Making Technology Visible: Connecting the Learning of Crafts, Circuitry and Coding in Youth e-Textile Designs

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Abstract: We examine high school students' designs with the LilyPad Arduino, an electronic textile (e-textile) construction kit used for designing programmable garments. Each kit contains a microcontroller, sensors and LED and other actuators that can be embedded in textiles. We conducted three workshops with 35 high school youth between 14-15 years in a science museum to document, describe and develop a framework for analyzing student learning. The analyses of workshop interactions, students' artifacts and reflections indicate how the fabrication of stitches, circuits and code reveals the underlying structures and processes of craft, engineering and programming in tangible and observable ways and renders visible how technology is designed and built. We discuss how this situated nature of e-textiles artifact production provides a promising context for student learning and generates new instructional designs of workshops and computational construction kits.

Introduction

This paper focuses on learning with a new type of tangible, programmable media called electronic textiles (e-textiles hereafter). E-textiles include young people's designs of programmable garments, accessories, and costumes. Such designs incorporate elements of embedded computing for controlling the behavior of fabric artifacts, novel materials such as conductive fibers or Velcro, sensors for light and sound, and actuators such as LEDs and speakers, in addition to traditional aspects of fabric crafts using needles, thread, and cloth among others. The development of the LilyPad Arduino (Buechley, 2006) has made e-textiles accessible to novice designers in the same way the design of Lego/Logo (Resnick & Ocko, 1991) did for robotic constructions. E-textiles introduce aesthetic elements that can enrich youth's expressive and intellectual lives and materials that make programming accessible to new groups (Eisenberg, Eisenberg, Buechley & Elumeze, 2006). To date, most of the work around e-textiles has focused on technical developments to test usability and design of materials and activities.

We take the next step in documenting, describing and analyzing the learning that takes place as high school youth engage in designing e-textile artifacts. In understanding students' design processes and products, we focus on how the craft activities situate and connect engineering and programming in e-textiles, making abstract concepts concrete for learners and making the learning that is (or is not) taking place visible to researchers. This is not just an effort to emphasize interdisciplinary connections present in e-textile designs but also to highlight what Eisenberg et al. (2006; see also Buechley, 2010) called the invisibility principle that "when technology is invisible, it is deliberately placed outside the users' awareness; thus there is little reason to communicate how the technology works, and how the user might extend or control it." (p. 2). It might be productive for expert programmers to know that their black-boxed programs may be taken up exactly and used as they are (Turkle & Papert, 1992), likewise average users might find it appropriate and functional not knowing how computer or software works. However, for learners this invisibility might be counterproductive in some instances because students are unable to grapple with the messiness of the technology: to take things apart and put them back together in a multitude of ways (Resnick, Berg & Eisenberg, 2000). In e-textiles, the fabrication of stitches, circuits and code can reveal the underlying structures and processes of craft, engineering and programming in tangible and observable ways and renders visible how technology is designed and built.

Our analyses focus on a series of workshops that took place in a science museum partnering with an urban public high school during the 2010-11 school year. A total of 35 female and male high school freshmen participated in designing e-textiles. While learning how to sew, how to make functional circuits, and how to write code to light up LEDs and control sensors are each important and valuable practices in their own right, learning how to see the connections between these parts is what makes learning to design e-textiles greater than its individual parts. How do young designers see the connections between the stitches they make and the functioning of the circuits they have drawn? How do they understand how writing the code relates to the circuits they have laid out? How can they craft pieces that allow changes in code and vice versa? Finally, what do students' conceptualizations of the relationships between craft, circuitry, and code tell us about what they are learning through their engagement with the LilyPad Arduino construction kit? These research questions are at the heart of the analytical framework we developed to understand students' learning with and through e-textiles. In the next sections, we review what we know about learning with tangible programmable artifacts at large.

Background

E-textiles are a relatively new development (Post, Orth, Russo, & Gershenfeld, 2000) and only in recent years have e-textile construction kits become available to novice programmers (Buechley, 2006; Ngai, Chan, Cheung, & Lau, 2009; Katterfeldt, Dittmar, & Schelhowe, 2009). Most of what we know about learning with such tangible construction kits comes from research on robotics activities developed and implemented across K-16 settings (Bers, 2009; Druin & Hendler, 2000). In general, these studies find robotics to be engaging activities for students of all ages (and even participating parents) but rarely provide much detail on how and what students learn in constructing a robot. A notable exception is a study by Sullivan (2008) that aligned learning robotics with practices and themes relevant for science literacy. She found that building robotics engages middle school students in (1) the "development of certain thinking skills such as computation and estimation, manipulation and observation, communication, and critical-response skills; (2) the ability to engage in the activity of inquiry" and "(3) the development of an understanding of the common themes of science such as systems, models, constancy and change and scale" (p. 374). Robotics activities are now a prominent part of afterschool programs and have developed over the last 10 years into a nation-wide network of competitions.

These findings are relevant for our work because e-textile activities share many common elements with robotics activities but are also distinct in some aspects. Like robotics, e-textiles involve designing and constructing physical artifacts that operate with different sensors and actuators and coordinating interactions via writing of program code. Unlike robotics, the purpose of these artifacts is not to compete but rather is aligned with more personal, decorative goals. Both construction activities are situated in different domains: in the case of robotics the artifacts are associated with the engineering of motors while in the case of e-textiles the artifacts are associated with the crafts of sewing and embroidery. Designing e-textile and robotics artifacts involve an array of different activities, each complex in its own right, that need to be coordinated. Understanding the learning of crafts, circuitry and code then draws on learning in multiple disciplinary contexts that have a longstanding disciplinary tradition, but with e-textiles they venture into newer territory.

The crafting involved in e-textiles is the most unusual practice and also the one that has a minimal foothold in traditional K-12 curricula, at least in the United States. Initially part of home economics, crafting involved sewing, embroidery, and knitting for girls and the wood and metal shop and for boys. Many of these crafts activities have been relegated to vocational schooling. Nowadays, the crafts are experiencing a renaissance outside of school in DIY communities as well as in fabrication labs that allow for personal manufacturing (Frauenfelder, 2010; Gauntlett, 2011). On the other hand, learning about circuitry, and by extension about electricity, is an established part of the K-12 science curriculum. Numerous studies have documented students' difficulties in understanding the concept of circuits (Engelhardt & Beichner, 2004; Perkins & Grotzer, 2005). Likewise, learning of programming has established the multiple challenges that beginning learners face in writing and implementing code (Guzdial, 2004; Palumbo, 1990; Soloway & Spohrer, 1989).

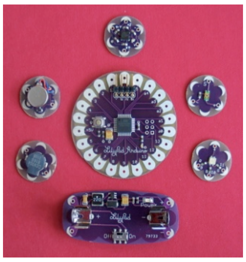
While it is possible to approach the learning with e-textiles from these respective disciplinary foundations, it is also clear that designing and making e-textile artifacts is more than learning discretely about crafts, circuitry or code. In fact, it is the intersection of these three disciplines that makes learning with e-textiles challenging while also providing an authentic context. In particular we examine some of the ways in which the materiality of e-textiles makes aspects of circuitry and programming visible to learners. Previous research has focused on students' alternative conceptions and how instructional activities can progressively enrich students' models of science (Perkins & Grotzer, 2005). Our research examines in more detail the situated nature of students' understanding of electrical circuits and program control flow that overlay and support each other. For instance due to the unusual nature of materials such as the conductive thread, students are challenged to develop understandings of conductivity that draw on some of their informal knowledge about circuits and electricity. Likewise, the less tangible aspect of control flow in programming overlays the coding of sensors and actuators that are connected via circuits. In the production of their e-textile designs, students negotiate and link representations of graphical, textual, symbolic, and material nature and create linkages by literally threading and tying them together. These connections are reminiscent of Blikstein's (2010) bifocal modeling that provides explicit links between physical artifacts and their computational counterparts that allow students to design and experiment with both representations. However, in the context of e-textile design, students are the ones constructing the links. Our analyses are a first effort to build a framework to captures the processes involved.

Methods

Participants were 35 freshmen, 14-15 years old, from a public magnet high school focused on science and technology in a large urban school district. The students' self-identified demographic make up was 23% African American, 29% Caucasian, 14% Asian, and 17% mixed race/ethnicity. Five students chose not to identify their race/ethnicity in survey responses. Just under half of the participants were girls (n=15). Overall, the demographics of the workshops reflected the diversity found in the school and district at large. In spite of students' interests in science and technology, only a few of our participants had prior programming experience and none had ever worked with electronic textiles when they elected to participate in the e-textiles workshops. The workshops were conducted as part of a partnership with a local science museum where students spent one afternoon a week at the museum learning about a topic of their choosing. For this study, we organized a series of three workshops, ranging in length from 4 to 6 weeks. Workshop sessions were held once a week and lasted for two hours. During this time period, students learned how to design and create their own e-textiles projects, beginning with aesthetic drawings, followed by circuit schematics, sewing/crafting of designs, and programming. The first workshop had all novices and therefore the concepts built more slowly upon one another; most students finished very simple e-textiles projects with 1-2 LEDs. In contrast, the second workshop had roughly half returning students and all but one of the students in the third workshop had prior experience with e-textiles. As students gained knowledge, their projects tended to increase in complexity and they experienced greater success. We also became better instructors and began to set tangible goals for each workshop session, like "sew two LEDs and program them," so the construction process became more recursive, with students identifying errors as they went rather than just at the end when their completed project did not function as they expected it would.

Materials

All students had access to the *LilyPad™ Arduino* construction kit (see Figure 1) that enables novice engineers/designers to embed electronic hardware into textiles (Buechley & Eisenberg, 2008; Buechley, Eisenberg, Catchen & Crockett, 2008). In addition, we provided various caps, t-shirts, gloves, cotton bags, fabric and felt pieces on which students could sew their projects in addition clothes or objects student brought themselves. The LilyPad kit is a set of sewable electronic components, including a programmable microcontroller and an assortment of sensors and actuators that allows users to build their own soft wearable computers. Users sew LilyPad modules together with conductive thread instead of traditional tools like insulated wire and soldering irons. To define the behaviors of the project, users employ the popular Arduino or ModKit development environments, enabling them to program the LilyPad microcontroller to manage sensor and output modules (like LEDs) employed in their designs.



The LilyPad™ Arduino kit and components. The microcontroller is in the center, and the other components, clockwise from the top, are: accelerometer, light sensor, tri-color LED, power supply (requires a AAA battery), speaker, and vibrating motor. An FTDI board and USB cable are also part of the introductory kit.

Figure 1. LilyPad™ Arduino.

Data Collection and Analyses

The data collection of all workshops included video recordings (focused on groups working at individual tables), field notes by two independent researchers, photographs of students' projects, and final interviews with students. The writings of field notes and interviews were refined in each successive workshop to increasingly focus on the process of design. For instance, in the final workshop two researchers wrote field notes focusing on the individual design decisions made by students with accompanying photographs of their designs at different stages of production (photographs were taken roughly every 60 minutes). This allowed us deeper insight into the ideas, challenges, and decisions that arose in the design process than was available on videos or in interviews about students' final projects. We also conducted casual ethnographic interviews with students every week in the final workshop, asking questions like, "What are your goals for this workshop?," "What parts of e-textiles do you still need help understanding?," and the more open-ended "tell me about your project." This allowed us to cull reflections from students in *process* rather than just at the end. Thus, like students' projects, the final workshop was the richest in details about students' design decisions and processes.

For analysis of workshop activities and case studies, we conducted a two-step open coding (Charmaz, 2000) of all our data (field notes, logged videos and interviews). To wit, we first began by reading a third of the data and listing some of the challenges of learning to design with e-textiles. We then created an initial coding scheme of the learning challenges, categorized by the overlap of crafting, circuitry, and coding, coded one section of the data together to build consensus, and proceeded to independently code two workshops. We then refined our coding scheme to reflect insights from this analysis of the data and re-coded all workshops. We created a thesaurus of codes with definitions and examples and indexed (i.e., counted) all codes, listing them by date with a 1-sentence summary. This allowed us to see which learning challenges were most prominent in individual workshops or across workshops. Below we discuss the most prevalent codes found across all workshops in regard to students' learning in e-textiles.

Results

In analyzing where students faced the greatest challenges in learning how to design e-textiles, we found some of the most significant learning occurred where the material and conceptual aspects of the projects overlapped. First we explain the ways that the physical aspects of crafting illuminated the inner workings of circuits. Then we describe how the materially embodied circuitry shed light on coding. Both of these findings stretch across the breadth of our data from all three workshops.

How Sewing Reveals the Intricacies of Circuits

When designing and creating their own electronic textiles projects, novices must not only sew (a new experience in and of itself for many students) but do so in a way that takes into account the conductivity of the thread they are working with and the fact that what they are sewing must ultimately result in functional electronic circuitry. In our analysis of students' design of e-textiles, we found three areas that were particularly non-intuitive: sewing for conductivity, tying knots to end a conductive line, and tidying up loose threads that created accidental short circuits. Each of these areas made qualities of circuits visible to the students in ways that they learned about basic aspects of circuitry.

Sewing for Conductivity

At the most elementary level, students learn that they must sew an electronic component to ensure *conductivity* as well as stability. If an electronic component like an LED is sewn too loosely or the stitches are too large, the connection between the component and the conductive thread may be lost when the textile bends. Unlike using alligator clips or soldering wires, where electricity is easily conducted on a slight touch between metal and metal, when attaching electrical parts to something more malleable like fabric, one must work (sew) to make sure there is a consistent physical connection. This is the most basic element of conductive sewing but it is not intuitive to novices. Nathaniel described this as a very frustrating part of making his project:

> RESEARCHER: What was the hardest part about the project?
> NATHANIEL: The sewing. The sewing.
> RESEARCHER: Why?
> NATHANIEL: Like, I know I went through it once, and I had like finished the thing. But it got loose. So I had to unthread it all, go back again.
> RESEARCHER: Because you hadn't sewn it tight enough?
> NATHANIEL: Yeah. *(Dec. 15, 2010, Video)*

Though Nathaniel thought his project was sewn adequately, when he tried to turn his lights on, the connection between the light and the conductive thread was too loose and he had to re-do the project. This happened for many students. We found that despite our instructions from the very beginning to sew each light with three stitches, most students did not do this until they understood the *reason* for this was to create a conductive connection. Thus students' understanding (or lack thereof) of this introductory concept of electrical circuits was made visible in their sewing for conductivity.

The Importance of Tying Knots

Whereas sewing electrical components on fabric made visible the need for conductive connections, tying knots revealed the way electricity takes the path of least resistance in a circuit. For instance, in order to direct electricity to flow through an LED one must consciously tie a knot to end the positive connection on one side of the LED, cut the thread, and start a completely new line of thread on the negative side. This separation between the sides is less visible when one uses alligator clips to connect an LED to a power source because the alligator clips have to be connected at each end anyway. Thus, even after using alligator clips to make and test circuits, in moving to thread many students made the common mistake of using one uncut thread to sew through the sides of an LED, in effect bypassing the LED in the circuit. Mallory described this mistake below.

> MALLORY: I just now learned like, when I sew here like. When I first, I was sewing through the positive part of [the LED]… [then] through the negative side and then so, it was kind of hard for me cause I was doin' it incorrectly? But now, I know not to.
> RESEARCHER: Do you understand why that doesn't work?
> MALLORY: Yeah… Well it's gonna go over it [the LED]. *(March 2, 2010, Video)*

Here Mallory described how she had sewn through both ends of an LED with the same thread, not realizing that she had to cut and separate the sides in order for electricity to flow through the LED rather than thread. As students began to understand conductive pathways, they came up with the phrase "sew like alligator clips" to formalize the concept.

Because of the non-trivial effort it took to tie a knot at the end of each positive and negative sewn line, especially for novices sewers, students were anxious to find ways to minimize the number of knots they needed to tie. They were keen to simplify their circuits, which could be done by using one conductive line to connect the negative (or positive) sides of multiple LEDs *without* the need to tie knots at every end (for an example see the diagram on the right of Figure 3, knots are shown in stars). So, it is okay to sew continuously through the negative ends of multiple LEDs but it is not okay to sew through the negative and positive ends of a single LED without tying knots and cutting the thread to direct electricity through the LED. To our surprise, we found the best way to convey this concept was to describe it in terms of how many knots they needed to tie. We showed this by comparing multiple electric diagrams and having students re-draw the electrical connections for the "fewest knots." Silas reported proudly about learning to rearrange circuits by connecting multiple sewn lines (i.e., "wires"):

> My learning experience with the lights has definitely changed--that's one thing. I can like, now, now that I know, um, the electric, um, what is that called? What am I trying to say? Um, how to hook up one wire [thread] from one end to another with positives and negatives, how to connect multiple wires [threads], and create multiple lights on 'em. *(March, 2011, Video)*

Many students like Silas said their favorite learning experience was figuring out what could be sewn together and what had to be sewn individually. This learning changed their designs substantially, with almost all students re-orienting their circuits so that either the positive or negative sides of their LEDs could be connected in one line, allowing for many more LEDs to be sewn on with fewer knots and less sewing effort.

Loose Threads Mean Short Circuits

One final circuitry concept that the element of crafting made visible was short circuits. In conductive sewing, crossed threads (which work like non-insulated wires) amount to crossed negative and positive lines, resulting in short circuits. This is non-intuitive from a crafting perspective where we are taught that "the back doesn't matter" because no one will see it when the project is finished. Yet in e-textiles, loose threads or too much sewing in a small space can cause the project to fail. Amari and Marcela learned to identify this problem in a project where they were trying to figure out why the LEDs would not turn on:

> AMARI: 'Kay, I think I found the problem with this.
> MARCELA: Okay, what is it?
> AMARI: Okay, I was looking at the back of it, and I think the problem is that if you look at it closely, these [threads] are all overlapping each other and that could affect the conductivity. *((Pointing to overlapping threads on the back))*
> MARCELA: "Oh yeah, 'cause negative can't overlap the positive. *(May 20, 2011, Video)*

When Amari pointed to the back of the project where many long ends of threads were touching, Marcela correctly identified this as a problem with short circuits where the negative and positive lines were overlapping. The girls solved the problem by trimming the threads and tying the knots closer to the surface of the fabric where they couldn't get loose and touch each other. All students struggled with the issue of short circuits, coming to terms with the idea that the threads conducted electricity even if they were just the loose ends of knots. Yet though it took time to learn this idea, by the end of each workshop, loose threads became one of the first things students looked to when trying to make their LEDs turn on.

How Embodied Circuitry Reveals the Intricacies of Coding

Not only did the materiality of crafting circuits bring out some conceptual issues about circuitry and electronics, but the crafted electronics revealed some concepts about coding and vice versa. At the most basic level, students learned that connecting LEDs to the LilyPad microcomputer was not the same as connecting them to a battery. First, the LilyPad had to be programmed. Kyra demonstrated her partial understanding of this idea when, having finished sewing her project with two LEDs connected to pins 8, 10, and a negative ground, she programmed pin 8 and then wondered why only one LED flashed on. A researcher pointed out to her that she had not yet programmed pin 10 – perhaps an obvious idea to people with programming experience but a novel idea to beginners. A week later Kyra summarized this episode as one of her most important learning experiences when she said "It helped me understand that things – that most things – can't work without a code" (Dec. 15, 2010, Video). Below we describe other ways that students learned about coding through circuitry, and circuitry through coding. We note that in each case, it was not until designs were actually material (sewn circuits) that the relationship between the two became clear to the students.

Why Parallel Circuitry Might Not Be the Best for Blinking Patterns

One challenge that students faced was to learn the affordances of different kinds of circuits. As we mentioned above, students had a vested interest in tying as few knots as possible and for this reason many were interested in making parallel circuits, with one continuous negative line connecting the negative pins of several LEDs and one continuous positive line connecting the positive pins of the LEDs. However, when it came to coding their circuits, they began to realize that parallel circuits did not afford them any opportunities to have their LEDs blink at different times – the shared positive and negative lines meant that all of the lights worked together. For instance, when Aaliyah was drawing out the design of her five-point star with an LED on each point, she decided that some of the LEDs should be sewn in parallel (see left diagram in Figure 2). However, two weeks later after her project was partially sewn and she had made some of the LEDs turn on, she changed her mind as she realized that she would not be able to blink each light independently (see right diagram of Figure 3 for final design). Her old design would not allow her to turn each LED on one by one, rather they would go on in groups that she could never change. This was a common dilemma students faced as they began to understand the relationship between the programming effects they desired and the implications of the design/crafting of their circuitry.

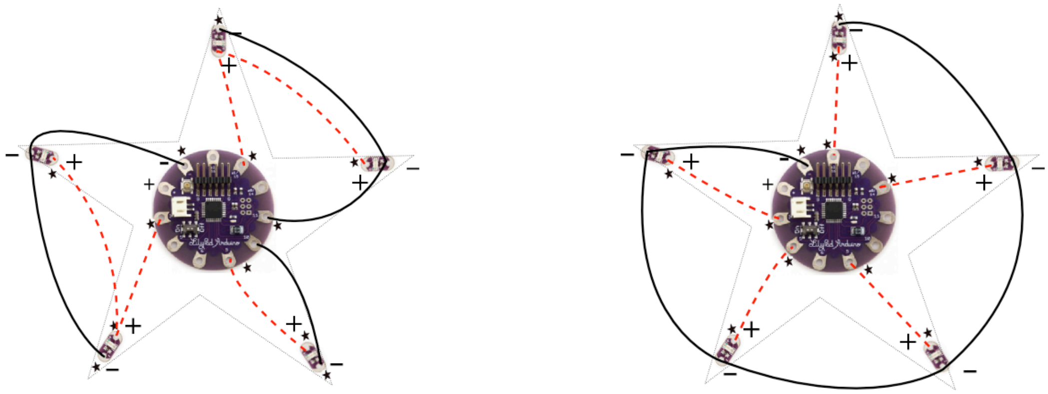


Figure 2: Aaliyah's original design (*left*) with two parallel circuits & one additional circuit and final design (*right*). with five independent circuits with a shared negative line. Negative lines are solid, positive lines are dashed, knots are shown with small stars (*).

On Hardwired and Programmable Ports

Another challenge that students faced at the intersection of circuitry and programming was learning about the affordances of the LilyPad. Two pins on the LilyPad (the + and the – pins) cannot be programmed and have constant polarization. The remaining (numbered or lettered) pins can be programmed to be either positive or negative. The first realization that students came to was the difference between these two types of pins. One type (the positive and the negative) was unalterable, while the other was completely programmable. Marcela described this as one of her biggest realizations: "I didn't get in the beginning why, you know how you connected to negative and then positive? I didn't get what does the number represent... And I didn't know you could make it anything you want." (March 2, 2011, Video). Once students realized that they could program any numbered or lettered pin on the LilyPad to be either positive *or* negative, they had a great deal of freedom to design their circuits. Still, the implications that some pins were hardwired while others were programmable did not come easily to everyone. Below we share how Amari became conscious of this relationship between circuitry design and programming:

> Amari had finished putting her 5 LEDs on the points of her five point star with the negative ends of the LEDs connected together around the outside (in a circle), securing them to the fabric and connecting the negative line to the – pin on the LilyPad. When she was sewing her first LED to the LilyPad (the outside part already finished) she asked where to connect it. I directed her to the #3, the closest numbered pin to that particular light. 'But what about the positive?' she asked, pointing out that the + pin was even closer. 'Well if you do that, the light will always be on - you won't be able to control it on and off,' I said. 'Hm. I won't mind. I'm going to do it anyway,' Amari said. *(May 18, 2011, Field note excerpt)*
>
> Amari programmed her lights to turn on, making them blink. The LED that she had connected to the + and the – pins of the LilyPad stayed on continuously. 'I know that you told me it

> would always be on and I did it anyway, but want to re-do it,' Amari said. Then she cut off the positive line of that LED and re-sewed it to a different, programmable pin on the LilyPad all on her own. (*May 25, 201, Field note excerpt)*

In this example, Amari did not seem to realize the full implications of connecting an LED to the hardwired pins until she had sewn her entire project and programmed the LEDs to blink. Then the implications of her circuitry design on her programming capabilities registered and she went to the trouble of undoing and redoing part of her project so that there were greater affordances for programming. Though it was frustrating to us to watch students make decisions that would limit their designs despite our admonitions, we were surprised at how many students were willing to re-design their projects, some going to great trouble to do so, when they finally understood why certain circuit designs would not allow for the programmed lighting effects they desired. It was truly a process of learning *through* design.

Discussion

One goal of our investigation was to understand how making technology visible could be beneficial in students' learning with e-textiles designs. In order to examine this aspect, we needed to understand first the particulars of how students approached the connections between circuit and code. Most of their problems fell into two areas: creating circuits with fabric and thread and programming physically laid out circuits. Remarkably, both of these broad categories involve the juncture of the conceptual and the physical, such that the material qualities of e-textiles made visible the conceptual issues of electronics and programming. In other words, the infusion of crafting into the domains of electronics and code made visible the inner workings of circuits and programming. Thus it was the initial move from circuit diagrams to actual sewn circuits and the subsequent move from abstract concepts of code to coding physical circuits embedded in cloth that held both the greatest challenge and, as we argue, some of the greatest opportunities for learning.

We see these findings as evidence that in certain circumstances it might be helpful to make technology visible for learning. Far too often technology designs are hidden away, and that purposefully so. Indeed, intentional invisibility or blackboxing has always been part of educational design. But even computational construction kits blackbox certain aspects of computation and processing so that novice programmers can focus on essential aspects of programming such as understanding control structures or variable inputs while not having to worry about syntax. In the end, these are always educational decisions on what to render visible or what to leave invisible (Resnick & Silverman, 2005). One can question whether students actually would be better served in not dealing with the knotty aspects of sewing in order to focus more on the functional aspects of designing circuits and programming sensors and actuators. Some e-textile construction kits indeed have provided a shortcut to the sewing by using snaps rather than thread and needle (Ngai et al, 2009). As such any computational construction kits makes certain aspects of e-textile design visible while hiding others, but the involvement with the design and functionality of technology is still miles away from the limited point-and-click interactions available in many commercial textile construction kits (Kafai et al., 2010).

Finally, using textiles and crafts in the digital age invariably brings the gender issue to the fore – an aspect that we have dealt with in a different paper in more detail – but which does belong to any discussion about technology and learning. E-textiles, of course, by design brings together sewing and fabrics that have been historically more associated with females together with engineering and computing that have been historically more associated with males (Searle, Kafai & Fields, in preparation). In this paper we examined the complicating of learning by making connections between crafts, circuitry, and code visible while a focus on gender reveals a complicated relationship in how cultural norms define who see themselves as technologists in the making or not. As such e-textiles occupy fertile territory for thought. Along the same lines, the domains of crafts and fabric also push to into the foreground issues of aesthetics and learning that are rarely discussed in the context of science and engineering (Fields, Kafai, & Searle, 2012). Functionalities present a rich context to think how personal uses can become motivations for functional aesthetics. Our study gave us rich food for thought on how to create and expand already popular hands-on activities for learning science into the computational realm.

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