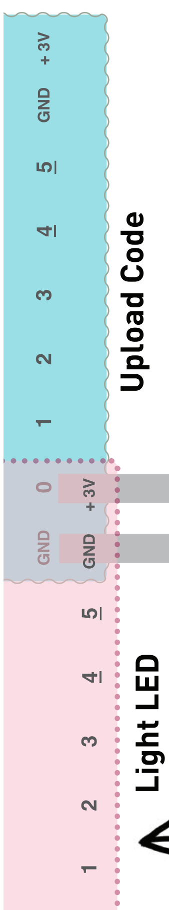
Your Story

Tell us the story! Questions to think about: what happened to bring these characters together? What do the objects tell us about the scene?

Light an LED!

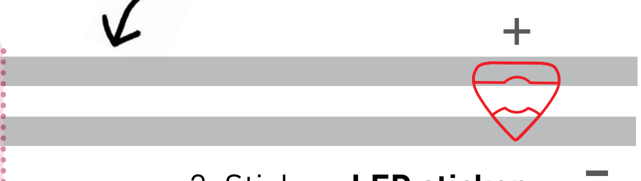
First, follow the directions below to build an electronic circuit using copper tape and an LED sticker. To test your circuit, clip the Chibi Chip onto the pink outline below. This will power the LED so you can make sure your circuit is working. Once you see your LED turn on, go to the next page to learn to program it.





1. Plug the Chibi Chip into a **power source**, so that the green PWR light comes on.

2. Stick **copper tape** over each of these gray lines.



3. Stick an **LED sticker** over the triangle footprint.

4. Align and **clip the Chibi Chip** to the page over this **dotted outline**
Make sure the metal pads of the clip touch your circuit.

5. Bask in the soft glow of the LED!

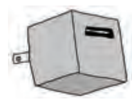
Turn on a light!

In this activity we will power up our Chibi Chip and use it to light up an LED sticker!

We will need:

Chibi Light LED sticker

copper tape



USB power
(Chibi Book, laptop or wall plug)

Chibi Chip

USB cable

1. Stick copper tape over each of these gray lines.

2. Stick an LED sticker over the triangle footprint.

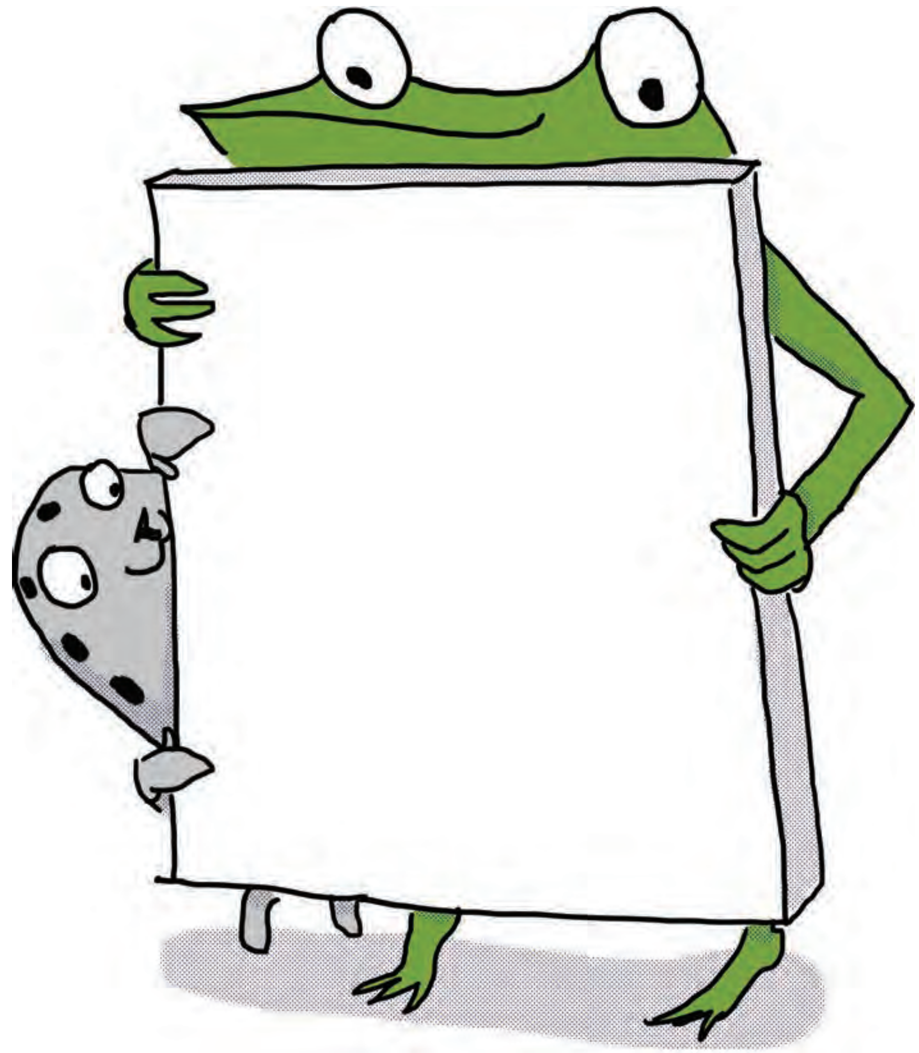
3. Plug the Chibi Chip into a power source, so that the green PWR light comes on.

4. Align and clip the Chibi Chip to the page over this rectangle. Make sure the metal pads of the clip touch your circuit.

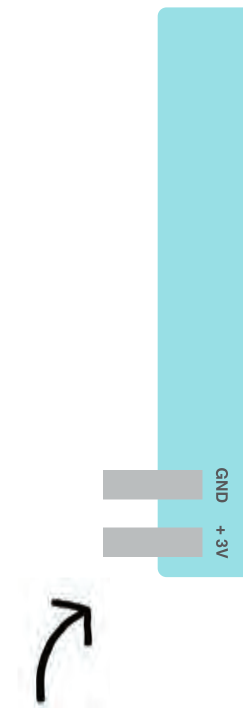
5. Bask in the soft white glow of the LED!

"You can see the LED's light through the paper!" exclaimed Sami. "Fern, let's draw something around the light."

What should Fern draw?



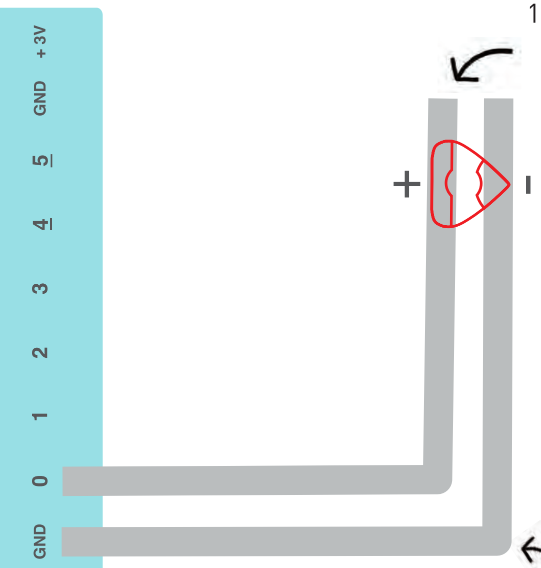
Design your own circuit on this page!



Start your circuit here, so you can clip on a Chibi Chip after you're finished!

Program this circuit

We can use a program to control a circuit of our own design. Try it with this template!



1. Stick copper tape on the gray lines. Remember to fold the tape at the turns!

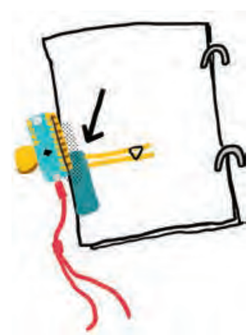
2. Stick down a LED.

3. Clip on a Chibi Chip.

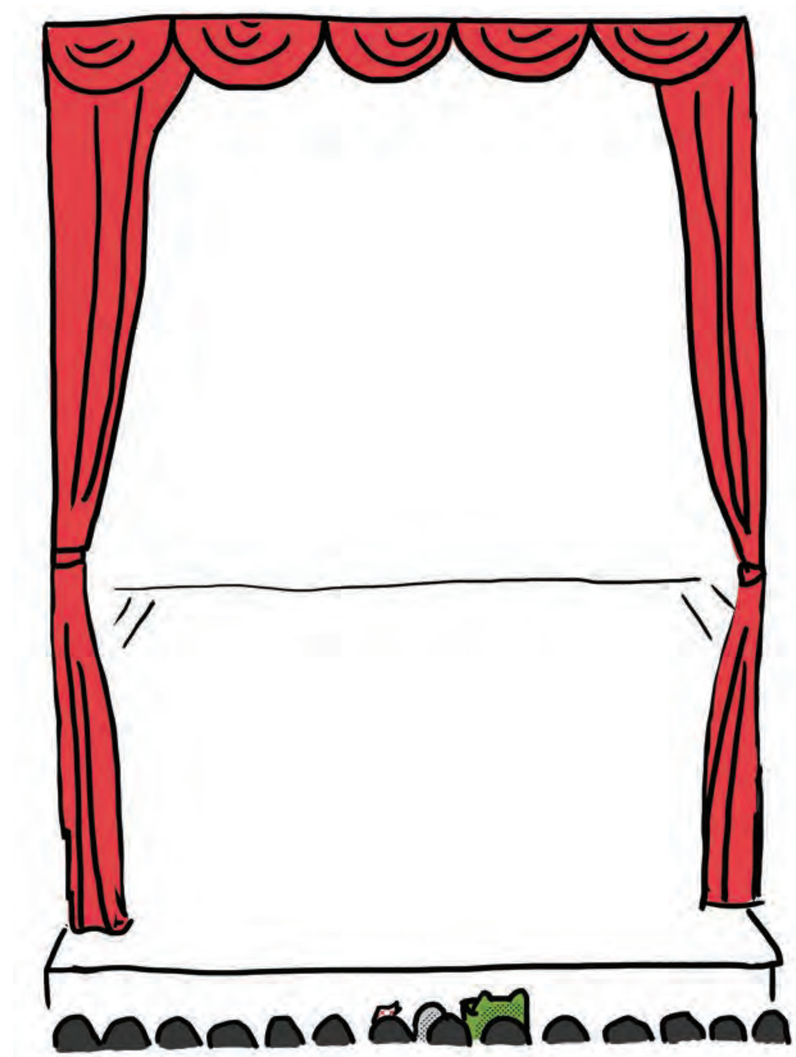
Remember to fold your tape and not cut or tear at the turns. Check out the facing page for a tape-folding trick to make neat turns!

See how when you connect the LED circuit to pin 0, the LED also blinks just like the indicator light on the Chibi Chip? That's because the pin sends power to both the light on the Chip as well as to any LEDs in a circuit connected to that pin.

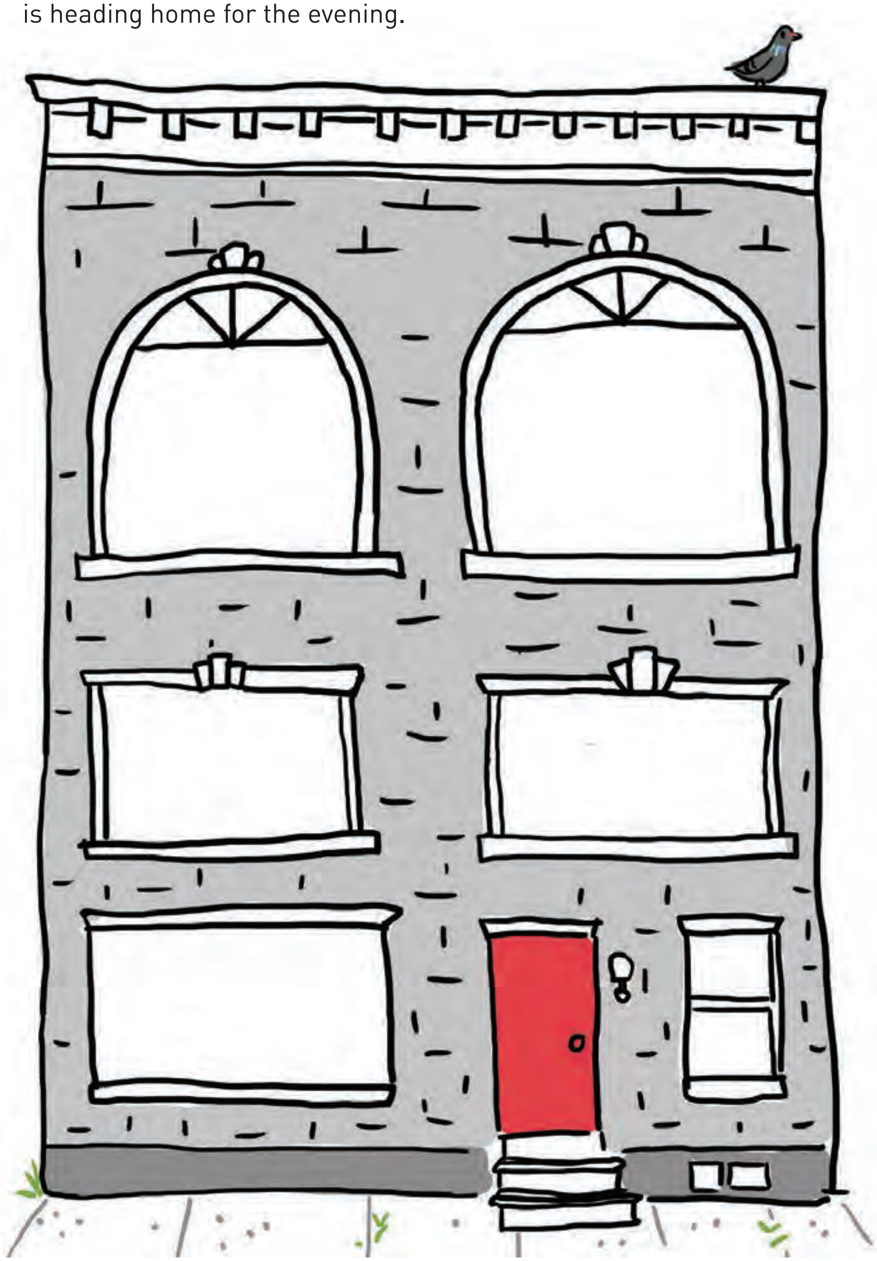
Try clipping GND and pin 0 to the "Turn on a Light" circuit on page **1-2**, and see that blink too!



Draw something on the back of this page to see the shadow of your drawing appear when the light blinks on!

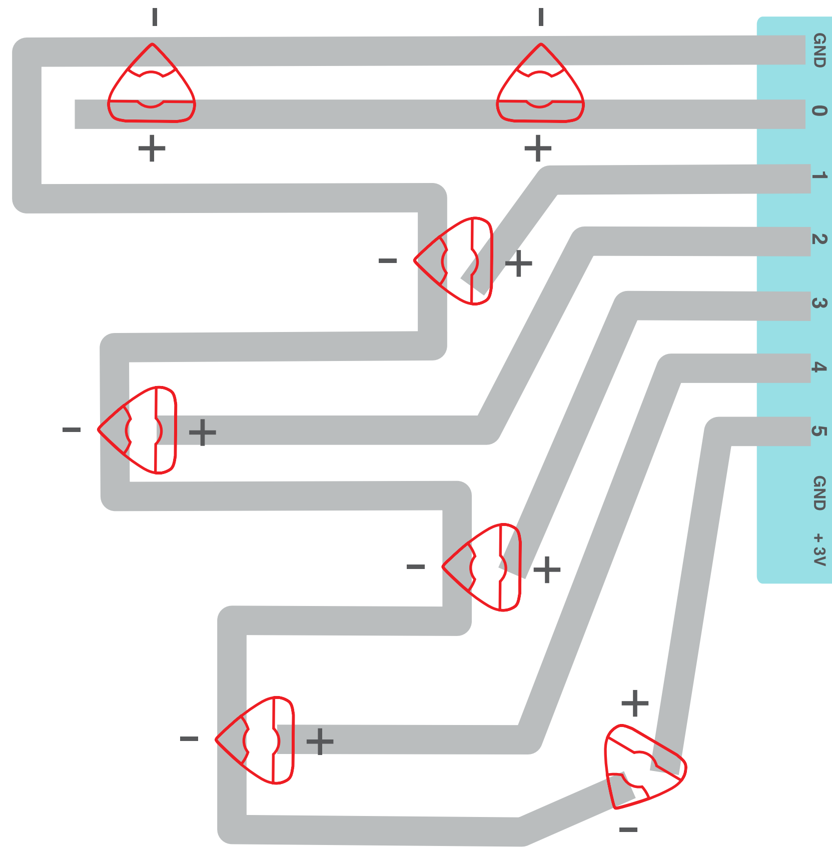


It's starting to get dark in Fern, Sami, and Carmen's town, so everyone is heading home for the evening.



Program this circuit

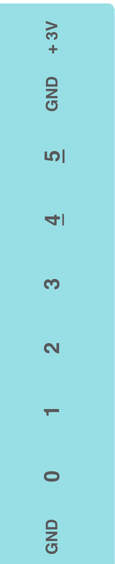
Just like before, we can clip the Chibi Chip to a circuit and control the lights using a program. Here's a circuit where all of the pins are connected to LEDs, and the LEDs are placed in spots that will light up the windows on the page **2-23**. Now we're ready to play with all the pins!



Can you get all 6 of the pins to blink in a pattern? If you get stuck while coding, check out ***Home → Examples → Six Pin Blink*** to help you get started!

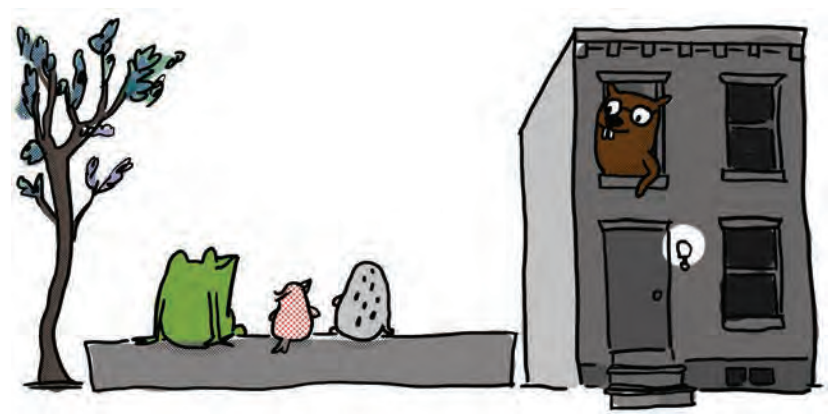
Let’s play!

Now it’s your turn to design your own circuit and light up the night sky (turn to page **2-30** for a preview).



Above is a Chibi Clip template to help you get started. Use as many pins, and whatever circuit shape you like! If you’re not sure how to start, take a look back at the circuit on page **2-25** for inspiration.

Remember: LEDs that are connected to the same pin will come on at the same time. Since the Chibi Chip has 6 programmable pins, you can control up to 6 separate groups of lights with one Chibi Chip!

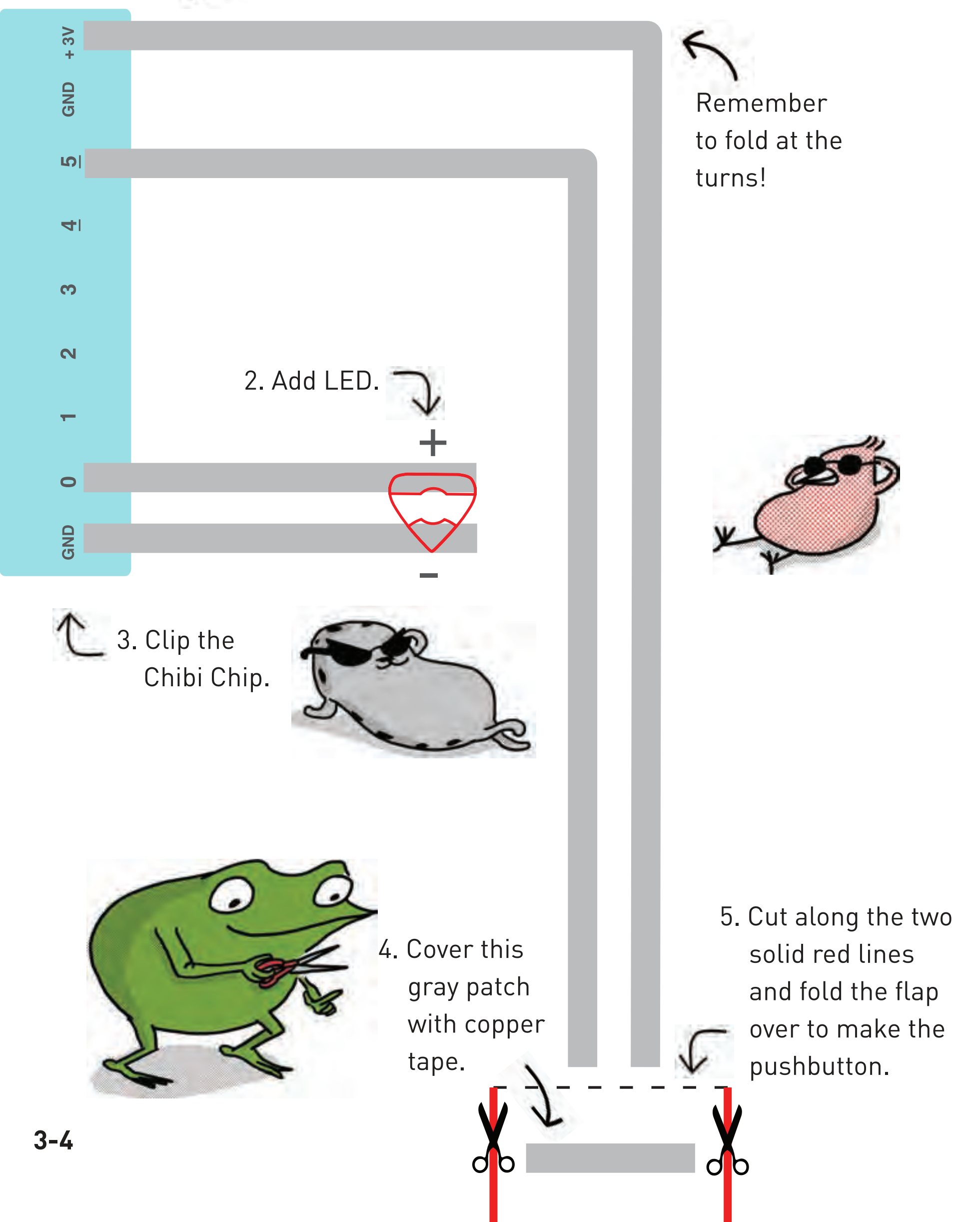


Edith the beaver overheard her three friends enjoying the light show and looked out her window.

“How am I missing out on this party?” cried Edith, and she quickly rushed out to join the fun.

Pushbutton Switch Template

1. Stick copper tape over the gray lines.



Remember to fold at the turns!

2. Add LED.

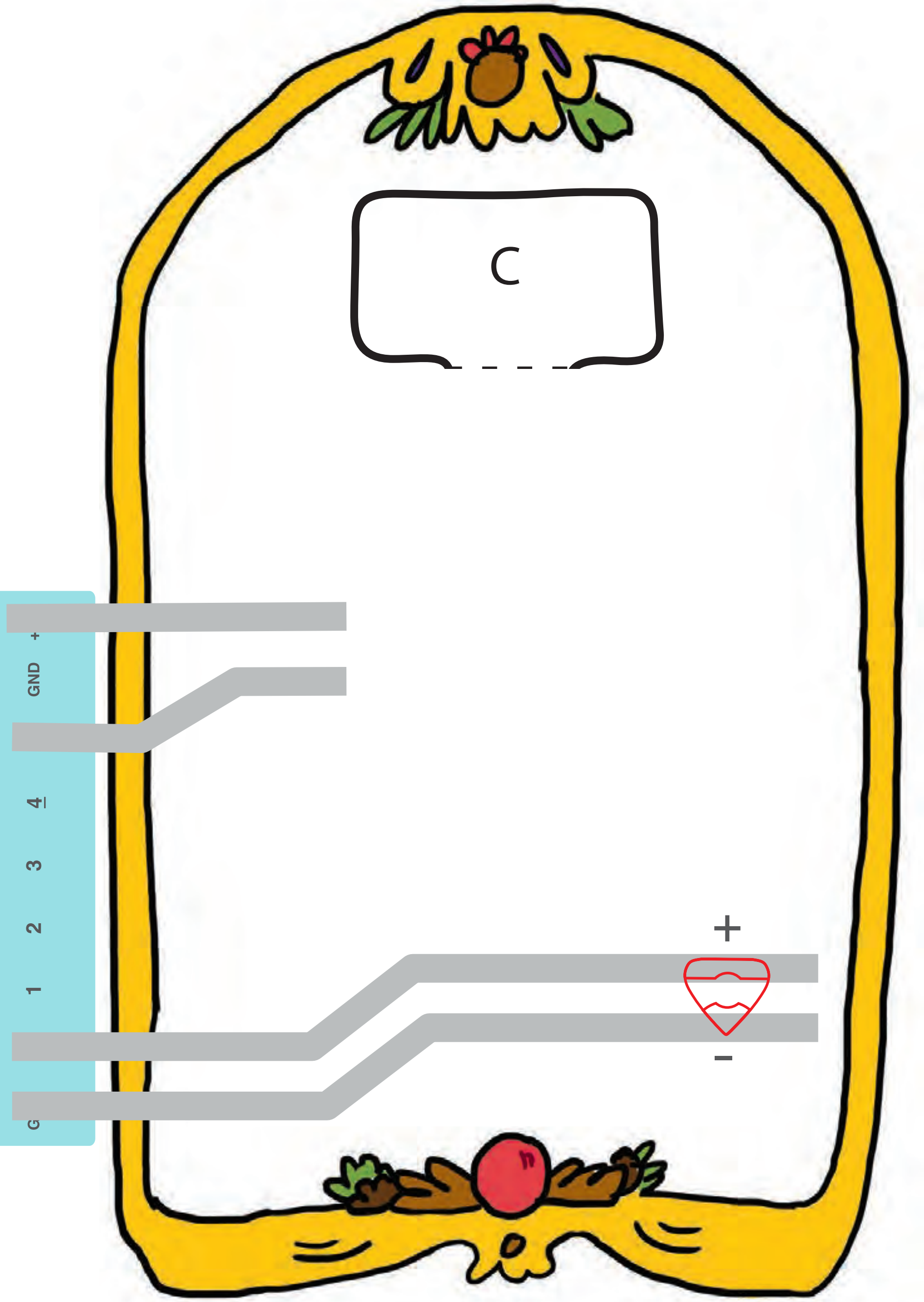
3. Clip the Chibi Chip.

4. Cover this gray patch with copper tape.

5. Cut along the two solid red lines and fold the flap over to make the pushbutton.

What happens when you press on Edith's tail?

What glows when the pointer reaches the switch? Craft the switch by following the instructions on page **3-23**!

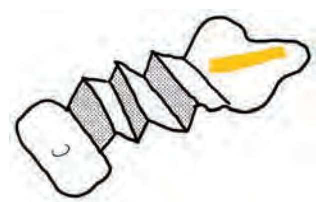


Pop-Up Switch

Make a Pop-Up Switch

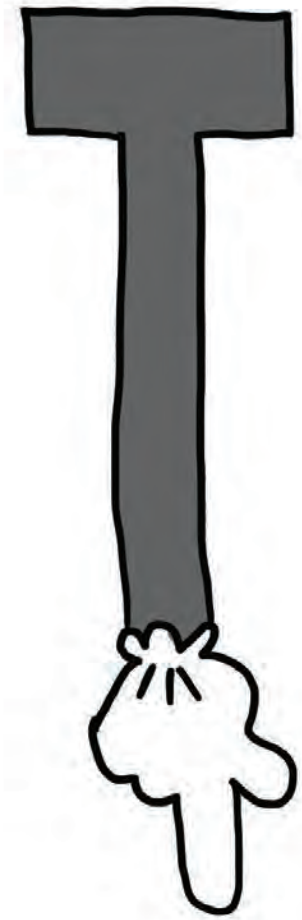
1. Cut out the pointer
.

2. Add copper tape to the back



3. Fold an accordion so that the pointer becomes a zig zag.

3. Tape the base over the footprint marked C on page **3-22**.



Make a Press-the-Flap Switch

1. Cut out the boot.

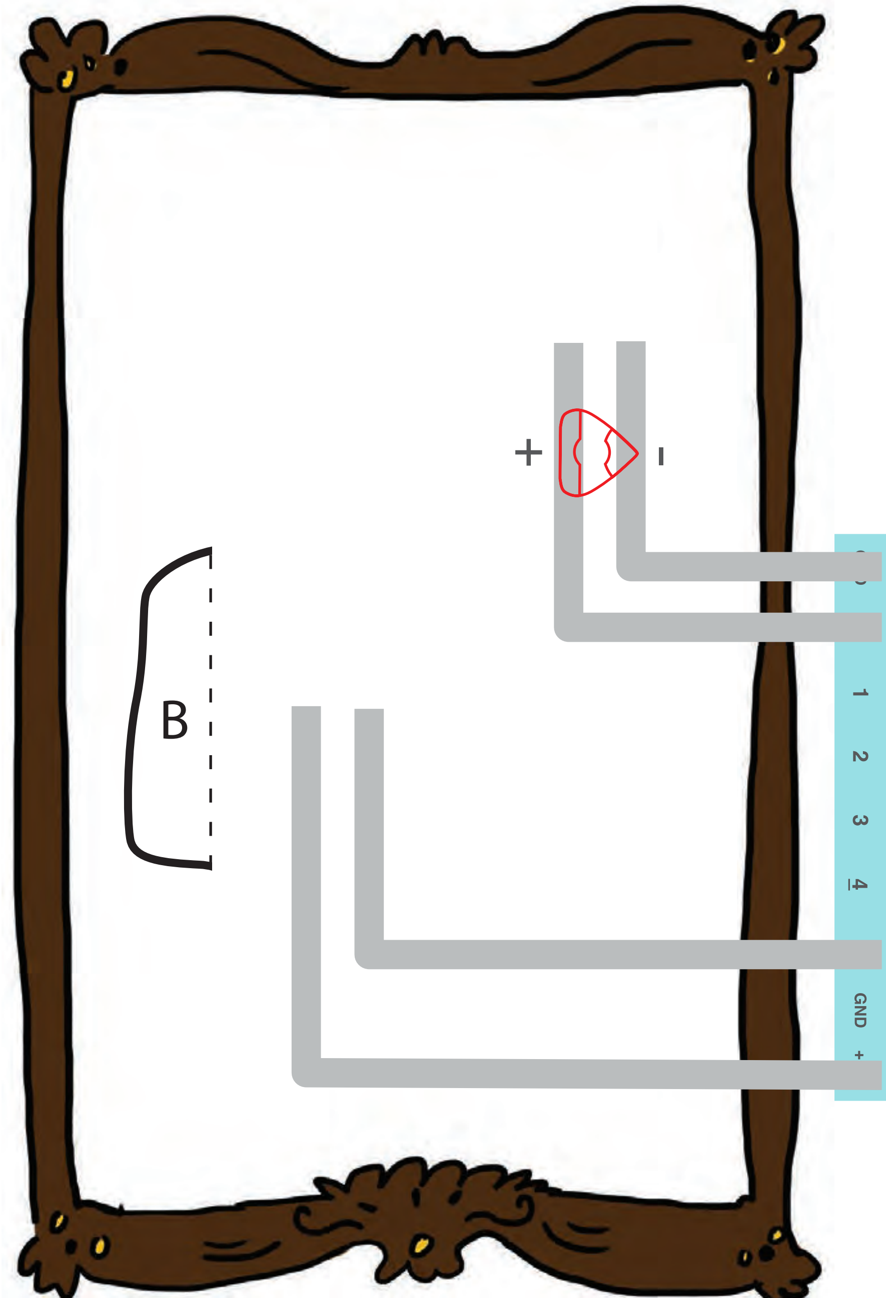
2. Add copper tape to the back.

3. Fold a flap

4. Tape the flap over the footprint marked B on page **3-27**.

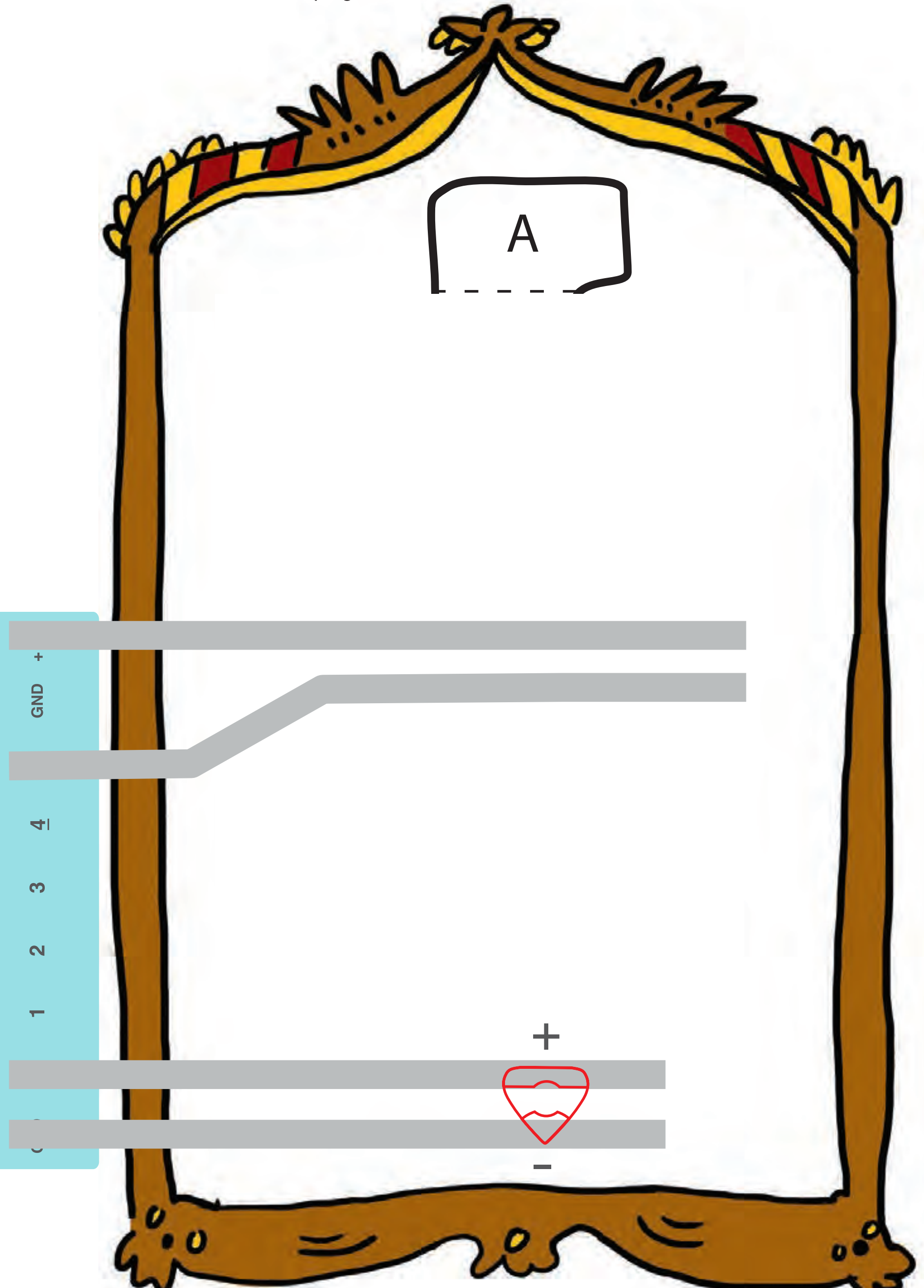
Here's what the finished press-the-flap switch looks like! Press the boot to close the switch.

What glows when we press on the boot? Make it below!



Press-the-flap

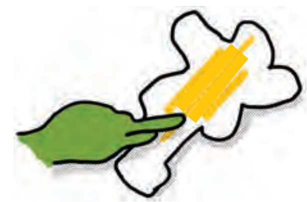
What glows when we blow on the flower? Craft the flower by following the instructions on page 3-29!



Wind Sensor

Make a Wind Sensor

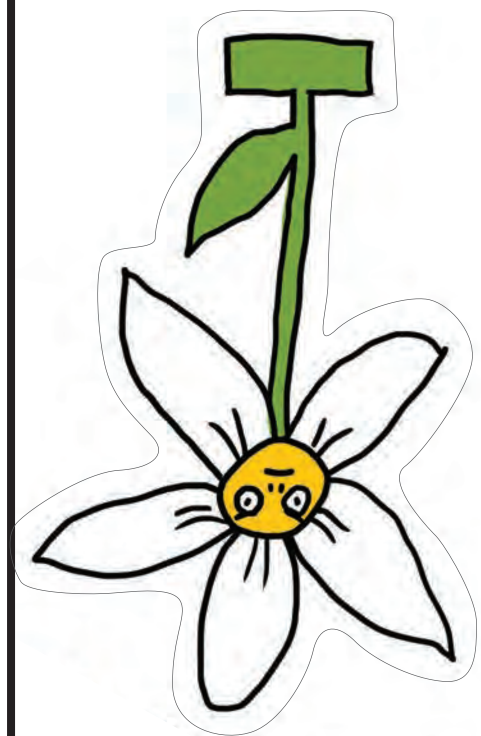
1. Cut out the flower



2. Add copper tape over the back side of the flower.

3. Fold up the base

4. Tape the flap over the footprint marked A on page **3-28**.



Here's what the finished wind sensor looks like! Blow on the flower to activate the switch.

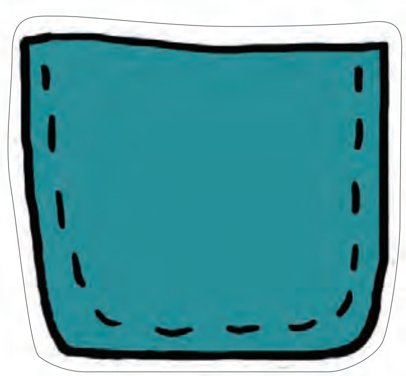
Make a Pocket Character Switch

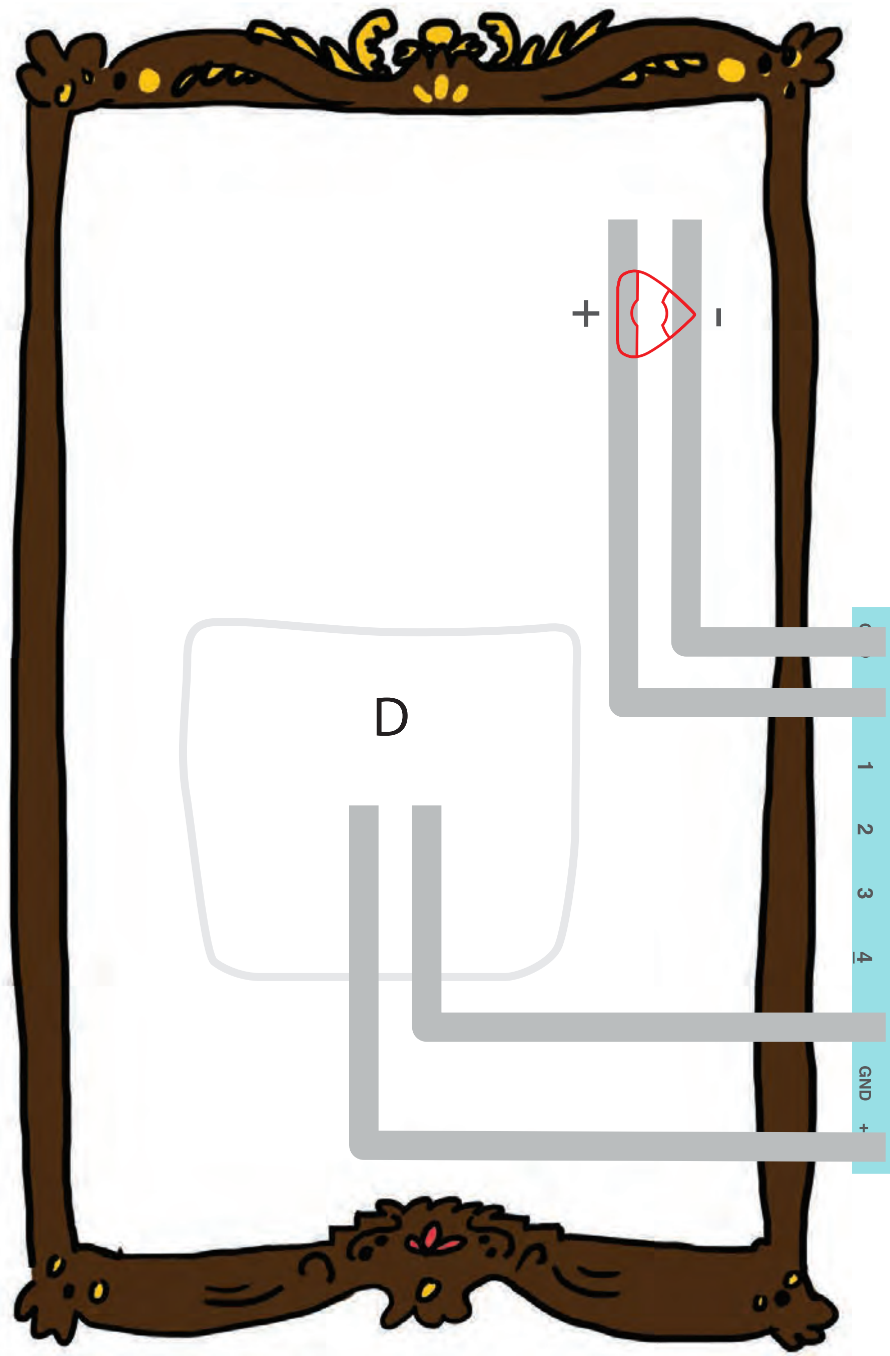
1. Cut out the cat and the pocket

2. Roll up the paper along the dotted lines at the bottom of the cat cutout. This makes the paper thicker so it presses more securely against the switch, making a stronger connection.

3. Add copper tape to the gray line, then build the circuit on page **3-33**.

4. Tape the pocket over the footprint marked D, by taping the left, right and bottom sides. *Be sure to leave the top open.* Now the pocket is ready to hold the cat!





Pocket Character Switch

GND 0 1 2 3 4 5 GND +3V

Your Switch!

Light Sensor Template

1. Stick copper tape over the gray lines.

2. Place the light sensor over the footprint, but **do not remove the wax paper backing**!

3. Stick conductive fabric patches over the copper tape and the light sensor's golden metal pads, like this:

This holds the light sensor in place while connecting it to the circuit!

4. Stick down LED

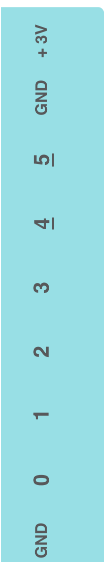
5. Clip the Chibi Chip

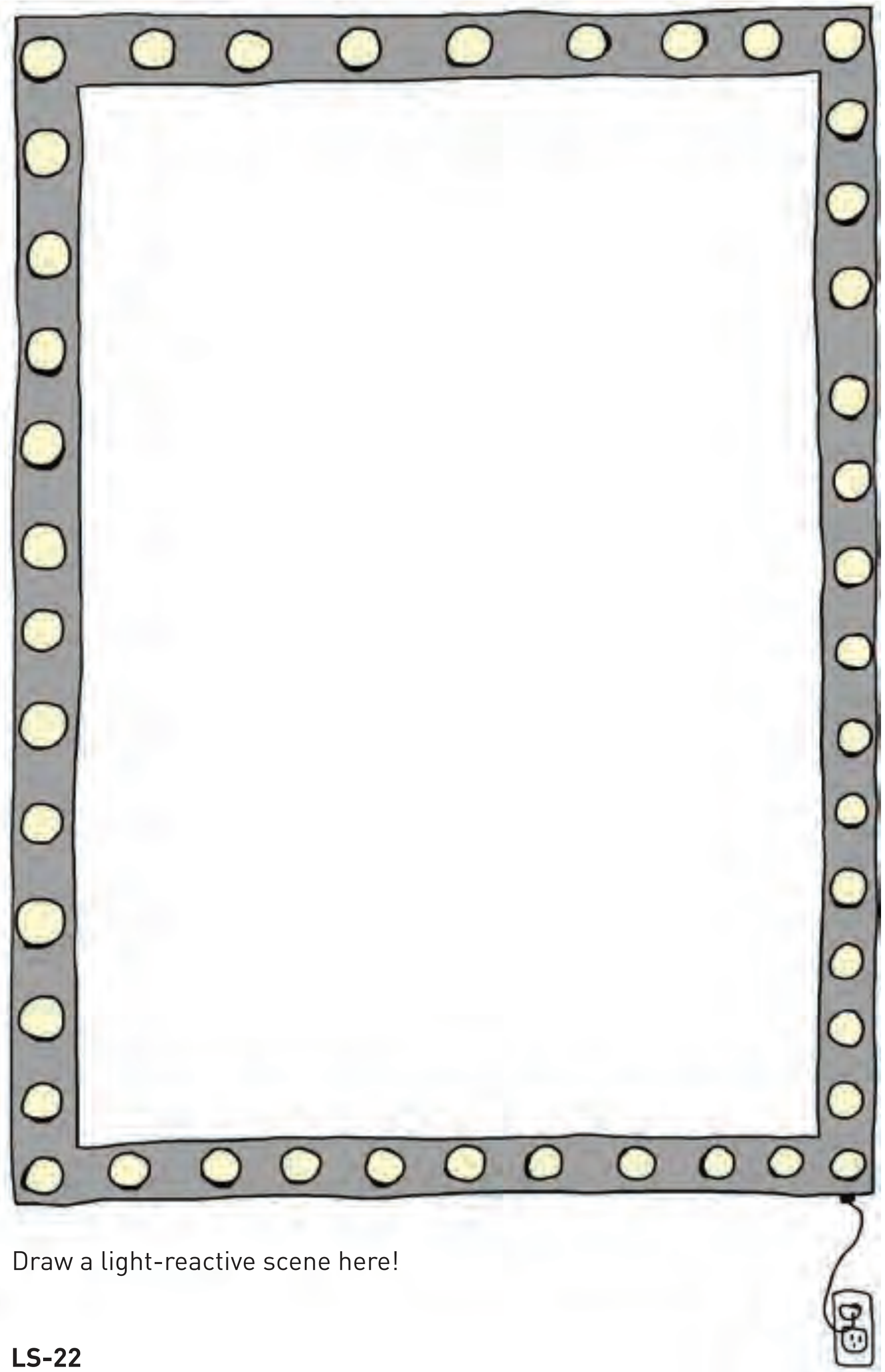
Connecting a light sensor with fabric patches lets us reuse the sensor sticker in other circuits! Just peel off the old fabric patches and use new patches to connect the light sensor to a new circuit.

When you shine a light at George, something fades away! What is it?

Let's Play!

Time to create your own light-reactive artwork! First, draw a scene on page **LS-22** and then build a light-reactive circuit for your artwork here!



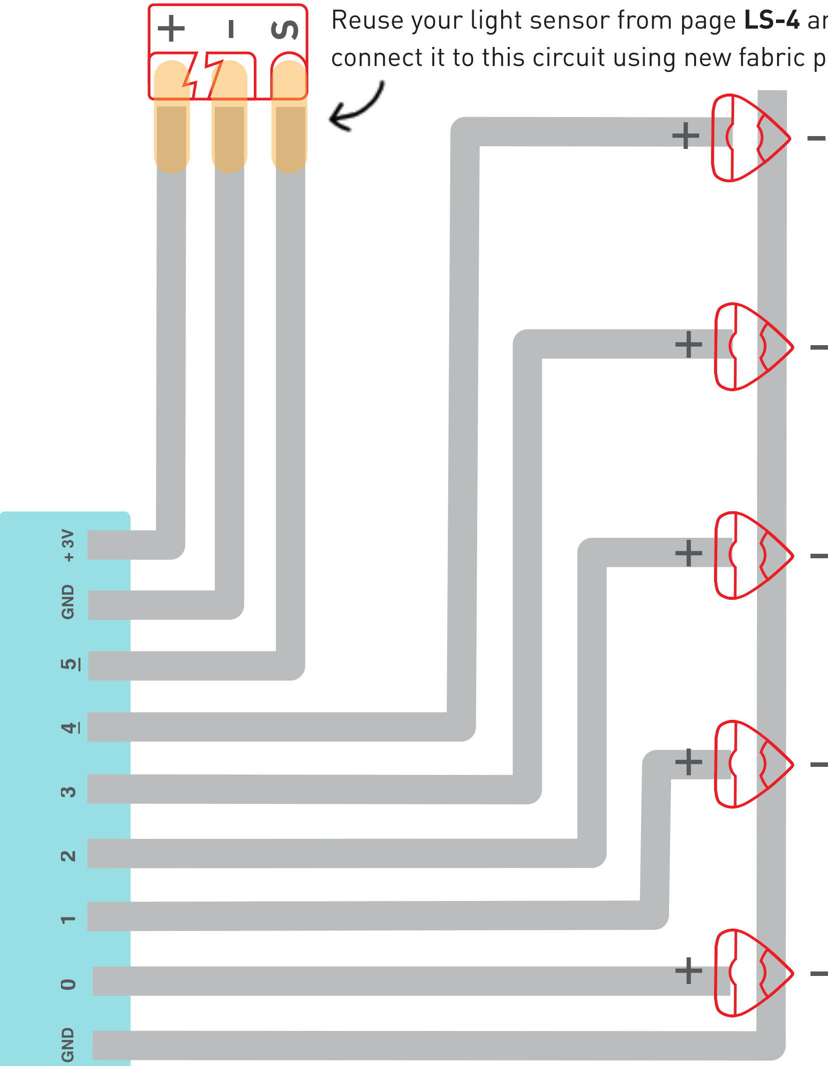


Draw a light-reactive scene here!

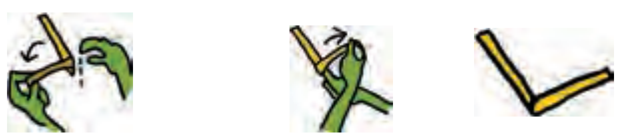
Light-o-Meter

The brighter the light sensor's reading, the more LEDs will light up!

Reuse your light sensor from page **LS-4** and connect it to this circuit using new fabric patches!



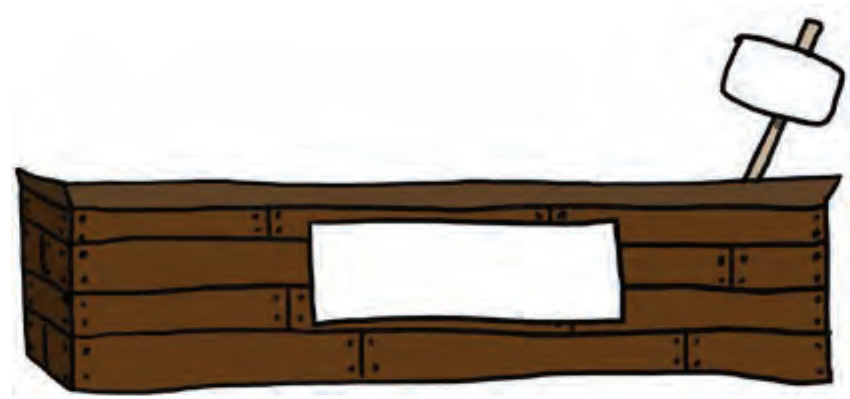
Turn copper tape at corners with this folding trick:



1. Fold tape back, so the sticky side faces up

2. Flip and turn the tape

3. Flatten the corner!

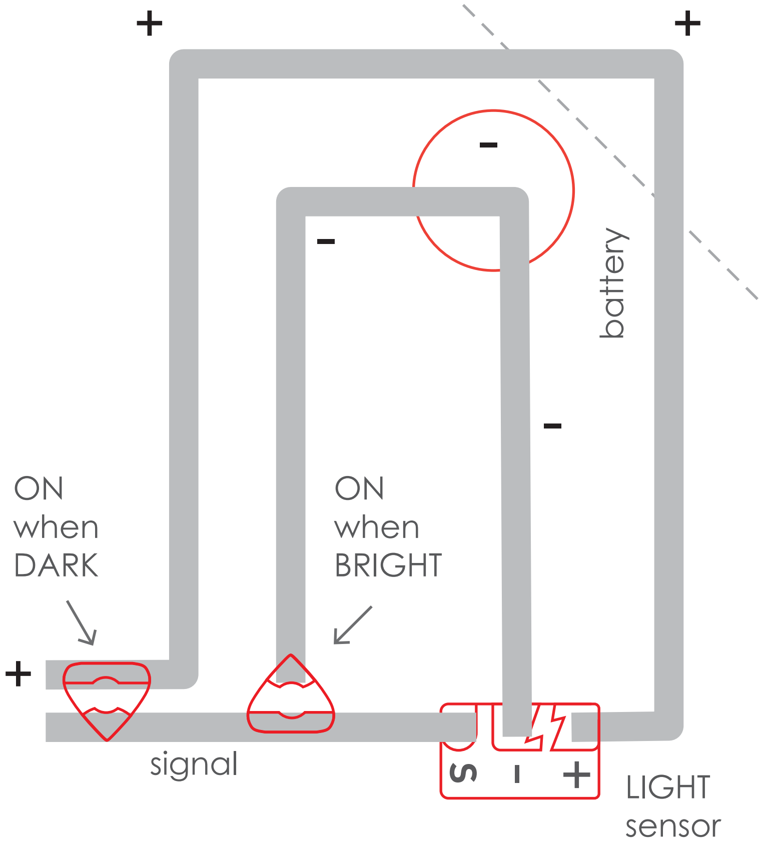


What grows when you shine light on the sun? Draw it above!

Make A Scene

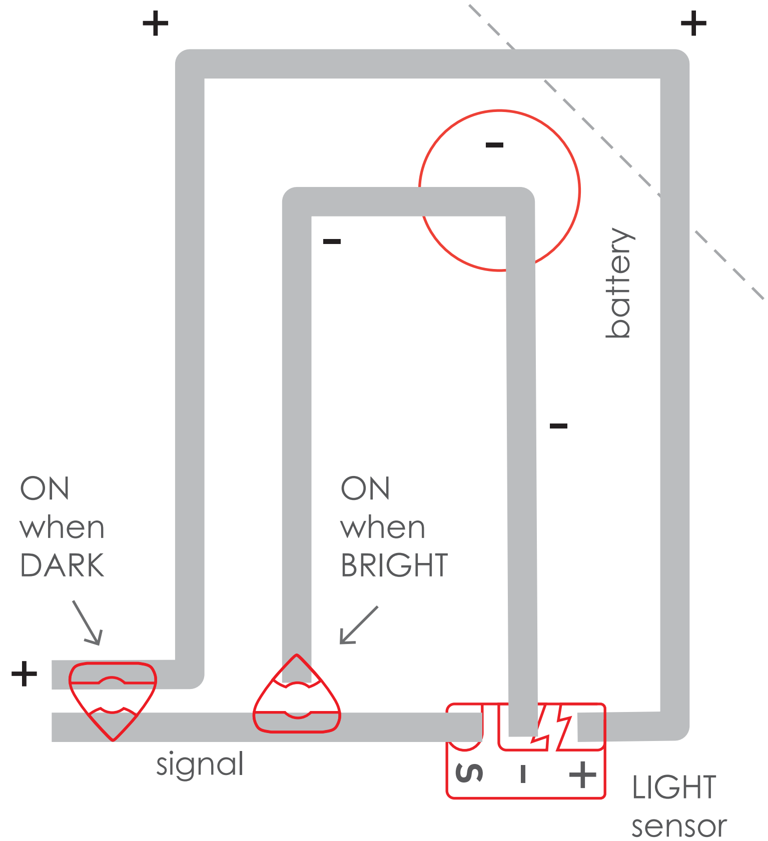
You've learned so much! Now use your coding chops to help Fern and friends design some light-up outfits for the parade.

GND 0 1 2 3 4 5 GND + 3V



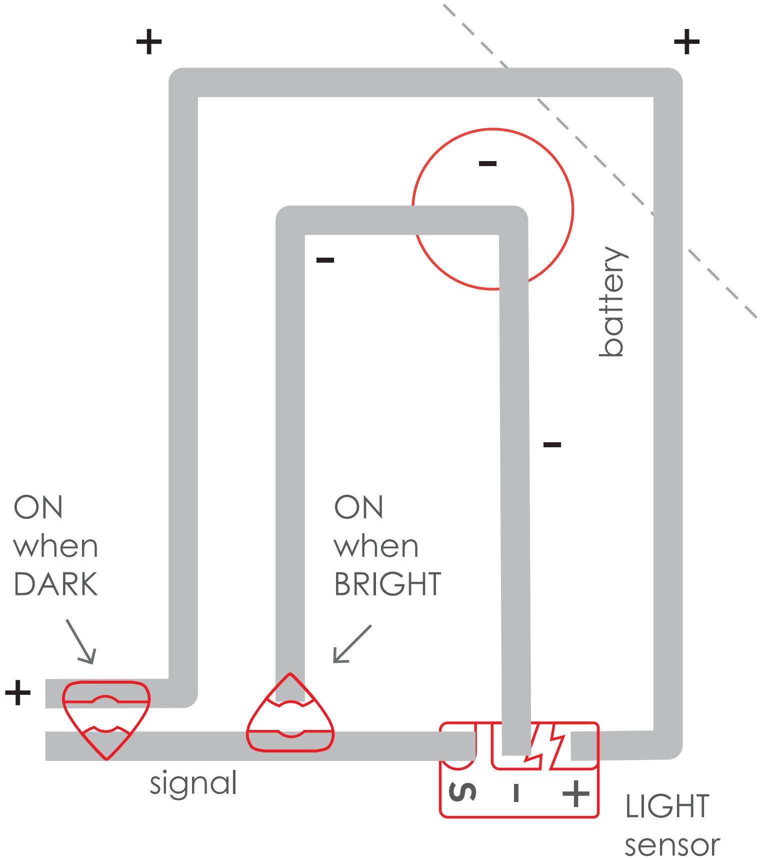
LIGHT SENSOR WITHOUT MICROCONTROLLER

chibi tronics



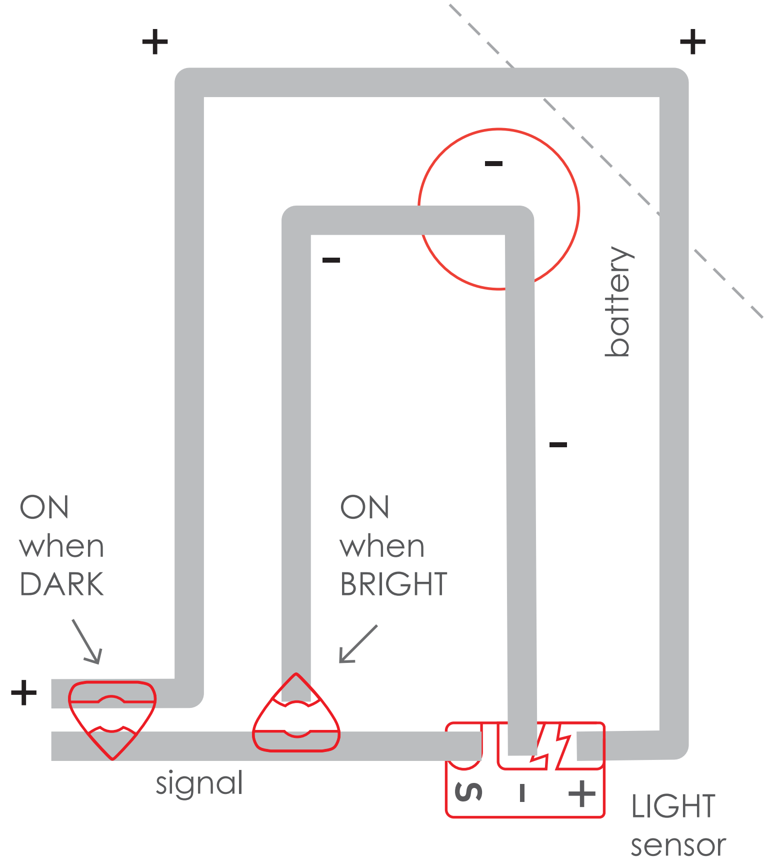
LIGHT SENSOR WITHOUT MICROCONTROLLER

chibi tronics



LIGHT SENSOR WITHOUT MICROCONTROLLER

chibi tronics



LIGHT SENSOR WITHOUT MICROCONTROLLER

chibi tronics