Chapter 5

Learning About Circuitry with E-Textiles in After-School Settings

Kylie Peppler and Diane Glosson

The relationship between various tools and the structuring of subject matter is central to many examinations of disciplinary learning. Papert, for one, called attention to the impact of specific tools ("objects to think with") (Papert 1980) on the ways that we learn and perceive subject matter. Of potential interest to anyone working with e-textiles in educational settings is the impact that working with these tools has on our ontological understanding of robotics, computing, and engineering, particularly in the ways that it contrasts with learning outcomes that derive from the use of more traditional tools (e.g., batteries, insulated wire, nails, thumbtacks, paper clips, bulbs, and so on). The historical prevalence of youths' conceptual misunderstandings of simple circuitry from learning with these traditional materials (Evans 1978; Tiberghien and Delacote 1976) provides additional justification for this exploration. For instance, traditional circuitry toolkits possess numerous design elements that make invisible what makes them work (e.g., the connecting wires in an incandescent bulb disappear behind an electrical contact foot and metallic screw cap; insulated wires prevent crossed lines from shorting out). By contrast, e-textile toolkits reveal underlying electrical structures and processes in tangible and observable ways, allowing designers to investigate aspects of circuits and computational technologies that are otherwise invisible to the user (Buechley 2010; Kafai and Peppler; under review).

Furthermore, dramatically changing the nature of the tools used to explore circuitry concepts (e.g., fabrics, threads, and other soft materials) inspires youth to ask questions they otherwise wouldn't have. Is cotton conductive? What makes energy pass through *this* material but not *that* one? Reevaluating garments and textiles beyond their immediately practical or aesthetic functions encourages youth to think more deeply about the circuitry concepts at play and the qualities of the physical materials themselves.

Seeking to explore whether the visibility inherent to these materials could prove significant for youths' conceptual understanding of circuitry, we invited youth from a local Boys and Girls Club to design a host of e-textile projects and reflect upon their production practices in a 20-hour workshop. All the while, we observed and analyzed youths' projects and interactions in the process of creation for evidence of improved understanding of core circuitry concepts. Results indicate that youth participants significantly gained in their understanding of multiple core circuitry concepts as well as their ability to diagram and create working circuits in parallel and series formations (Peppler and Glosson, in press).This work seeks to provide a foundation for integrating e-textile materials into standards-based practices in formal education systems and to illustrate how this might be taught and assessed in the classroom.

Workshop Description

Our e-textile workshop was designed as part of the local Boys and Girls Club summer program. Seventeen youth, ages 7–12, participated in the entire twenty-hour, ten-session e-textile curriculum lasting for two hours per day over a two-week period. The e-textile workshop targeted five central concepts important to the study of circuitry that are more commonly taught using traditional materials: current *flow* (R. Osborne 1981; R. Osborne 1983; Shipstone 1984), battery *polarity* (R. Osborne 1983; J. Osborne et al. 1991; Asoko 1996; Shepardson and Moje 1994), circuit *connectivity* (R. Osborne 1983; Asoko 1996), and the diagramming of circuits in *series* (R. Osborne 1983; J. Osborne et al. 1991) and *parallel* (Shepardson and Moje 1994) formations which are further defined below:

1. Current *flow* is defined as the circular path electrons take around a circuit (R. Osborne 1981). For e-textile projects, we assessed participants' ability to stitch loops with no redundant lines or instances of shorts (i.e., loose threads touching the opposite terminal line).
2. Battery *polarity* involves connecting battery terminals to the cor responding output terminals in a circuit (i.e., + to + and - to -). In the context of e-textiles, we assessed whether youth could orient the positive and negative terminals of circuit components correctly in relationship to the power source.
3. Circuit *connectivity* pertains to the joining of the battery, bulb, and wires to form a working circuit (R. Osborne 1983; J. Osborne et al. 1991; Shepardson and Moje 1994). In the absence of these materials, we adapted the term in our assessment of youths' e-textiles projects to define connectivity as the craft of the circuit. That is, the lines (i.e., conductive thread) had to securely connect one component to another with attention being paid to the particular points of conductivity (e.g., looping the conductive thread through the terminal hole for a strong connection).
4. A *series* circuit is one where electrical current flows sequentially through every component in the circuit. In a series circuit, any electron progresses through all components to form a single path, meaning that energy diminishes as it progresses through each component in the circuit (such as a string of light-emitting diodes [LEDs]).
5. In a *parallel* circuit, the electrical current divides into two or more paths before recombining to complete the circuit. Working with e-textiles, electrons in a parallel circuit go through two (or more) LEDs at the same time, meaning that the electron's energy given to each LED is identical.

These circuitry concepts were explored in a series of three projects selected by the youth participants over the course of the 10 sessions, of which two are presented here: an introductory simple circuit quilt square and a programmable wristband with persistence-of-vision (POV) tracking. Taking place in an informal environment, participants' creative production with these tools was largely defined by free exploration and experimentation; direct instruction was limited to three brief presentations, and youth often turned to peer or mentor support for advice and inspiration on their individual projects.

Below, we address the science concepts manifested in two of the youths' e-textile projects—the quilt square and the POV bracelet—as well as what the youths' projects revealed about their understandings of current flow, circuit connectivity, battery polarity, and series vs. parallel circuits. Throughout, we augment these findings with vignettes of how these understandings were cultivated through moment-to-moment interactions with the tools, peers, and workshop mentors.

Learning about Simple Circuits: Simple Circuit Quilt Square

The quilt square project provided an introduction to designing simple circuit forms as well as an opportunity for youth to play with the new materials—threading a self-threading needle, sewing with conductive thread, practicing making secure knots—and reflect about the basic requirements of creating a complete simple circuit with an illuminated LED.

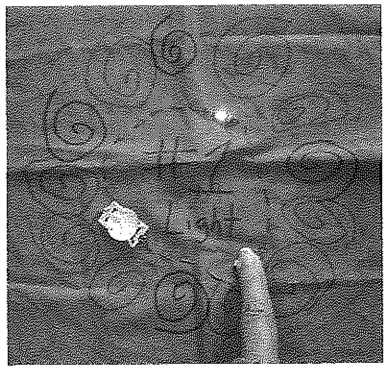


Fig 37 e-Quilt square designed by BGC youth

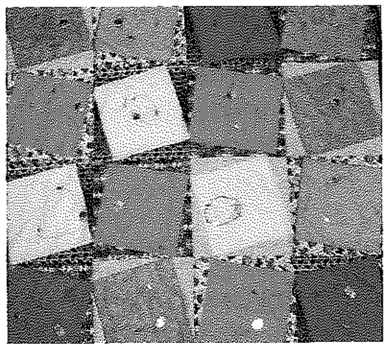


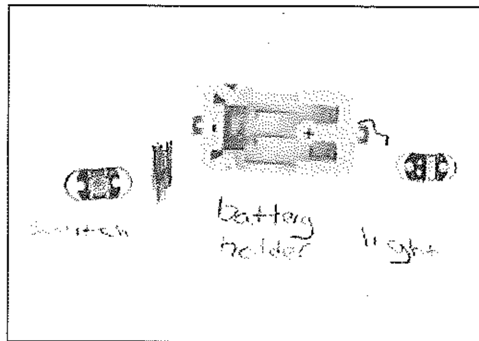
Fig 38 The completed e-Quilt contains 16 working circuits each designed and created by BGC youth

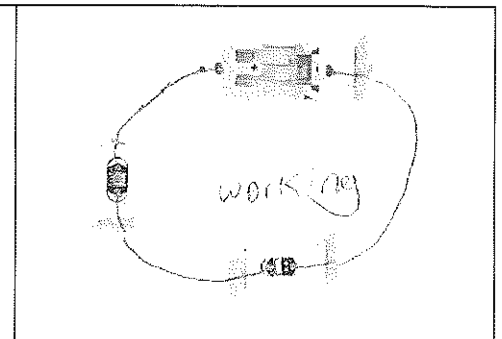
Each square consisted of a 12"x12" swatch of fabric upon which each youth stitched a closed circuit using one LED, a battery, a switch (button or slide) and conductive thread (Figure 37).

Before the youth began their projects, we asked them to draw circuit diagrams in order for us to assess their preexisting understanding of current flow, connections, and polarity. In this first drawing, they attempted to diagram a simple working circuit using pencil and custom LilyPad component stickers. Once their diagrams were complete, the youth then adapted their drawing to their quilting square. However, once engaged with the physical materials, initial misunderstandings of circuitry in the abstract came to the fore. The evidence that these misunderstandings had been amended through the experience of working with the e-textile materials was abundantly clear when compared with the hand-drawn circuit diagrams these youth made later in the workshop. Through projects like these, they revealed significant gains in their ability to not only diagram a working circuit, but also in their demonstrated understandings of current flow, connectivity, and polarity (Peppler and Glosson, in press). Figure 39 provides an illustrative example of how one girl's circuitry understandings developed over the course of working with the e-textile materials.

As illustrated here, 10-year-old Courtney in her first drawing appeared to understand the need for three parts to a circuit—switch, battery holder, and LED—in the (unprompted) labeling of the parts and that a connection needed to be made from the battery holder to the LED. However, she lacked the understanding of current flow (circuit path), polarity, and the importance of solid connections of conductive thread to the conductive holes. This would have been immediately evident when she first attempted to realize this drawing using the physical materials. By contrast, Courtney in her later diagram showed an understanding of a working circuit including the current flow, connections, and polarity.

To see this understanding developing in the moment-to-moment interactions over the course of the workshop, we recorded and analyzed conversations taking





Initially, Courtney lacked the understanding of: • Current flow: there is no circular path from the battery to each component. • Polarity: the LED's negative terminal is incorrectly oriented toward the battery's positive one. • Connections: the lines drawn don't connect to any of the small terminal holes in any of the component.	By the end, Courtney showed an improved understanding of: • Current flow: there's a clear circular path in the diagram connecting all of the components in the circuit. • Polarity: the LED is positioned correctly toward the battery terminals (- to -) • Connections: there is a mindful consideration that the drawn lines extend over the edge of the sticker, directly into the terminal ports.

Fig 39 Courtney's circuit drawings at the start and end of the workshop

place among the youth, their peers and the research team that touched upon the key circuitry concepts at play in these projects. The following excerpt is from a conversation between a researcher and an 8-year-old boy working on his quilt square about the importance of tracking polarity in the context of e-textiles:

Researcher: So you want to do the same thing to the LED that you did...
Ryan: No, I mean...where is this one? (pointing to the switch part sticker)
Researcher: I'll get that one for you in a second (gestures towards parts table) but first go through the LED.
Ryan: (positions LED to sew)
Researcher: You are about to make a fatal mistake. (Points towards Ryan) what is it?
Ryan: The plus is going to the minus.
Researcher: Yes! So you want to switch this (LED) around (gestures in a circle). Now plus is going to plus.

In this early example with sewing the quilt squares, the youth had already learned that the plus terminal of the battery needed to be connected to the plus terminal in the LED with conductive thread. So when the researcher warned Ryan of a "fatal mistake" as he was about to sew the negative terminal connecting it to the positive battery terminal, polarity was one of the first things Ryan checked for. His response could have been due to a phrase that was used extensively by the staff and the youth: "plus to plus and minus to minus" (i.e., the positive terminal in the battery should connect to the positive terminal in the LED, just as the negative terminal in the battery should connect to the negative terminal of the LED). We believe this mantra may have contributed to the significant gains in the youths' understanding of polarity as reflected in the pre- and post-test diagram assessments.

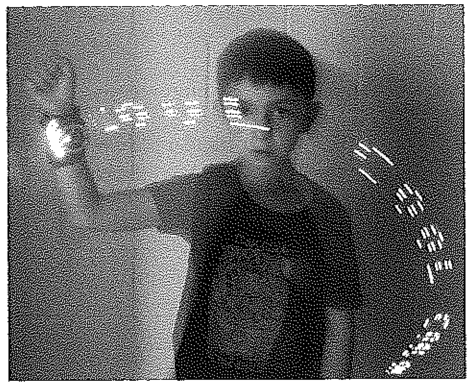
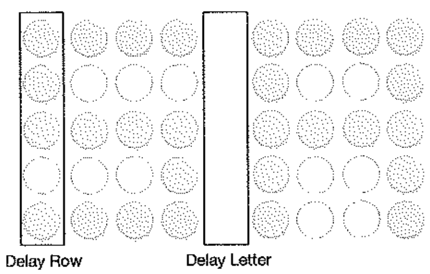


Fig 40 young POV designer illustrates his moving POV wristband and readout in low lighting conditions (T); sample display code for letters SA including the delay row and letter (B)



After the workshop, the completed "e-Quilt," shown in Figure 38, was highlighted and displayed at the Boys and Girls Club annual art exhibition at the local city hall, which was attended by the mayor, community members, Boys and Girls Club staff, the young artists and their family and friends. At the exhibition, workshop participants anxiously searched for their circuits to light, shared stories with their parents about the making of their quilt square, and were excited to locate their friends' circuits as well. The e-Quilt project provided not only a valuable showcase for the Boys and Girls Club to highlight what learning opportunities the Club can offer youth in the community, the exhibition also provided youth with an occasion to introduce their artistic and scientific skills to their broader community.

Learning about Series and Parallel Circuits: Persistence-of-Vision (POV) Wristband

The LilyPad POV wristband is a wearable version of a persistence-of-vision display, the illusion that an image continues to persist even though part of the image has changed. The LilyPad POV can be thought of as a digital version of the old-fashioned zoetrope used for simple animation.[1] The POV bracelet creates words by rapidly alternating patterns of LEDs stitched in a row. When youth sweep their arms horizontally, the flashing LEDs appear to spell a visible word in the air (Figure 40).

Workshop youth stitched LEDs into their bracelets to enable each LED to be lit separately through the LilyPad Arduino programming. In order for each LED to be programmed separately, the positive LED terminal holes were connected to individ-

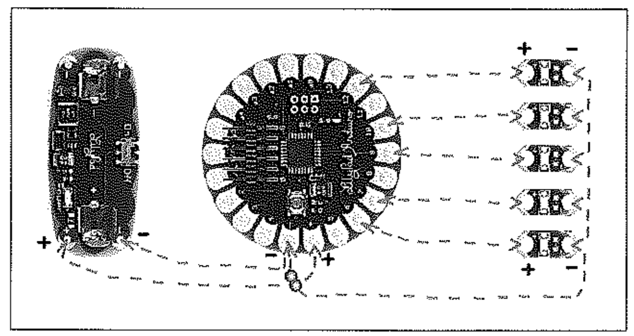
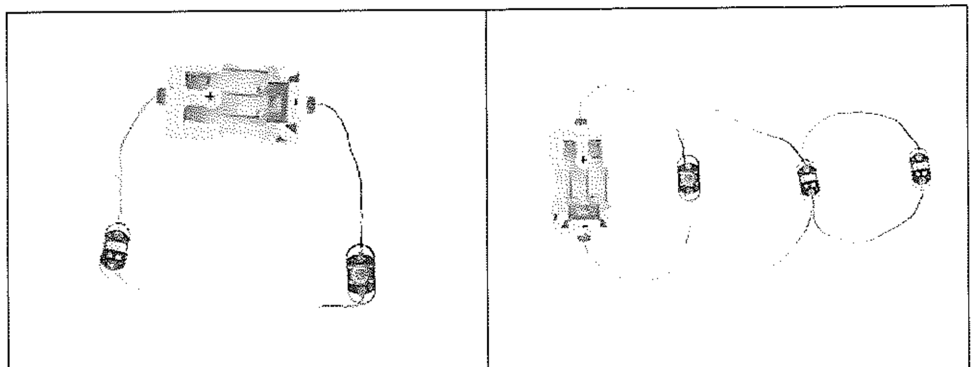


Fig 41 (T) Superkids with super powers! Fig 42 (B) Diagram of the POV Wristband Design

ual LilyPad petals (i.e., terminal holes), and the negative LED terminals were stitched as one line into the negative petal of the LilyPad Arduino (which they also stitched into their bracelets) (Figures 41 & 42). Youth worked with a computer programmer to convert text into Arduino code that could be uploaded to the LilyPad. Constraints of time and a primary emphasis on the basics of circuitry in this workshop prohibited us from dedicating more time to the youths' learning of programming concepts. However, we hope that some initial transparency into the process of computer programming will provide youth with a foundation for future explorations with creative computation, which we have explored more fully in our later workshops.

During the electricity lesson, parallel circuits were explained in terms of not only the LEDs being in parallel form (placed next to one another) but also how this placement allowed for the LEDs to produce a brighter light. It was explained as "in a parallel circuit, an electron goes through EITHER one LED or the other" while the series circuit electrons had to progress through both LEDs, losing energy along the way



Jovita's drawing shows an understanding of polarity and current flow (circuit path for a series circuit) however, she lacks understanding of the importance of connections of conductive thread and incorrectly places the LEDs in series as opposed to the requested parallel circuit form.	Jovita's diagram shows an understanding of polarity, connections, and current flow as well as correctly places the LEDs in parallel.

Fig 43 Jovita's circuit diagrams, drawn at the start and end of the workshop

and thus producing a dimmer light as the series progressed. Similar to the circuit diagrams that youth drew before and after their quilt square projects, we asked the children to draw a parallel circuit diagram before and after the POV bracelet activity. Figure 43 is an illustrative example of Jovita's understanding of a parallel circuit as drawn in her circuit diagrams at the start and end of the workshop.

In the pre-test, 10-year-old Jovita appears to understand polarity and current flow for a series circuit yet lacks the ability to place the LEDs in a parallel configuration in her diagram (e.g., all the LEDs are, instead, aligned in a series). The post-test, by contrast, correctly places the LEDs in parallel with one another. However, the placement of the switch (opposite both of the battery holder's terminals) allows the LEDs to stay lit continuously until the switch is pushed. This is in effect the opposite of the solution to the prompt where the push button switch would turn on the circuit. While not incorrect, per se, it is a rather peculiar design.

In the following, two researchers engage a small group about 10-year-old Dalmar's POV wristband, calling specific attention to the workings of parallel versus series circuits:

Researcher 1: The one on the left is called series, why do you think it's called "series"?
Dalmar: Because they [the LEDs] are by each other.
Researcher 1: And why do you think the other one is called "parallel"?
Dalmar: Because they are parallel to each other.
Researcher 2: Yes, exactly. So it's easy to tell the difference, right? Series and parallel. OK, so this is how all electronics works... when you put an electron in the battery, it wants to go to the other side of the battery, right?
Dylan (age 8): Yeah.
Researcher 2: It's attracted to the other side. So it will go through these LEDs to get to the other side (points to series circuit diagram on the laptop screen). Now with a series circuit the electron loses some energy in going from this side of the battery to the other side of the battery. And in a series circuit it loses half of its energy on one LED and half of it on the other one...But in a parallel circuit (points to the parallel circuit diagram on the laptop screen) the electron either goes through one LED or it goes through the other LED. So the electron gives all of its energy to one LED or the other LED. So how do you think this is going to affect the brightness of the LED? You guys found this out yesterday, you did this parallel vs. series.
Shawnte (age 9): Hook it up to some wires.
Researcher 2: Which one was brighter? Parallel or series?
Many Youth: Parallel.
Researcher 2: Right, right. Because of this (points to the parallel diagram). The electron goes across the LED and it gives all of its energy to the LED, while in the series it divides energy between the two LEDs. That's why it's dimmer in series. So which one do you guys want to use?
Many Youth: Parallel.

This exchange between the youth and the researchers took place the day after the youth had played in small groups while building series and parallel circuits. During that playtime, the youth were left to explore the connections while using multiple LEDs in making both series and parallel forms. The exchange captured above calls attention to two things: 1) the children could apply the definitions of series and parallel circuits correctly, and 2) they had learned the implications of these designs for the circuits (i.e., that parallel circuits produced brighter LEDs while series circuits produced dimmer ones with the battery power available).

Moving Beyond the Club

Beyond learning about circuitry, the real promise of e-textile artifacts is their capacity to follow youth into their peer and family settings, potentially transforming their identities in these social circles and sparking relevant conversations. Demonstrating the power that physical artifacts can have to cultivate these conversations, we present a sample exchange between two workshop participants—8-year-old Ryan and 10-year-old Noah—and Ryan's mother at the end of the workshop:

Mother: What is "L.D."?
Ryan: L.E.D.—it's a special type of light. And, guess what? In Chicago there is a museum with 4,000 LED lights on one dress.
Mother: What is the idea behind this? (gesturing towards the square)...that this works, how?
Ryan: It's the plus...I mean. That here's the plus (points) it goes to plus (points) and through the minus. (To Noah) how does that work (pointing to switch)?
Noah: It doesn't matter which way that goes.
Ryan: Oh, it doesn't?
Noah: No.
Ryan: Then it goes through that (points to switch) and then minus goes to minus.
Mother: So, this is minus?
Ryan: And it doesn't really matter what side this is on (points to switch).
Mother: How does this [project] work? (passes Noah the 3V battery).
Noah: Yeah (takes the battery).
Ryan: You have to put this [battery] on the conductive tape (points).
Noah: Yeah.
Mother: Where is the tape? Is it conductive tape? (Looking closer at the project).
Ryan: Yeah, that means it has electricity through it and we have electricity through us.
Mother: We have electricity...through us?
Ryan: Electricity is basically electrons and protons.
Mother: Ohhh.
Noah : Actually we have a small amount of [it]...Your brain takes 100 watts to work.
Mother: Ohhh.

The conversation highlights the opportunities for Ryan and Noah to display what they learned, facilitated, and illustrated by the presence of tangible, mobile artifacts.

As shown here, several of these circuitry concepts were new to Ryan's mother (at least in this physical incarnation), and the youths' ability to take these projects home with them increased the likelihood that these STEM-related conversations could continue with other family members and peers and in the other spaces in their lives.

As it turns out, new conversations were sparked back at home through the youths' experiences with e-textiles, though they weren't limited to science content. Another youth's mother reported the following day that her 7-year-old son had taken notice "as if for the first time" of the cross-stitching work she had on display at home, having a newfound respect for her crafting techniques. She reported that he had exclaimed, "Ooh, Mom, your stitching is so good here! It's nice and even." This mother later expressed to us that, having all boys, she never anticipated that she could have these types of conversations with her kids. Conversations such as these underscore the ability of artifacts that sit at the intersection of high and low tech to spur meaningful conversations amongst family members.

Discussion

From the marked shifts in the workshop participants' circuit diagrams, as well as their ability to create a variety of functioning circuits using the e-textile toolkits, we gather that the youth learned at least four traditional circuitry concepts—current flow, battery polarity, circuit connectivity, and diagramming circuits in a series—within the context of e-textiles throughout the workshop. The diagramming-plus-"hands-on" components of each workshop activity mirror several of the pedagogical methods that employ more traditional toolkits, and some of the intermediate results—the youths' exuberance at having the bulb in their circuit illuminate or the need for youth to reassess their diagram if their physical circuit failed to work, for example—were shared across both approaches. However, the learning outcomes of the e-textile workshop, where participants significantly gained in their understanding of all four targeted circuitry concepts (Peppler and Glosson, in press), stand in contrast to the difficult learning curve and frequent lingering misconceptions promoted by the instruction of circuitry through more traditional kits as described in numerous studies (R. Osborne 1983; Shipstone 1984; J. Osborne et al. 1991; Asoko 1996; Shepardson and Moje 1994). We believe that the e-textile materials, themselves, may be largely responsible for this difference in outcomes.

What makes these materials so different with regard to youths' learning trajectories? Until further research is conducted, we can only speculate, though we have a number of hypotheses based on our observations.

E-textile tools are "unforgiving"—coated wires, magnets, and snaps to easily affix lines and components together are design elements of traditional toolkits intended to prevent mistakes and consequently have some inevitable trade-offs for understanding how electricity operates. The materials explored here, by comparison, did not put in place such safeguards, so the youth were put in positions to make mistakes through which they could learn about polarity, shorted circuits, and other concepts in the process of troubleshooting. By enabling such opportunities to happen, these tools may afford greater visibility into what makes one circuit work and not another.

E-textile projects provide opportunities for embodied learning of circuitry—working with e-textiles or traditional circuitry toolkits provides tangible, hands-on experiences with building a circuit. However, youth must invest substantially more time in an e-textile project to create a functioning circuit (whereas this could be done in about two minutes using a kit consisting of magnets and snaps as seen in many youth science exhibits). From our observations, we found that deeper, continuous engagement with the e-textiles materials over a longer period of time led youth into deeper and more sustained reflection than what could have been achieved in only a few minutes. In this regard, the speed with which one arrives at an answer may not necessarily be the best indicator of rich learning outcomes.

E-textile projects encourage youth to see familiar phenomena in unfamiliar ways—youth have close relationships with their clothing, as the various types of materials that adorn their persons are seen, touched, and manipulated daily. However, youth don't associate fabric materials or threads with something conductive. Seeing the qualities of these soft materials in unexpected ways enables youth to forge new connections; both because they have previous familiarity with clothing, but also they haven't thought about the qualities of conductive materials, more broadly, as a way of sorting the world.

Our investigation into e-textile creation as a potential vehicle for learning circuits acknowledges that the tools we use and make available play a formidable role in shaping our conceptual understandings, and, moreover, that new tools can bring clarity to concepts that are often challenging. As shown here, e-textile projects can successfully engage youth in core science content—subject matter that has been difficult in prior approaches to make conceptual sense to youth. The workshop youths' aforementioned gains as well as their ability to explain their understandings to peers and parents demonstrate that e-textiles can offer an alternative and also efficacious introduction to electronics.

Workshops such as the one described here demonstrate that classroom teachers can leverage e-textiles for efficacious science content learning. Further research in how to best translate these types of informal workshop environments into classroom pedagogy is still required. Other chapters in this volume provide a start by pointing to workshop models that occur within the school day. Furthermore, although this study focused on simple working circuits and four core circuitry concepts, future research studies could include adding directional flow to the current model as well as more advanced constructions to complex circuitry.

Endnote

1. The zoetrope is a cylinder with static images pasted on the inside. Each image is a slight modification of the previous image. By cutting slits in the cylinder and spinning it, the viewer effectively sees motion.

Textile Messages

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To Seymour Papert, the grandfather of this work

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