Cupcake Cushions, Scooby Doo Shirts, and Soft Boomboxes: E-Textiles in High School to Promote Computational Concepts, Practices, and Perceptions

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ABSTRACT

In this paper, we present and discuss the use of electronic textiles (e-textiles) for introducing key computational concepts and practices and broadening participation and perceptions about computing. The starting point of our work was the design and implementation of a curriculum module using the Lilypad Arduino in a pre-AP high school class. To understand students' learning of concepts, practices, and perceptions of computing, we focused on the structure and functionality of circuits and program code and their design approaches to making and debugging their e-textile creations, and on their views on computing by examining pre-post interviews. Our discussion addresses the challenges and potential of using e-textiles materials and activities for designing introductory courses that can reach a broader student population.

Categories and Subject Descriptors

K.3.0 **[Computers and Education]:** General

Keywords

Electronic textiles, education, K-12

1. INTRODUCTION

In the past decade, many efforts have focused on broadening access to and participation in computer science education to address the generally low number of students interested in CS and the underrepresentation of women and minorities in the US [21]. Some have developed programming tools to simplify the mechanics of learning to program thus helping young, novice programmers to become more fluent and expressive with new technologies [17]. Others have examined the social and cultural barriers that impede participation [18] or focused on the use of new activities like game and story design to recruit more girls and women into computing [8; 10; 13]. Efforts are also underway to create networks of opportunities through statewide alliances between schools, afterschool programs and college outreach [3].

New developments of tangible construction kits such as the Lilypad Arduino [4] include sewable microcontrollers, sensors and actuators, to teach programming and engineering concepts. While e-textile construction kits are similar in many functional aspects to robotics construction kits that connect to engineering and computing, they use soft materials rather than motors and gears, and bring in crafting techniques such as sewing that historically have a more feminine orientation. In previous work [14], we described youth's learning with e-textiles in an after school environment as taking place at the intersections of crafting, coding, and circuitry, which allowed us to capture the interdisciplinary nature of e-textile designs. Here, we extend these descriptions to current developments in computational thinking [21] using a framework developed by Brennan & Resnick [2] to make it relevant for in-school application.

In this paper, we report on the design and implementation of a 10-week e-textile module we conducted with 15 high school students (16 - 18 years) as part of a pre-AP CS class. We analyzed students' completed artifacts, design approaches (and how they evolved over time), and reflective interviews guided by the following research questions: (1) How were computational concepts and practices reflected in the design of students' e-textiles? (2) What changed in students' perceptions of computing? In the discussion, we highlight what we can learn from our experiences about developing new introductory courses in K-12 computing.

2. BACKGROUND

There are many compelling examples of how computing curricula can not only provide a rich introduction into computational concepts and practices but also generate personally relevant contexts, provide bridges to real-world applications, and connect to larger groups of students. Successful approaches on the college level have used programming multimedia applications [12], testing game designs [10], or designing mobile apps [22]. On the K-12 level, robotics [1], interface designs [23], game design [13] and storytelling classes [16] have been also successful in broadening students' participation in and perceptions of programming.

However, curricular extensions that build on arts and crafts oriented activities and materials have received far less attention. The recent development of commercially available e-textile construction kits such as the LilyPad Arduino and others provides the missing connection between craft-based activities and computing [6]. But so far, most activities have focused on afterschool programs, leaving the 'more serious' programming to traditional activities. In order to expand the portfolio of available computing curricula, we developed and implemented an e-textile unit as one component of a pre-AP CS class in high school.

Bringing e-textiles into the classroom requires us to articulate what exactly that is that students are engaged in and how their learning relates to what is valued in computing. In previous work [14], we conceptualized youth's learning with e-textiles as taking place at the intersections of crafting, coding, and circuitry, which allowed us to capture the interdisciplinary nature of e-textile designs. Equally important is to establish a connection to computational thinking that Wing [21] described as the "ability to engage in problem solving, designing systems, and understand human behavior" (p. 6). Brennan & Resnick [2] distinguished between computational concepts, practices and perspectives to highlight the multiple dimensions of computational thinking. Computational concepts refer to elements such as sequences, loops, parallelism, events, conditionals, operators, and data structures that are present in many programming languages. Computational practices refer to activities such as being incremental, reusing and remixing, testing and debugging, and modularizing and abstracting that designers use to create programs. While some aspects of concepts and practices appear to be easily applicable to what is being accomplished in making with e-textiles, it is not clear how the interdisciplinary elements such as the circuitry and crafting will be being accounted for in students' learning.

Computational perspectives such as expressing, connecting, and questioning refer to worldviews that designers develop as they engage with digital media. Computational perspectives connect to a core concern in broadening participation that focuses on learners' perceptions of computing, how students define computing, where they see applications for computing, and how they see themselves within the field and future careers. Studies that have examined students' perceptions of computing [8; 27] often hear descriptions such as "being boring or tedious", "only for smart students", "antisocial", and "lacking creativity." The classroom implementation we conducted affords us the opportunity to re-examine these perceptions because of the particular positioning of e-textiles within a larger computing culture. By design, e-textiles are a hybrid, combining traditionally masculine activities such as engineering and computing with traditionally feminine activities such as crafting and sewing. We were interested in whether learning with e-textile materials could indeed broaden not only participation but also perceptions of computing. Taken together, the focus on computational concepts, practices, and perspectives allows us to examine students' understanding of core CS concepts, the generative thinking practices students developed through the process of bringing their e-textile designs to fruition, and students changing perceptions of computer science.

3. METHODS

3.1 Participants

A class of 15 students (7 girls and 8 boys) ages 16-18 years from a public high school participated in a 10-week (19 meetings) e-textiles module as part of their elective computer science class. The students reflected the demographic makeup of the school: 49% African American, 8% Latino, 7% Asian/Pacific Islander, 34% White, and 2% Other. Because the school is a public science and technology magnet school, each student is issued a laptop. Students in the class had spent September to March working with programming in Alice and many had also taken a physics course where they programmed robots, but students had no prior experience with e-textiles. The course met twice a week for 65 minutes per session. While the course was implemented twice, with 15 different students each, in this paper we report only on the second implementation from March to May 2012. The designer and teacher of the course was one of the co-authors (Kaplan), a fourth-year undergraduate majoring in digital media design with an interest in becoming a computer science teacher. He created curricular materials and had two years of experience teaching after-school e-textile workshops but had little classroom teaching experience. He developed the e-textiles curriculum (described in more detail in 4.1) and taught it as part of his senior capstone project for his education minor. Additionally, a graduate student (Searle) with prior experience in both e-textiles and teaching collected observational data. She aided students with e-textile design, construction, and coding as needed and documented research in field notes and interviews.

3.2 Analysis of E-Textile Projects

We documented students' design processes through collection of hand drawn "blueprints" of designs, hourly photographs of their e-textile designs, and copies of their Arduino code. We then created portfolios for each student where we combined the elements described above to provide a more complete portrait of the learning of computational concepts and practices as students moved through the process of creating their e-textile artifacts. To understand students' learning of computational *concepts*, we examined circuit designs, code and final artifacts to evaluate how students used input/output, digital and analog connections, control flow, and structures such as sequences, conditionals, loops, operators, and variables in Arduino. Then, to get a grasp on students' learning of computational *practices*, we inductively identified different approaches to computing evident in our observation notes about students' design processes and within students' designs themselves. We classified these approaches as incremental practices (developing a little bit, trying out), reusing and remixing practices, and testing and debugging practices.

3.3 Analysis of Interviews

In order to understand students' computational *perceptions*, we analyzed pre/post interviews in which students reflected on their e-textile designs as indicators for how they saw computation as a medium for expression. We conducted substantive (30+ minutes each), semi-structured pre- and post-interviews with 11 of the 15 students in which we asked students how their project had changed from their early ideas to completion, what they were most proud of and what was most challenging, what they felt they had learned about computer science in the process, whether their ideas about computer science had changed, and whether the project had influenced their future goals. All interviews were logged and then analyzed [7] focusing on the three aspects: personal relevancy of computing, potential study and career path in computing, and expanded understanding of computing at large.

4. FINDINGS

4.1 Design of e-Textile High School Class

The design of the e-textile class initially followed an outline proposed by Buechley and colleagues [5] that structured the course into six units focusing on circuit designs, code, and materials. While we used some of these units in our course (such as learning about circuits and code), we decided to design activities around students' completion of individual e-textiles projects that included four or more LEDs (light-emitting diodes) and two or more electrically conductive patches. Table 1 provides an overview of the focal daily class activities and materials (e.g., sample designs, starter projects, debugging activities, design consultations, flexible lessons and assessments) that proved to be instrumental in communicating key ideas and helping students complete their projects.

Table 1: Overview of e-Textile Class Activities

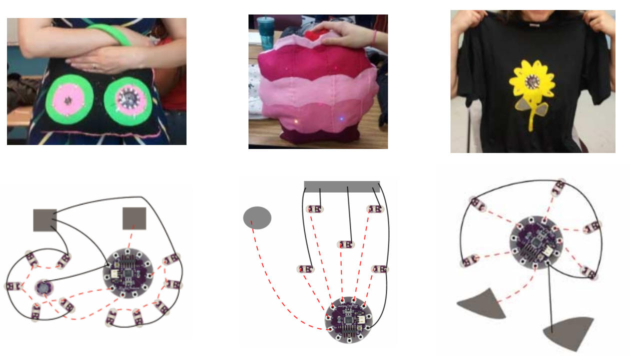
Days	Activity	Description
1 -3	Simple Electric Circuits & Conductive Sewing with Starter Projects	Brief review of electricity (how it works, using a flashlight, introducing basic notations); Students make simple circuits using alligator clips, a battery, a switch, and 1 LED followed by learning how to sew with conductive thread to create their first soft circuits. Finally, in pairs or small groups, students work through a series of simple circuit debugging activities.
4 - 5	Programming with Arduino & LilyPad ProtoSnap Boards	Instructor demonstrates on screen how to program LEDs on the ProtoSnap board. Students then program in pairs, turning on multiple LEDs and exploring various blinking patterns and other actuators (e.g., vibe board and sound buzzer). Variables introduced at the end of day 4.
6-8	Basic E-Textile Design Schemes & Individual Design Consultations	Introduction of computational circuit diagrams showing two conductive patches and four LEDs connected to the LilyPad. Students generate their own designs, focusing first on their chosen aesthetic and later on the logistics of circuitry and coding. "Design Consultations" were required before construction could begin; a course instructor or expert research team member met individually with students to finalize their design diagrams.
9 - 18	Culminating E-Textile Design: Crafting, Coding, & Debugging	Students implement their designs, first cutting pieces of conductive and non-conductive fabric and ironing these on their project. Then students sew electrical components together to the LilyPad, testing each line with alligator clips and/or a multimeter. Short lessons on code concepts are interspersed amidst longer periods where students work on their individual projects. More complex coding concepts are introduced on an individual basis as they are relevant to students' projects. Students iteratively test and debug their designs, developing solutions to address them. Some students add new components on toward the end.
19	Final Presentations	Students demonstrate and explain their e-textile project.

In completing their e-textile projects, students demonstrated the ability to customize designs in ways that were both functional but also aesthetic, with a personal touch. Projects had to follow certain guidelines, namely to include a LilyPad microcontroller, 4 LEDs, and at least 2 conductive patches that, when pressed at the same time, acted as a sensor of electrical resistance. It was the freedom within these design requirements that afforded creativity for students' designs in terms of what they made and how they made this, which in turn led to deeper learning [11]. In addition, we provided a *template* for students showing how these components could be connected together and required one-on-one *design consultations* to help them finalize their circuit designs. Yet, the diversity of students' projects surprised us; these included a stuffed octopus, a soft boombox, a cupcake pillow, a Scooby Doo shirt, and a Jamaica-themed shirt. Students' adapted the template to the requirements of their own projects. For instance, in making his soft boombox, Lloyd created two sets of 5 LEDs in parallel circuits that interacted with two conductive patches and a sound buzzer. In his Scooby Doo t-shirt, Will used 4 positive patches that each acted as separate sensors when connected to a central negative patch. These and other innovations required intricate circuit topology both for efficiency (e.g. using a common negative thread to connect multiple LEDs) and insulation (i.e., keeping positive and negative lines from touching). Variations of circuitry further led to innovative coding in order to determine the conditions and effects of the size of the conductive patches, which provided different ranges of resistance (from 800-1000, from 450-1000, etc.), the number of patches that allowed for multiple inputs, and the numbers and placement of LEDs and other actuators. Thus, the design constraints allowed for creative variance that provided unique technical challenges for each students. Additionally, this creative freedom helped students feel a great deal of ownership in designing their projects, something we discuss further in section 4.3.

4.2 Computational Concepts and Practices

Another way to understand the complexity and learning in making e-textile artifacts, is to examine more closely *how* students approached making them, their computational practices, and *what* they included in terms of computational concepts. Before any e-textile can be programmed, it needs to have functional circuits that connect sensors and actuators to the LilyPad Arduino. All students accomplished this in their e-textile designs. However, the actual circuit diagrams varied significantly. Students differed in how many pieces they connected, what kind of circuits they used to accomplish their desired efforts, and most importantly, how they coordinated functionality with their aesthetic requirements. How much functionality drove aesthetics and vice versa, is difficult to gauge, but it was a constant tension in students' design processes, complicated further when coding demands were integrated that required particular circuit designs [14].

Many of the initial circuit blueprints had some mistakes and demonstrated a lack of efficiency. For example, students did not make connections between negative pins and devices, crossed negative and positive lines, made redundant circuit lines, or lacked efficiency in connecting positive or negative lines (i.e., making many independent lines instead of strategically utilizing continuous ones). However, we observed that all students developed final designs that were refined and efficient, customized to their aesthetic requirements and the functionalities they implemented through coding. For instance, in making her cupcake pillow, Trinity changed her initial circuit design to minimize redundancy. Instead of having negative lines from five LEDs criss-crossing her design, she directed them all to one large negatively charged patch which acted as a common ground. She also re-ordered the positives lines from the 5 LEDs such that they made more sense spatially. Her final design was more symmetric, made better use of space, and was more efficient to sew (see Figure 1). Similarly with his octopus, Marty came up with a clever design solution, replacing 8 independent lines from the LilyPad to 8 LEDs by making the back of his stuffed octopus one large conductive patch that acted as a continuous negative line to the LilyPad and the 8 LEDs. Other students utilized parallel circuits in order to connect multiple LEDs that they wanted to behave similarly or expanded their projects to include additional components like speakers or extra LEDs. Of course, these changes affected each student's development of code for his or her project.



Lloyd	Trinity	Giuliana
If 2 patches touched, - each LED ring blinks on and off in turn while sound buzzer plays "Super Mario's theme" song. *Else if two patches squeezed, each LED ring blinks on and off in turn without music.* *Else, all LEDs off.*	*If two patches touched, - all LEDs fade in and out.* *Else, all LEDs turned off.*	*If two conductive patches touched, - each LED blink on and off in a counter-clockwise direction* *Else, all LEDs e turned off.*

Figure 1: Selection of student e-textile designs: Lloyd's boombox, Trinity's Cupcake Cushion, Giuliana's Sunflower shirt

While each project had different layouts and programmed behaviors, the Arduino program code for these final projects all incorporated key computational concepts such as sequences, loops, conditionals, operators, and variables. First, to set up the digital or analog pins on the LilyPad Arduino that connected input or output devices, students had to understand the relationship between the layout of their electronic circuit and the program code. Second, students had to define output of four or more LEDs. Some students added a speaker to their circuits and remixed the starter code (which we provided) to make sound. To accomplish these tasks, students learned how to include delay functions to adjust how long an LED stayed on or to synchronize LED lights with the beep sounds. Third, students had to code output behaviors for the sensors that connected to the two or more conductive patches. This required the use of conditional statements and loops with variables for storing input values. Some programs featured more complex functionality using multiple conditional statements.

Students engaged in various computational practices to design circuits and code, but mostly in an iterative cycle of imagining and designing and constructing a little bit, then trying it out, and then developing it further when they designed circuits and code. While we provided two basic starter code examples, all students had to customize the code to work with their particular physical designs. We found that all students were able to use and remix starter code examples to create specific behaviors for their circuit designs. In this process, students needed to test and debug the code to make sure that their projects worked as expected. Debugging e-textiles is a complicated process, more so than debugging regular program code, because not only the code but also the circuit design or crafting can cause bugs that need to be fixed. It is these interdependencies [14] that engage students in complex problem solving.

4.3 Perceptions of Computing

Relevancy of Computing. Previous studies have found that students often see computing as irrelevant to their own lives [9; 24]. In pre-interviews, most students revealed that coding remained a mystery removed from their everyday interactions with computers. Carlton expressed a common theme when he said, "I'm sure computers are lovely, but it's not something I'd like to delve into." This sentiment was shared by other students who stressed a disconnect between their everyday lives, future career aspirations, and computer programming. Megan described wanting to go into a career in international relations and said, "I think that I'd use computers, but it's not like I'll be doing coding or anything." We highlight this gap between the perceived need for computing in current and future lives, in particular because it is still prevalent even in science and technology magnet high schools.

In post-interviews conducted after the e-textiles module, students demonstrated a shift towards viewing computing as more relevant to their identities, their daily lives, and their career choices. Students stressed that e-textiles provided the opportunity to use computing as an outlet for personal creativity, or customizability. Many students (7 out of 11) focused on the *aesthetic customizability* of a project. Lloyd, for instance, said that he had been tuning out in the course prior to the e-textiles module but contrasted this with his positive engagement in making a soft boombox. Describing his project he said, "This is music, it's a boombox. A boombox expresses how I feel....Music is my identity." Fewer students (4 of 11) focused on *behavioral customizability* noting that they could shape not only how a project looked but also how it technically functioned.

In addition, more than half of the students (6 of 11) articulated how their e-textiles projects could fit in with or be used in their everyday lives and, by extension, recognized other devices they used in their daily lives that were programmed (cell phones, for instance) or could be programmed (a doorbell). For instance, Megans's project allowed her to transform an "ugly" shirt from her uncle into a useful object, which she can both use to scare her younger siblings and as a Halloween costume. Abeni and Trinity initially conceived of their projects as gifts for others. Keenan and Lloyd both described how they wanted to include their e-textile projects within their personal trophy collections as proof of their accomplishments.

Ability to See Oneself as a Computer Scientist. While all the students saw themselves as fairly competent in using technology on a daily basis—this self-assessment should not come as a surprise since all of them elected to be part of a science and technology magnet school—there were still substantial differences in how their perceptions of themselves as programmers shifted. A large group (7 out of 11) was initially intimidated or even completely disinterested in programming but felt greater competency after the class, expressing a sense of accomplishment, or even surprise about the fact that 'I did this.' Giuliana initially described herself as someone who was not good at programming but after the class she talked about her project (and specifically learning to write in Arduino) as a huge accomplishment, "I think it's just this moment like, "I did it! Finally... Yup. I'm that cool. I programmed a shirt to light up.... I think it's just that moment of accomplishment."

The remainder of the interviewed students (4 out of 11) felt more expertise in programming at the beginning, but after class felt more validated in this expertise after having demonstrated their increased ability to identify and solve programming problems with e-textiles. Reflecting on the class Raven described how exciting it was to speak the same language, "Like we're talking in terms that I've never thought I would never speak… And I'm like, 'I'm understanding everything that you're saying', which is really nice." She connected her ability to understand problem solving and computing with being part of a larger community, with which she now shares a common vocabulary and understanding. Some students like Will, who self-identified as someone who knew about programming before class, proclaimed that they now more clearly understood the connection between programming an e-textiles project in class to programming in other situations, like video games at Activision.

Perceptions of Computing as a Field. Most students also gained a better idea of the field at large, initially conceptualizing computing as something contained only "within the screen" but expanding it after class to see included tangible, real world objects. This perception was most clearly connected to the unique e-textiles projects themselves; almost all students noted that the class was more "hands-on" and that you could really "touch" the products you were working on (as opposed to computer programs in Alice). Trinity liked the e-textiles took programming "outside of [the] computer", while Megan pointed out, "we can touch it, we can feel it, we know what's going on". Several students also described the tangibility of the project with respect to how they could more easily 'show off' their projects to their friends and family once it was done. When asked what she would do with her project, Abeni replied, "Hang it in my room. So when my friends come in, they can touch it. My parents don't know about this, so... it's really cool." Some students even went further by relating projects to professional applications in the real world. In some cases, this meant seeing their individual projects as being on a trajectory toward professional e-textile projects, such as LED sneakers for children or costumes worn by celebrity musicians.

5. DISCUSSION

We see the introduction of e-textiles into high school curriculum as part of a larger effort to broaden the portfolio of available materials, activities, and pedagogies in CS education in K-12. Our findings indicate that the class was successful in promoting a rich array of computing concepts and practices while at the same time broadening perceptions of computing. Designing e-textiles addressed many of the reservations that youth often have expressed about computing: it integrated multiple disciplines of computing, engineering and crafting, had real-world relevance since it involved repurposing and augmenting everyday items, and allowed for creative expression through the creation of personal e-textile artifacts within given design constraints [24]. It was the unique combination of all these aspects, not a single one alone, that accounted for the success. Through our analysis of the students' perceptions of computing before and after the e-textiles class, we demonstrated how creating e-textiles artifacts shifted their perspectives on computing. Students expanded in their thinking about relevancy of computing to their personal lives, understanding of themselves as computer scientists, and their understanding of computing as a field. Admittedly, we have downplayed the role of crafts and the physical techniques of creating soft computational circuits in order to emphasize more traditionally valued academic learning in circuitry and coding. Yet these aspects are intricately related to the particular development of circuits and code in e-textiles [14].

While we didn't have the room to describe in much detail the various curricular activities beyond the final culmination e-textile project, we believe these played an equally important role in helping students to learn computational concepts and to engage in computational practices. Like robotics workshops, we did structure the e-textile class around the activity of designing a final artifact as its ultimate outcome. But we also made generous use of a series of smaller stepping stone starter and debugging projects along the way that provided additional experiences for students to understand the complexities of particular design aspects. For instance, *starter projects* with a simple circuit that includes an LED, battery, and switch provided introductions to conductive sewing. Students learned sewing techniques as well as key rules of thumb: (1) connect positive to positive and negative to negative, (2) do not sew through both the positive and negative ends of a component, and (3) do not cross positive and negative threads/lines. Alternatively, *debugging projects* [15], presented students with problems in circuit or code design of finished e-textile projects. For instance, one debugging project tested students' knowledge of short circuits while in another they had to correctly connect a series of positive and negative lines to create a functional circuit, and in yet a third they had to alter the connections to obtain the desired behavior when a button switch was pressed. As students worked through the debugging projects they were asked to complete a series of questions about each circuitry problem.

All high school students were equally engaged in the various aspects of crafting, circuitry and coding and this should perhaps be counted as the biggest success. Many of the other curricular innovations such as game design and robotics workshops are often heavily geared towards male students because of how the professional communities are structured. In designing e-textiles, we found present what Resnick and Silverman [19] called the "wide walls" of construction kits that allow for diverse set of interests to expressed in programmable activities. But rather than to work in the "existing clubhouse" we opened a new one, or new doors, to stay with the metaphors of low floors, high ceilings, and wide walls that are often used in thinking about creating computational construction kits for beginners. Making personal and portable computational projects with materials that connect to everyday experiences and mundane activities such as crafting and sewing provided a new window to see the general and personal relevance of computing.

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