Hands-on with Paper Circuits: Quickly Prototyping Interactive Designs

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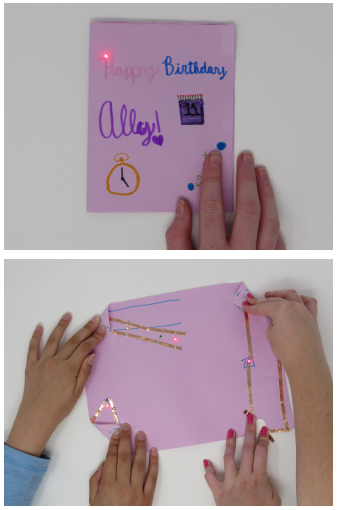

Figure 1: Light-up card made by young women during a paper circuits activity with Girl Scouts of America. Top: Card front. Bottom: Inside of the card with LEDs lit up.

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Abstract
Educators have been working towards creating a more diverse computing community by engaging people in designing with computing technology. We present a Teachable Moment demonstration of paper circuits – one hands-on activity to engage people in learning about and designing with electronic circuits. Paper circuits is a fast, inexpensive introduction to circuits, that has the flexibility to also be used for interactive prototypes or Wizard-of-Oz. To this end, we describe a basic paper circuits activity in detail and suggest how paper circuits could be used as a prototyping design tool for HCI educators.

Author Keywords
Paper circuits; HCI education; prototyping; interactions.

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);** *Systems and tools for interaction design;*
•**Social and professional topics** → **Computing education;**

Introduction
STEM and HCI education has an important role in creating a pipeline for a diverse, inclusive future of computing that designs technologies reflecting the diverse world we live in (e.g., Figure 1). Recently, there have been several projects

Table 1: Supply list for a basic paper circuit with the cost per person.

Item	Amnt.	Cost
CR2032 Battery	1	$0.60
LED	1	$0.02
Copper Tape	.5m	$0.20
Paper Template	1	$0.05
Total		**$0.87**

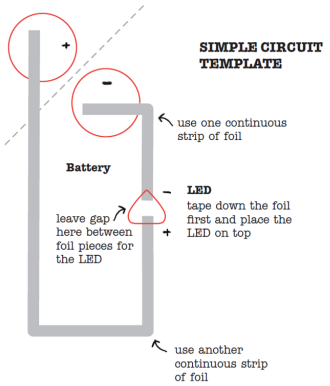

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Figure 2: Basic circuit template from Qi et al.'s [10] Circuit Sticker Sketchbook.

focusing on forming a more inclusive community through computer science in K-12 curriculum [4], programming [2, 9], and sensing [5]. Although these projects have shown success, many are long-term, comprehensive projects requiring a significant resource commitment. Educators, especially those reaching out to computing novices, are less well-equipped to teach people about designing with computing technology, such as electronics.

Teaching people to design with electronics is challenging, especially given how little experience people often have with related topics, such as circuits. HCI researchers have developed an array of tools and activities to engage novices of all ages in designing with electronics, ranging from e-textiles projects with children [8] to physical electronic toolkits for older adults [6]. The LilyPad Arduino, for example, was developed as an e-textile toolkit to engage girls in STEM activities [3]. Education researchers have used these tools to teach computing fundamentals (e.g., circuits with LilyPad [8]). Many tools and programs are typically designed to educate novices to computer science and HCI over the long term, making them less adept for brief engagements that support quickly getting them up to speed with prototyping.

We see an opportunity to engage people in prototyping technology through a short, hands-on activity that quickly teaches them more about circuits so they can test interactive designs (Figure 1). Researchers have found that teaching young children about computing technology through hands-on activities improved their learning, likely due to the collaboration it encourages [7]. To this end, we contribute a Teachable Moment demonstration to the EduCHI Symposium on paper circuits – a tool HCI educators can use to engage people in prototyping. In the following sections, we describe a basic paper circuits activity, and we describe how to support people to prototype designs.

A Guide to Paper Circuits

Paper circuits activities are a great introductory tool for teaching people the basics of electric circuits, while getting them more comfortable in creating with them. There are several ways to set up paper circuits activities, but at a minimum, educators need a power source, an electrical component (e.g., an LED), a conductive material, and paper. People can expand upon these basic components by adding in soldering, toolkits, or more advanced materials. Below we outline how we typically set up paper circuits activities to engage novices to electronics, focusing on the materials and the activity.

Materials

To construct a basic paper circuit, educators need a base set of supplies to get started (Table 1). First, we recommend CR2032 3V watch batteries to power the paper circuits. If educators are planning to reuse the activity multiple times, they may want to consider rechargeable watch batteries. We encourage starting with small, inexpensive LEDs as the first electronic component. We have used other components, such as piezo buzzers for vibration, but LEDs are less expensive and easier to quickly connect into a circuit.

For the conductive material, we recommend using conductive copper tape, but there are also conductive ink pens or conductive paint. The advantages of copper tape is that it is less mess, easy to solder onto, and hard to accidentally leave gaps that break continuity. Conductive ink and paint can more easily integrate into aesthetically pleasing projects, but they tend to be more expensive than tape.

We recommend using a template for a basic circuit from Qi et al.'s Circuit Sticker Sketchbook [10] (Figure 2). The printed templates include scaffolding for the activity, such as

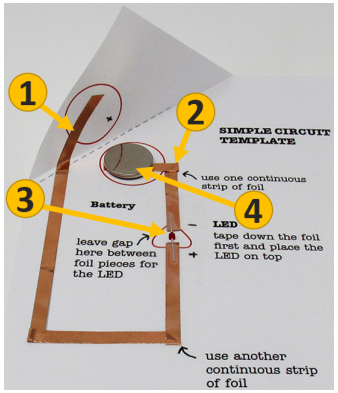

Figure 3: Labelled basic paper circuit example.

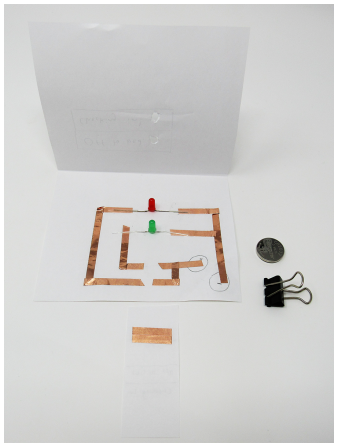

Figure 4: The inside of the example prototype we developed in 20 minutes. The copper tape slider determines which light turns on.

where to leave gaps for the LEDs, to help guide people as they build circuits.

In addition to these disposable supplies, people will need to share scissors to cut the copper tape and cellophane tape to attach the components.

Base Paper Circuits Activity

To start a paper circuit (Step 1 in Figure 3), begin by laying the copper tape to form the circuit. Start near a corner where the battery will go. Try to use one continuous piece of copper tape until where you need to leave a gap for the electrical component (e.g., an LED). Continue around after the gap, ending where the battery will lay (Step 2).

Next, attach the LED to the copper tape with the cellophane tape (Step 3). Depending on the students, this may be an opportunity to discuss polarity – talking about the positive and negative side of the LED and battery. However, if the LED is placed backwards, simply flip the battery over.

Finally, place the battery down in the corner, and fold the corner over to connect the copper to both sides of the battery, lighting up the LED (Step 4). This base activity took a group of 26 older adults 7 minutes on average.

Prototyping Interactions with Paper Circuits

Once people know how to create a basic paper circuit, they can begin to integrate paper circuits into prototypes to prototype interactions or even Wizard-of-Oz. Qi et al.'s Circuit Sticker Sketchbook [10], offers more ideas beyond the basic circuit, including parallel circuits for multiple lights, switches, blinking actions, and a pressure sensor. In our own outreach efforts, we allowed people to explore creating with paper circuits by making interactive cards (e.g., Figure 1).

We see an opportunity for HCI educators to use paper circuits in conjunction with lessons on prototyping interactions. HCI researchers have used activities, such as electronic toolkits to teach people about computing technology so they can engage in the design of technology [1]. Similarly, HCI educators could use paper circuits to support people in quickly prototyping interactions. For example, in only 20 minutes we prototyped an aging in place system for checking in with a loved one by sliding a switch to let them know when you wake up (Figures 4 and 5).

Paper circuits could also be modified to integrate more advanced functionality with electronic toolkits. Chibitronics [11] is a commercialized paper-based toolkit stemming from Qi et al.'s work [10]. They created the Chibi Chip (Figure 6), a microcontroller clip for paper-based circuits that is programmed in an online editor at Microsoft's MakeCode.org [9]. In a workshop, we took Craftec [6] – a toolkit for older adults to use their crafting skills to create with technology – and developed a paper circuit template to integrate an LED and light sensor (Figure 7). Covering the light sensor flipped the LED on and off, but we could have created other interactions.

Conclusion

Paper circuits as a Teachable Moment would add to the EduCHI symposium as a tool for HCI educators to engage people in prototyping with electronics circuits. Engaging people could have a broader impact by reaching out to underrepresented youth to get them interested in STEM earlier, and create a pipeline of future representative HCI practitioners. Paper circuits, in particular, has advantages over similar tools in that it is fast, inexpensive, and requires little capital investment to run. Educators can build on the basic circuit with additional examples to support creative interaction prototypes.

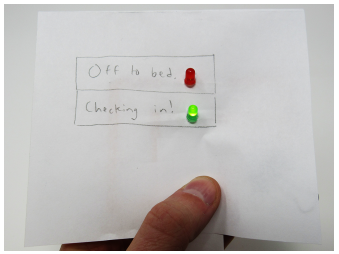

Figure 5: The front of the example prototype we developed in 20 minutes.

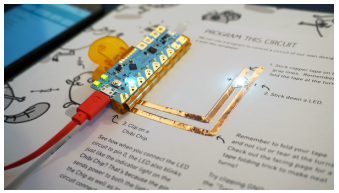

Figure 6: Chibi Chip example from https://chibitronics.com/.

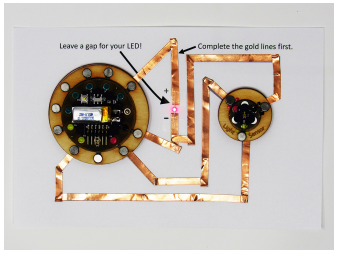

Figure 7: Integrating the Craftec electronic toolkit with a paper circuit template.

If accepted, I would present this work as a demonstration for EduCHI attendees. I start by describing paper circuits, have attendees make their own basic circuit, and end by discussing prototyping interactions. I could be finished within the 10 minutes allotted for short submissions.

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