Diversifying High School Students' Views About Computing with Electronic Textiles

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ABSTRACT

More than twenty years ago, Turkle and Papert wrote about the lack of epistemological pluralism in computing and the resulting exclusivity in the field. Although research on what constitutes a personal epistemology has expanded since then, students continue to hold narrow views of computing that are disconnected from the field at large. To align with current research, we use the term "views" to encompass students' expectations of, attitudes towards, and beliefs about computing. We took a crafts-oriented approach to expanding students' views of computing and broadening participation in computer science by engaging high school students in a 10-week electronic textiles unit. Students were introduced to computational concepts and practices as they designed and programmed electronic artifacts. We found their views shifted from pre- to post-interviews in ways that allowed them to see computing as accessible, transparent, personal, and creative. We discuss how e-textiles materials and the design of classroom activities brought back a diversity of ways thinking about who can do computing, how to do it, and what computing can be.

Categories and Subject Descriptors

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

Keywords

Electronic textiles, education, K-12, broadening participation, attitude, novice programmers

1. INTRODUCTION

More than twenty years ago, Sherry Turkle and Seymour Papert [33] wrote an article about the lack of diversity in approaches to computing, where abstract, rule-driven "hard" styles were seen as more valid approaches to problem solving than negotiated, tinkering "soft" styles. In privileging "hard" approaches, the field at-large pushed forward a particular kind of pedagogy, which promoted a "top-down," "divide-and-conquer" approach over a more "bricoleur" perspective, which relied on constant rearrangement and negotiation of materials. Because certain groups were shown to prefer this "bricoleur" approach (particularly girls), Turkle and Papert [33] argued for the need to diversify approaches for thinking about and teaching computing, thus promoting what they called "epistemological pluralism". In this way, educators could work to broaden engagement in computing. Throughout the years these insights fueled many shifts in pedagogy, including changing learning and teaching cultures around computer science in schools [22], providing appealing programming activities [16, 19, 24], and developing programming tools [18] to make technology cultures more inclusive to girls and students from underrepresented backgrounds. Research on college-level introductory programming courses has also attempted broaden participation in computing by addressing factors influencing student success [2], examining students' perceptions of computing [31], and developing interventions like pair programming or giving students a meaningful context for doing computing [14, 26] Nonetheless, several studies have documented students' continued disinterest in computer science and the ways these relate to students' stereotypical perceptions of the field at-large [8, 12, 35]. In this paper, we return to the question of epistemological pluralism and its potential to broaden participation in computing through a new intervention in computer science: the tangible and expressive use of electronic textiles.

While there have been many efforts to change perceptions and broaden participation to unlock the existing clubhouses of computing [21, 22], a very different approach has been to build new clubhouses of computing [4]. By clubhouses, we refer to the exclusive, club-like atmosphere of many computing spaces. In their work, Margolis & Fisher [21] focused on the gender gap in computing and unlocking "boys only" clubhouses to include female participants. We extend the metaphor to include how additional ways of thinking about and doing computing can also be valued. We envision these new clubhouses as not only more inclusive but also as more culturally distinct spaces where multiple ways of knowing about and doing computing are valued.

One approach to building new clubhouses of computing has been to employ computational construction kits, such as the LilyPad Arduino Construction Kit for making electronic textiles [3, 5], that challenge conventional conceptions of computing. Electronic textiles are made by stitching together sewable microcontrollers (e.g., the LilyPad Arduino), different actuators (LEDs, speakers), and sensors with conductive thread on a fabric backing (perhaps a sweatshirt or bag) and programming them to execute particular behaviors, such as causing a series of LEDs to blink faster or slower depending on the values read from a light sensor (i.e. how light or dark a given environment is) (see Figure

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1). By design, electronic textiles (e-textiles hereafter) combine practices such as engineering and computing, which have historically have been viewed as masculine activities, with sewing and crafting, which have been viewed as feminine activities [30]. E-textiles also add a tangible dimension to computing that so far has mostly been experienced in the virtual realm with the exception of robotics (generally a male-dominated activity). Finally, e-textiles move computing from stationary machines into the wearable domain. By their very design, e-textiles challenge norms by engaging with ideas about what computing can be (tangible, wearable), who can do it (women, men), how it can be done (crafting, sewing), and why and where it matters.

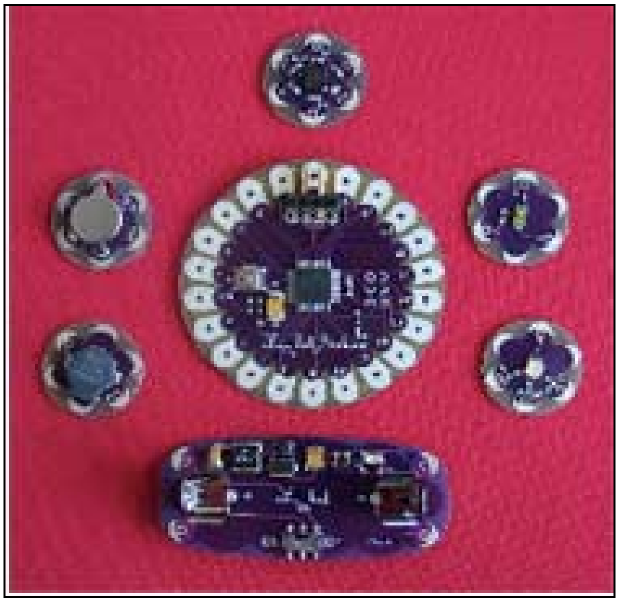

Figure 1: The LilyPad Arduino construction kit.

Prior research with electronic textiles in high school classes [17] became the starting point for this investigation into how students conceptualized computing culture and their places within such a culture before and after engaging with e-textiles. We wanted to revisit epistemological pluralism in computing culture [33] in light of the relevance that students' views of learning have shown in other fields [1, 13, 28]. To this end, we focus on extensive debriefing interviews with high school participants in a 10-week e-textile unit as part of an elective computer science class at their high school. Within these interviews, we focused on students' perceptions of the computational process and computer science as a field. Our research addresses the following questions: How does taking a hands-on, crafts-oriented approach to computing in an elective computer science course influence how students engage with learning computational concepts and practices? How might this shift their conceptions about computing culture at-large and their place within it? In the discussion, we review how the physicality of e-textiles materials themselves and the design of classroom activities can foster a diversity of ways of thinking about computing and contribute to broadening participation within the field of computer science.

2. BACKGROUND

Recent work by educational psychologists has defined an epistemological standpoint to a discipline as having at least two components, (1) an individual's views/attitudes about the discipline and (2) an individual's conceptualization of the nature of knowledge production within the discipline [1, 13]. Students and professionals within a given discipline are likely to have vastly different epistemological standpoints, and these standpoints may influence how successful an individual is within a discipline. In this paper we focus primarily on the first component of an epistemological standpoint. We explore how students' attitudes towards computing are shaped by engagement with e-textiles materials and how these relate (or fail to relate) to computational thinking.

As a starting point for our investigation into student views about computing, we draw upon the multiple approaches to computing identified by Turkle and Papert [33]. Based on interviews with elementary school students working with the Logo programming environment and college students enrolled in an introductory computer science course, Turkle and Papert [33] found that numerous students employed a bricolage approach to computing that valued more concrete rather than abstract approaches to engaging with computer code. This "soft" approach valued "mid-course corrections" and "negotiations" of material for the purposes of problem solving (p. 136). While such a perspective ran counter to the usual approach to computing favored by the computer science community, students using these strategies were shown to be equally successful in arriving at viable solutions. Despite this finding, computer science pedagogies have continued to favor the "top-down, divide-and-conquer [...] 'planner's'" approach to coding (p. 136), thus continuing to alienate those who thrived using the more expressive, "conversational" styles of the bricoleur. This divide in computing has deepened over the years rather than dissipated, even as digital technologies have moved out of the computer laboratories and workplaces and infiltrated our everyday lives.

In addition to the preferred approaches to computing outlined by Turkle and Papert [33], there are numerous studies that illustrate that teenagers' thinking about computing is fairly stereotypical, describing it as "tedious", "boring" and just "sitting in front a screen all day… working in solitude" [35, see also 8, 12]. Students additionally viewed the field as not creative, despite the fact that they were often enthusiastically involved in the products of computation (blogs, social networking services, etc.). Even younger students, when asked to draw a computer scientist, mirror these sentiments by drawing a white male with a beard, crazy hair, and pocket protector [23; see also 6]. These views of computing and computer scientists reflect students' perspectives.

Within the discipline the nature of computing is seen as capturing "aspects of designing systems, solving problems, and understanding human behaviors" [34, p.6], otherwise referred to as computational thinking. Computational thinking—while often strictly associated with computer science—applies computer science principles to other disciplines in order to help break down the constituent elements of any problem, determine their relationship to each other and the greater whole, and then devise algorithms to arrive at an automated solution. While this view on the nature of computing is not uncontested, it does present a professional view that understanding the world computationally gives a particular lens to understanding problems and contributing to their solutions. Today, numerous efforts are underway to promote computational thinking in K-12 [25] but much has focused on developing activities that engage students in computing, leaving aside the thorny issues of how students think about computing. In this paper we seek to connect these two issues by addressing the relationship between activities used to teach computational concepts and practices and students' perceptions of the computation process before and after participating in those activities. In this paper, we argue that by engaging students in activities rooted in a variety of approaches to computing—particularly the more bricoleur-friendly approach of e-textiles—we are able to expand not only their knowledge base but also their ideas about what computing is.

3. PARTICIPANTS, RESEARCH METHODS, DATA SOURCES & ANALYSIS

Participants were 27 high school juniors and seniors, 16-18 years old, from a public magnet high school focused on science and technology in a large urban school district. The demographic composition of our group of participants mirrored the overall demographics of the school: 46% African American, 10% Latino, 9% Asian/Pacific Islander, 33% White, and 2% other. Forty-nine percent of students received free or reduced lunch. Students' experiences with computing varied widely prior to their freshman year of high school when each student was issued a laptop for academic and personal use during the school year. All participants were enrolled in an elective computer science course that met for an hour twice per week. Prior to engaging with e-textiles, they had spent a semester learning to program in Alice [www.Alice.org], an environment for programming 3D animations. Many participants had also taken a physics course during which they programmed robots. We implemented two 10-week e-textiles units in which students, split into two groups, were introduced to the basics of e-textiles through building and debugging simple circuits, writing code for LilyPad ProtoSnap boards, and finally engaging in the process of designing, making, and programming their own e-textile artifacts. Students were tasked with making an e-textile artifact using the LilyPad Arduino, 2–4 LEDs, and two conductive fabric patches that acted as touch sensors (see Figure 2) [for more details on the curriculum see, 17].

We conducted and recorded pre- and post-project interviews with 24 of the 27 students based on their willingness to participate and availability during the school day. Each interview was semi-structured in nature and lasted for approximately 30 minutes. In both interviews, we asked students about their experiences with computing to-date and whether or not they had career aspirations related to computing. In the post-interviews, we asked additional questions about what they learned, how they saw themselves in relation to computing, and whether or not they found the assignment creative. All interviews were logged, which involves a close but not word-for-word transcription [9, 10]. Any segments directly quoted in this paper were fully transcribed at a later date. We then conducted a thematic analysis using a grounded theory approach [7] choosing to focus on the accessibility of computing via e-textiles, the transparency and functionality in learning computing using e-textiles, the positionality of participants' and their e-textile artifacts in relation to computing and to other audiences, such as parents or siblings, and the creativity of the assignment. In this paper we focus primarily on findings from the post-project interviews because they illustrate the impact of a 10-week engagement with e-textiles on students' attitudes towards and perceptions of computing.

4. FINDINGS

We begin by providing an overview of students' perceptions as they were expressed in pre-interviews. One overarching theme that arose from analyzing the pre-interviews was the understanding of computer science as narrow and limited (limited to the screen, a solitary activity) versus a broader sense of its relevance in everyday contexts. In pre-interviews, students were very vague about computing and said things like, "I knew that it is dealing with programs and computers" (Giuliana, pre-interview, 12/08/11) or "I knew it had something to do with computers...So I thought maybe like computers and test tubes...computer science!" (Marsha, pre-interview, 12/07/11). For other (mostly male) students, computing was linked to game play and wanting to know what went on "behind the scenes." These conceptions of computing expressed in the pre-interviews illustrate the narrow view of the field often found in others studies [35, 8, 12].

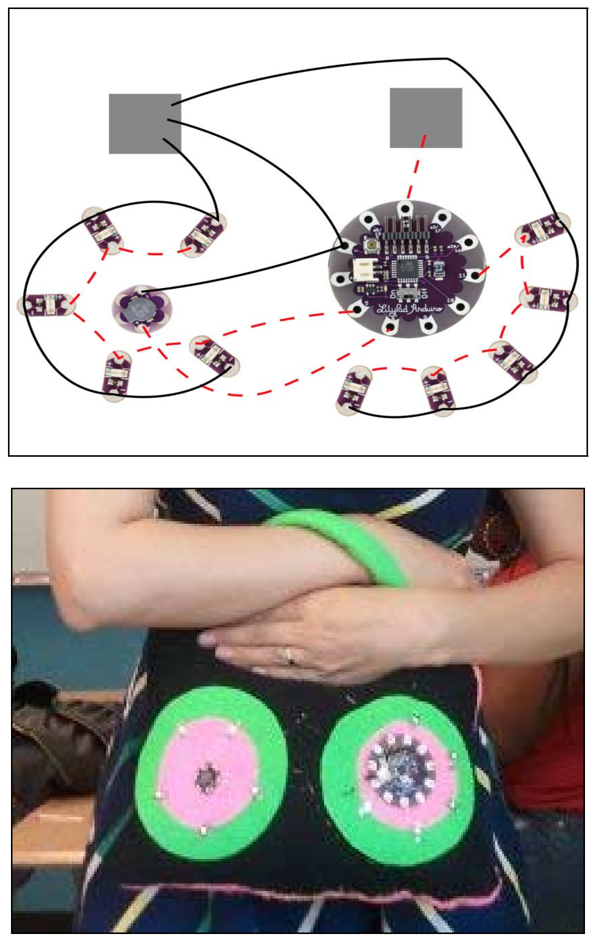

Figure 2: E-Textile Boombox by Lloyd: The circuitry diagram (upper) and completed artifact (lower design).

In addition to thinking about computing in narrow ways, students had difficulties connecting what they did in school with what computing professionals do. Specifically, they saw a disconnect between the highly constrained "drag and drop" programming environment they were working with in Alice and the kinds of scenarios they were asked to create ("learning how to make a fish swim around an island") and "real programming" as done by professionals. Out of 24 students who participated in these interviews, only four students made comments about the logic of computer programming or the importance of planning and sequencing which we might associate with the more prevalent, top-down approach to computing.

In post-interviews, students more clearly articulated a range of perspectives on computing, which could be linked to professional practice. This could be viewed as a first step in developing students' epistemological stances towards computing as a discipline. Of the twenty-four students who completed post-interviews, 23 students noted that the initial hands-on, low tech nature of making an e-textile artifact and the ability to literally see one's progress (e.g., number of stitches sewn, number of lights), made it more *accessible*. All twenty-four students also commented that the ability to make code visible by watching one's lights go on, and tracing connections between components by looking at the stitching made e-textiles more *transparent* than other computing activities. These students (24/24) also noted that that e-textiles projects highlighted issues of *positionality and audience* in ways that other computing assignments did not because they could choose to emphasize particular personal interests in what they made, and they could also more easily show the project off to parents and friends because of the physical, portable nature of e-textiles. Finally, a smaller (18/24) but still significant number of students appreciated the *creativity* and *variability* in learning computing using e-textiles. In spite of the fact that all students were given the same assignment with the noted constraints, many enjoyed the process and observed that all of the class projects looked distinct (see Figure 3). To expand on these themes, we provide vignettes of individual students' perspectives. These vignettes provide more detail on each theme as they played out in students' reflections on their learning with e-textiles.

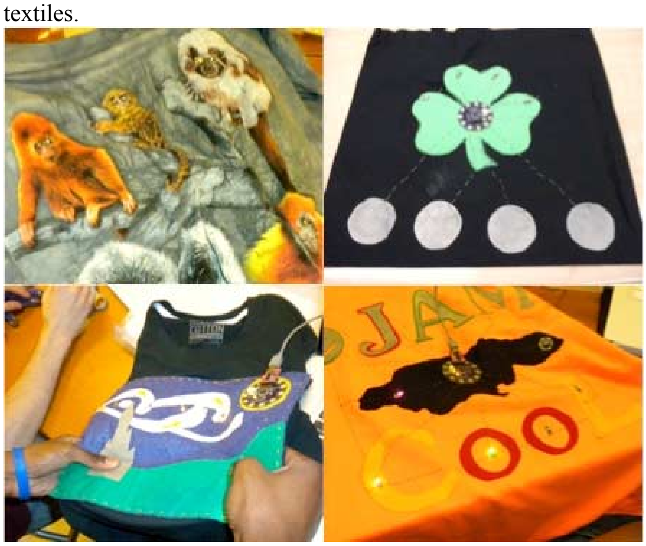

Figure 3: E-textile Artifacts, belonging to (clockwise from top left) Megan, Bridget, Eldore, and Carlton.

4.1 Accessibility: Moving Computing Beyond the Screen

Like many of the other students, Carlton entered the semester course without much previous experience with programming. Even though he had seen e-textiles style products for children in the real world, he did not originally think about those in terms of computer science. The e-textiles unit expanded his understanding of the general applicability of computation. As Carlton described, "e-textiles kind of widened the possibility of what Computer Science can do or what... how it can be applied to one's life…. it kind of opens up the possibilities to what it can do and how it can serve a purpose in our day-to-day lives" (post-interview, 6/1/12). While Carlton viewed the previous work he had done on Alice as entirely contained within the computer, for e-textiles, he described how the computation could be tangibly appreciated: "with this... you create something on the computer and it can... you know, breathe life in a t-shirt." Like other students, working with e-textiles allowed Carlton to connect the work he did for a school assignment with the work of professional computer scientists who tackle real-world problems and program objects used in our everyday lives.

Carlton was also able to access computing in the e-textiles unit because of its connection to craft. Whether or not students had experience with sewing or coding (Carlton had neither), all the students were able to "set the bar [appropriately] low" to where they were comfortable (post-interview, 6/1/12). The existence of these multiple access points (whether through sewing or through coding) promoted the feeling that e-textiles construction was available to all, thus challenging existing stereotypes about the high barrier to entry into computer science. Overall, students' familiarity with e-textiles artifacts in the world, the varieties of hands-on skills required for e-textiles crafting, and their sense of accomplishment derived from tangibly being able to see one's progress, created a sense of greater accessibility to computing than might have been afforded through traditional, formal approaches to teaching computer science.

4.2 Transparency and Functionality: Seeing and Feeling Computing in Action

In her pre-interview, Megan described herself as being "really comfortable with a computer" and various software programs but not the coding behind it, in spite of using Scratch in engineering class and "messing around" with some online design tools. She did not choose to take computer science as an elective but was placed into it because the course worked in her schedule. She tried to withdraw from the course and, when that failed, resigned herself to taking computer science because at least it was "better than drama." Given her less than enthusiastic response to the class before the e-textiles unit and initial difficulties with threading needles for conductive sewing, we were not surprised when Megan set out to make the ugliest, creepiest e-textile project she could manage. A family member had given her what she described as an "ugly monkey t-shirt" and she decided that adding lights could only improve upon the design [see Figure 3].

Over time, as Megan added lights and other conductive elements to her shirt and learned more about programming, Megan began to like programming. In her post-interview she said, "I loved programming… we worked with the [LilyPad ProtoSnap boards]...and, um, it was fun seeing how like, if I made this do something, it's gonna vibrate and if I add in this port, it's going to you know, light up here." (post-interview, 5/21/12). The process Megan described—one of being able to build code on a computer and immediately see its impact in the behavior of lights and other actuators—was a central theme in many students' reflections on computing with e-textiles.

When asked to compare e-textiles to other things she had done in computer science, Megan said:

> Well, there's a lot more hands-on stuff, there's a lot of what we did before with Alice and, like, making a program happen. But now, it's like, now we have to sew, we have to figure out how the circuits work, and then we can go onto the computer and make stuff happen. But it's a lot more like -- we can touch it, we can feel it, we know what's going on with our hands and not just with looking at it and hoping that it works (post-interview, 5/21/12).

For novices, this ability to connect code to a physical artifact and "know that it works" is highly motivating. As Megan noted, she still had to use the kinds of computational concepts and practices taught in other introductory computer science classes, but she had to link the pieces to a more complex whole and was able to derive instant, incredibly satisfying feedback when testing code. In this sense, the tangibility of making e-textiles made the process of computing more transparent to students.

4.3 Positionality and Audience: Using Code to Tell a Story

Eldore also lacked prior computer science experience, but was enamored with code from the beginning of the class. In his pre-interview, he emphasized the progression in his learning about programming and made connections to his love of video games. Eldore decided to make a shirt emphasizing his pride in being Jamaican, with an outline of the island, a smiley face, and "Cool JAM" spelled out. JAM was used not only as short form for Jamaica, but also because of Jamaica's world renown for reggae music. As Eldore described:

> So you can see there's a lot of story behind my shirt... and also, I added a speaker to make it play a Bob Marley song and also I added a LED to show where I was from in Jamaica on the map and... my negative patch was my smiley face and the J-A-M were all my positive patches. And I had it programmed to when you press the negative patch and a letter, it can do a chase effect or it lights up or it just blinks (post-interview, 5/25/12).

What is notable here is the way in which Eldore combines craft and technical elements to tell a story utilizing a coded e-textile artifact, from using an LED to spotlight where he was from in Jamaica to playing reggae music. Furthermore, Eldore's desire for these personal connections pushed him to work through a potential circuitry problem when he had no digital ports remaining for his speaker and to learn more advanced programming skills. The reggae song he chose, Bob Marley's "One Love" is a rhythmically complex song and it took many tries to code the speaker to play something that began to resemble "One Love." As Eldore reflected when asked about challenges he had faced in coding his project:

> Coding challenges... Getting the hertz and everything for the song, the chorus that I'm using… It's very complicated because you have to have the perfect delay in between each note and you have to... sometimes you have to increase the octave and you have to put in another delay after the delay to make it delay some more. So it's very complicated just to get the sound to do what you want it to do. So... I'm currently working on perfecting that.

Importantly, the speaker wasn't part of Eldore's initial idea but evolved over time as he worked on the project, something that more than likely would have been excluded in more top-down approaches to programming.

Eldore was also excited about showing off his shirt to an audience. Many students reflected similar sentiments in their post-interviews, wanting to show it off to friends and family and then placing it in their rooms as a trophy of sorts. What stood out for us was not only that making an e-textile artifact was seen as a tremendous personal accomplishment (in a way that making a fish swim around an island in Alice was not), but also that parents and friends could understand and share in the accomplishment. The desire of Eldore and other students to use their e-textile artifacts to "say something" to a particular audience highlights the ways in which e-textiles provide a meaningful context for learning computing.

4.4 Creativity and Variability: Taking Ownership of Computing

Both Charles and Will enjoyed the greater level of innovation and creativity afforded to them through the e-textiles course. Students were all free to choose the aesthetic design of their projects even though there were a number of technical limitations on all projects (number of LEDs and conductive patches). Charles, in particular, described this as freedom to "create our own thing" for his project. He spoke about the diversity of projects found within the class and how it motivated people:

> So I've seen a whole bunch of different projects like recycling, shamrocks, names, stuff like that. And I think people wanted to complete that, because instead of just having something that someone assigned, you don't really want to complete that because it's not your own, and you know everybody's going to have that (post-interview, 5/15/12).

In his own work, he created a shirt with an icon of an eagle along with letters spelling out the word 'Eagles' in honor of his love of Philadelphia's NFL team, the Eagles (see Figure 4).

While Charles focused on the diversity of project designs, Will focused on the expansive possibilities of coding. In particular, he liked the way that he could code and recode his Scooby-Doo themed t-shirt (see Figure 4): "It's a lot easier to change what you want the shirt to do… [in order to] give the shirt a different look even though it's the exact same thing". Will contrasted this with the "repetitive[ness]" of formal approaches to computer science (i.e., Alice) he was previously exposed to, which he describes as follows: "although we were making different programs, nothing was different. We were programming something to do something and then we would watch it." Within the shared constraints of the e-textile project then, students had what Will called "a bigger realm of creativity" that allowed for greater autonomy and personal expression. Overall, rather than making identical projects, students were motivated by the multiple possibilities of e-textiles to take ownership of the computing process by making something unique to them.

Figure 4: In-progress e-textiles t-shirts designed by Charles (top) and Will (bottom).

5. DISCUSSION

E-textiles are purposefully designed as a hybrid technology that combines elements of craft and circuitry with computer programming [5]. Our findings suggest that students learning with e-textiles created a link between coding and making that opened up their views of computer science. Across the interviews, we saw students' engagement with bricoleur approaches to computing through the themes of *transparency and functionality* and *creativity and variability*. Rather than being hidden from view in a series of procedures, code is made highly visible through the stitching and the lights turning on and off as part of the design. As Megan described when she talked about coming to love programming, students could trace the circuits they had sewn with their fingers and *feel* their impact, just as they could *see* the code they had written play out in the behavior of the conductive patches, lights, and speakers that were components of their e-textile artifacts. Megan's approach to coding was based more on expressivity and improvisation, rather than abstract, top-down planning. In Will's description of coding and recoding his shirt, he similarly articulates this 'softer' approach to computation, which depends more on constant rearrangement rather than predetermined plans. Other elements of the class, such as external reflections allowed students to see and translate their own and others' work, essentially contributing to an open horizon of observation [13]. These qualities of e-textiles initiated a shift in students' thinking about code, highlighting how a crafts-centered perspective to computation, as opposed to a "black box" perspective [27] can promote shifts in students' epistemological stances.

E-textiles also allowed students to more easily make connections between practical, classroom computing activities and the work done by 'real world' computer scientists.. This became most apparent when looking at the themes of *accessibility* and *positionality/audience*. By making an e-textile t-shirt, Carlton was able to connect what he did in class with what's done by professional computer scientists on commercially available products such as light up sneakers for children or the costumes worn by rock stars and other kinds of performers. Eldore likewise emphasized his ability to show off his Jamaica themed shirt to friends, family, and even strangers on public transportation. He appreciated that others could value his computational handiwork, which was much more difficult in an environment like Alice where student-made games and animations fell short of others' expectations. Most students made these kinds of connections; they saw themselves not only as learners within the classroom, but also as designers making products that had value in the real world. Many students additionally shifted from seeing themselves as inexperienced novices in pre-interviews to individuals with enough experience to help others design and program an e-textile artifact. In these ways our findings suggest that working with e-textiles can help students feel more connected to the work of computer scientists at large.

We would be amiss, however, if we didn't take into account other factors that might explain students' broadened perspectives on computing. While e-textiles could be taught in a very traditional, abstracted way, the design challenge and the social structure of this class loosely followed a studio model of design [26]. Rather than being forced to create identical projects (as occurred in the Alice curriculum), students were given a few constraints (use of the Lilypad, number of LEDs and sensing patches) within which they could create individualized projects. The tangibility of e-textiles in terms of the materials themselves coupled with the studio atmosphere of the class allowed students to observe and constructively critique each others' work, promoting transparency in the process of coding. In other words, beyond the technology itself, the class environment also became a model for transparency. Students could easily share ideas and provide support and critique since the artifacts visibly displayed their work, and could garner attention not only from peers in class but also others outside of the classroom space. This ability to 'show off' one's work suggests a provocative idea about the role of audience in the nature of computing. As highlighted above, students considered their peers and family members as an audience for their computational products; computational work was therefore done not only for themselves or for an assignment but for a personally and culturally relevant audience [9]. Indeed, we could argue that considerations of audience shaped the students' programming and design. The concept of audience, long an important concept in literacy studies [32], may thus have an important role in shaping students' understanding of computing. Key questions that expert writers ask—"What is the purpose of the writing? What form should it take? Who is the audience?" [20 p. 180]—suggest key questions that programmers should also ask: What is the purpose of this code? What form should it take? Who is (or are) the audience(s)? Current standards of computing touch ever so lightly on the need to understand the specifications and requirements for a computer program. We suggest taking this a step further to examine the role of authorship of code, attending to the cognitive and sociocultural conditions of its production and reception by authentic audiences. Might such a connection provide students with critical ways of thinking about various approaches to computation, and their differential values within the field at large? We hope that future research will examine these connections.

E-textiles are part of a broader movement that brings a new layer of concreteness and tangibility to earlier progressive approaches to programming education. Turkle and Papert [33] argued that tinkerers viewed virtual objects on the computer as dabs of paint rather than as abstractions as the planners viewed them. Types of programming software that allow students to program visual objects, such as Scratch, lend themselves to a more artistic, expressive form of computing. Taking this a step further, we suggest that with e-textiles the programmable objects are dabs of light—light controlled by programming LEDs on and off or by altering their levels of brightness. These new computational objects take the artistic expression allowed in progressive programming platforms a step further, especially when combined with the mobility and aesthetics of crafts. They connect computing into multiple domains: personal and playful, artistic and creative, as well as geeky and algorithmic. Students' programming illustrated in this paper has less to do with the efficiency of code (fewer lines of code and more "elegant" solutions) and more to do with enacting their visions of what they want to accomplish. Moving away from the traditional aesthetic of abstract, 'black-boxed' computing than is currently dominant in formal computer science education, this work instead illustrates a personal, functional aesthetic of computing [11] that involves individual expression, practical functionality, and attunement to potential viewers and wearers of the computational object. This is much closer to a vision that computing is a human invention, and that what determines the elegance or beauty of code is a social construct rather than an absolute.

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