The LilyPad Arduino: Using Computational Textiles to Investigate Engagement, Aesthetics, and Diversity in Computer Science Education

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ABSTRACT
The advent of novel materials (such as conductive fibers) combined with accessible embedded computing platforms have made it possible to re-imagine the landscapes of fabric and electronic crafts—extending these landscapes with the creative range of electronic/computational textiles or *e-textiles*. This paper describes the *LilyPad Arduino*, a fabric-based construction kit that enables novices to design and build their own soft wearables and other textile artifacts. The kit consists of a microcontroller and an assortment of sensors and actuators in stitch-able packages; these elements can be sewn to cloth substrates and each other with conductive thread to build e-textiles. This paper will introduce the latest version of the kit; reflect on its affordances; present the results of our most recent user studies; and discuss possible directions for future work in the area of personalized e-textile design and its relation to technology education.

Author Keywords
LilyPad Arduino, computational textiles, electronic textiles, e-textiles, smart textiles, wearable computing, construction kits.

ACM Classification Keywords
K.3.0 [Computers and Education]: General; H.5.2 [Information Interfaces and Presentation]: User Interfaces; C.3 [Special Purpose and Application-Based Systems]—microprocessor/ microcomputer applications, real-time and embedded systems.

INTRODUCTION
In the past decade, the notion of "human computer interaction" has expanded to accommodate a likewise-expanded portrait of "computing" more generally. People no longer interact with desktop applications exclusively, but with a burgeoning landscape of computational media—including handheld computers, "intelligent" or adaptive sensor-equipped environments, and robotic pets, just to name a few. Human computer interaction takes place in the course of many novel or unexpected activities: while driving, while exercising, while handling a "Furby" toy, while printing out a three-dimensional object in plastic or metal.

Even as the range of computational media continues to expand—and with it, the range of human computer interaction—certain basic questions concerning our collective attitudes toward technology stubbornly persist. Much of the foundational rhetoric concerning technology portrays it in terms of saving labor, avoiding presumed drudgery through automation, or making tasks easier and faster—rather in the tradition of the washing machine, McCormick reaper, or electric can-opener. Another common rhetorical theme is the view of technology as a source of entertainment or distraction—exemplified, prior to the computer age, by recorded music or amusement park rides, and more recently by arcade video games, iPods, and adaptive toys. Both these rhetorical traditions in turn dictate specific themes for the study of interaction: the "labor-saving" tradition stresses themes such as rapid (and error-free) use, ease of learning, and improved productivity, while the "entertainment" tradition stresses (again) ease of learning, holding the user's attention, comparative preferences between different entertainment technologies, and so forth.

Both of these traditions—technology as automation, and technology as entertainment—can point to tremendous successes (both before and after the advent of computing) in improving the human condition. But there is still another way of thinking about technology that leads, in its own turn, to still other themes of designing and measuring interaction. This is the theme of technology as expanding and democratizing the range of human expression and creativity—technology as the design of musical instruments, oil paints, and accessible programming languages, to name a few examples. In this tradition,

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themes of interaction focus on whether users can do things, or express things, that were formerly beyond their range, and whether they acquire a deep and satisfying understanding of the technological medium itself. "Ease of use", in this tradition, is a more ambiguous concept: it may not necessarily be easy to acquire expertise in the new medium (think about the difficulty, say, of learning to play clarinet), but if well-designed, the new technology rewards prolonged experience and the growth of personalized expertise. (See [16] for an eloquent argument along these lines.)

This paper focuses on our efforts to develop an expressive medium for textile-based ubiquitous computing—a construction kit (called the LilyPad Arduino or simply the LilyPad) that allows users, both schoolchildren and adults, to build and program their own wearable computers. While the LilyPad is a prototype (in point of fact, one of a series of successively refined prototypes), we believe it represents a good example of novel directions in the "creativity expansion" tradition of technology and interaction design. In the following section of this paper, we first describe the physical and material design of the LilyPad, and discuss the means for programming e-textile devices constructed with the kit. The third section describes our workshop-based user studies of the kit, and discusses several of the dimensions that we have stressed in attempting to assess and interpret user experience: the originality or interest of their creations, the way in which the kit affects their attitude about working in an electronic/computational medium, the depth of users' engagement, and the nature and diversity of populations that appear to be interested in work with the kit (with particular attention in this case to gender issues). In the final section, we discuss plans for future work on the LilyPad Arduino and its successors in the still-very-early tradition of creative, accessible e-textile design.

THE LILYPAD ARDUINO

The LilyPad Arduino is a system for experimenting with embedded computation that allows users to build their own soft wearables by sewing fabric-mounted microcontroller, sensor and actuator modules together with conductive thread. Our goal in developing the kit has been to produce a system analogous to Lego Mindstorms. The kit was designed to engage kids (and adults) in computing and electronics and teach them fundamental skills in these areas by allowing them to creatively experiment with e-textiles in the same way that the Mindstorms kit allows people to experiment with robotics.

"Hard" Ware

We introduced the first version of our kit in 2006 [3]. Figure 1 shows top and bottom views of the microcontroller piece that formed the heart of this kit. To build this piece, we attached a through-hole-packaged ATTiny26 microcontroller to a fabric PCB—a cloth printed circuit board (PCB) made out of a combination of traditional and electrically conductive fabrics. (For more information about fabric PCBs, see [4].) The patch is 2.5 x 2.5 x .5 inches (63.5 x 63.5 x 12 mm), with a hard footprint .825 x 1.825 inches (20 x 46 mm). It has 17 conductive fabric tabs that lead to pins on the microcontroller. When a user sews through a tab with conductive thread, she makes an electrical connection between the fabric and thread. Two of the conductive tabs lead to power and ground on the chip, and are sewn to a power supply when the patched is employed in a design. The remaining 15 tabs serve as general-purpose input/output (I/O) channels that can be used to receive sensor input and control output devices like light emitting diodes (LEDs), speakers, and vibrating motors.

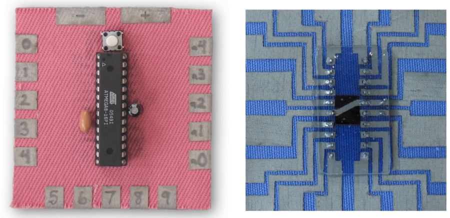

Figure 1. Top and bottom views of microcontroller patches from the first e-textile construction kit.

It is worth noting that, aside from the fact that it is on fabric, the circuit shown in Figure 1 looks very much like a traditional circuit board. The traces are laid out in straight lines, and the board itself is a square. In crafting the board, we transferred the habits we had developed working with hard circuits to fabric. Traditional circuit boards are designed according to a specific set of goals, including packing as many components into as small as space as possible, dissipating heat effectively, and allowing for automation of board layout and construction. After initial user studies and conversations with colleagues, we realized that our fabric circuits were not bound by the same constraints and goals. Other (rather exotic) concerns, like aesthetics and sew-ability, were more important to us. This prompted us to radically redesign our boards to create the LilyPad, which this paper introduces.

Figure 2. The LilyPad

The LilyPad, shown in Figure 2, improves upon the first microcontroller patch in a number of ways. (Throughout the text we will use the term "LilyPad" interchangeably to refer both to the board shown in Figure 2, and the complete LilyPad Arduino construction kit.) By rethinking circuit board layout, we were able to make significant improvements in both aesthetics and functionality. First of all, the circular format allowed us to employ surface mount (SMD) components. The thin right-angled lines of traditional circuit boards were extremely difficult to reproduce with delicate conductive fabric on the SMD scale, but a circular layout allowed us to build robust triangular traces that radiated out from the center of the board.

The SMD components, in turn, reduced the vertical height of the microcontroller board by a factor of five and the hard footprint by over half while adding more I/O tabs. We also employed a more powerful microcontroller in the new design, the ATMega168, which has eight times as much memory and significantly more I/O pins than the ATTiny26. The LilyPad is 2.48 x 2.48 x .1 inches (63 x 63 x 2.5 mm), with a hard footprint of .78 x .78 inches (20 x 20 mm), and has 26 conductive fabric tabs, 23 of which are general purpose I/O. The use of SMD components also made it easy to automate the labeling of the board. As can be seen in Figures 1 and 2, the labels for the first kit were, somewhat clumsily, drawn on by hand, while the labels for the LilyPad were etched by a laser cutter. Finally—and significantly—the LilyPad is undeniably more attractive than the first board.

Textiles, and especially clothing, play important roles in society, roles that are closely tied to aesthetics. People are quite particular about what they put on their bodies, and for good reason. Clothing communicates a person's gender, religious belief, and class among other things [7]. Wearable computing researchers have traditionally focused primarily on technical implementations and applications. (See [2] and [14] for lovely counter examples.) We believe that an appreciation of the social importance of fashion, and an accompanying investigation of aesthetics and design, should accompany research in this area. We feel that the "look" of the LilyPad deeply influences users' experience of the kit.

Figure 3. Sensors and actuators, a stitch-able battery holder, and a spool of conductive thread.

To conclude our description of the kit's hardware, we must introduce its supporting materials. While the LilyPad is the central component, the kit also contains an assortment of I/O pieces, a power supply, conductive thread, and insulating fabric paint. Figure 3 shows some of these components: a fabric-mounted tilt sensor and vibrating motor, a stitch-able battery holder, two fabric switches—one a pressure switch and the other a hook and loop (Velcro) on-off switch—and a spool of conductive thread.

Software

The software has also improved significantly since we first introduced the kit. In the initial version, users had to employ traditional ATMEL microcontroller programming tools to specify patch behavior. To program a patch, a user had to write code in a text editor and compile and load this code onto his chip using command line tools and special programming hardware. This system required that the user remove his chip from the patch, plug it into a programmer board, download his program, unplug it from the programmer and put it back into his patch to run the program. Needless to say, this process was extremely cumbersome.

After an initial user study, during which we confirmed this system to be truly dreadful, we began to make use of a wonderful existing tool—the Arduino integrated development environment (IDE) [1]—for patch programming. The Arduino IDE is part of a larger combined software/hardware platform designed to introduce novices to physical computing; the complete platform includes an Arduino hardware board in addition to the software. The Arduino IDE allows users to write programs, in C or Processing, that control an Arduino board, in our case, the LilyPad Arduino. Figure 4 shows the Arduino IDE and a sample LilyPad program.

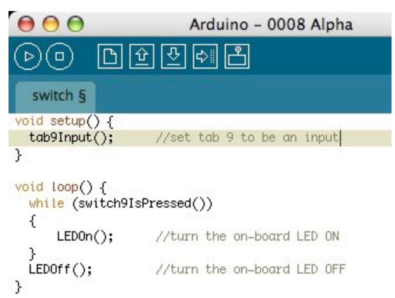

Figure 4. The Arduino IDE

To enable the LilyPad to communicate with the Arduino IDE, we built the LilyPad from hardware that is similar to the Arduino hardware and modified the open source Arduino software to specifically support the LilyPad. We also developed several libraries that allow users to easily control an assortment of sensors and output devices. To program the LilyPad, a user clips it to a USB device that supplies the patch with power and facilitates computer-patch communication.

We want to emphasize the fact that we did not develop the Arduino system. There are several reasons for our decision not to build a dedicated LilyPad programming environment.

First of all, we felt that what was most interesting about the area we were exploring was the "hard" ware—the soft, fabric-based electronics—and we wanted to focus our efforts in this area. Second, we were so entranced by the e-textile medium and its unique affordances that we wanted to make our ideas and tools accessible to as wide an audience as possible. (In a first step towards making this medium widely accessible, we just released an open source, commercial version of the LilyPad Arduino that is based on stitch-able, manufactured (hard) circuit boards.)

By using the Arduino software we make use, not only of professional-grade software and documentation, but also the vibrant and growing community of Arduino users. Though a simpler, tailored programming environment would undoubtedly be easier for novices to master, we felt that the practical and social benefits that the Arduino software provided were important and worth a slightly steeper learning curve. Users can join, contribute to, and learn from the novice-friendly Arduino community, both while they are participating in one of our workshops and after its conclusion. The experiences this paper reports on should be viewed as the first steps towards our larger aspiration of sparking and supporting independent e-textile hobbyist communities. We felt that the Arduino tools could contribute significantly to this goal.

USER STUDIES

We have now held six workshops employing our construction kit, five of which used the first version and one which used the LilyPad. We have found that e-textile workshops are, in many ways, analogous to Lego robotics workshops—introducing a similar set of programming and electronics skills; however, e-textiles present some unique challenges. Robots built out of Legos can rapidly be taken apart and reassembled; students learn by iteratively testing and rebuilding their designs. In contrast, since stitches are difficult to remove, a student must invest in a period of careful engineering and design before she can embark on constructing an e-textile. This makes the design/build process more challenging, but the permanence of e-textiles provides a corresponding benefit. Since designs are hard to take apart, they are robust and can endure the wear and tear of use; they can be integrated into people's lives. A longer discussion of our first four workshops and the unique curricular challenges and opportunities presented by the e-textile medium can be found in [5]. This paper will focus on our most recent study.

Class Structure

Our most recent workshop was held during one week in June of 2007. The class—whose title was "Learn to Make Your Own Electronic Fashion", and whose enrollment was restricted to 10 students, aged 10-14—met each weekday for three hours. (The class was offered as part of a summer science program in our town called "Science Discovery", in which students pay to participate in science-related classes.) Of the students who signed up, nine were female and one was male—a point to which we will return later, in the section on diversity.

The workshop began with an introduction to circuits and sewing combined into an activity we call "sewing circuits", in which users stitch out simple circuits with conductive thread and LEDs [4]. Students were also led through activities that introduced them to electrical resistance and multi-meters. We then moved into a series of exercises designed to teach the participants basic programming skills and introduce the facilities of the LilyPad kit. For these exercises, students paired up at computer stations and each group was given a LilyPad, a different sensor and actuator pair, and some alligator clips. The LilyPad was attached to a computer's USB port through which it communicated with the Arduino software and harvested power, and sensors and actuators were clipped to the LilyPad with alligator clips. Starting from example programs, groups were instructed to experiment with their devices. At the end of this session, each group gave a short presentation, demonstrating their program and devices.

Figure 5. Two girls working on their designs.

After these exploratory activities, which took up the first day and a half of the workshop, participants were given the opportunity to design and build their own e-textiles. Since early experience had shown us that, left to their own devices, students would focus on construction and decoration to the exclusion of programming and troubleshooting, students were guided through the construction phase. We had each student begin by stitching on a battery, LilyPad and one actuator. Then students were instructed to program their (incomplete) constructions. This forced them to detect electrical shorts and other construction errors, and begin to work with programming at a relatively early stage. Throughout the construction phase, we encouraged them to use alligator clips to prototype their designs. Instructors (first and third authors) were always on hand to assist students with programming, sewing and debugging. The class culminated in a fashion show presented to parents and friends at the end of the week. Figure 5 shows two students working on their designs.

Research Methodology

Students (and their parents) were notified at the beginning of the workshop that the class was part of an ongoing research study and advised that they did not have to participate in the study unless they wanted to. We handed out surveys at the beginning and the end of class designed to assess motivational issues. Eight out of the ten students filled out both pre and post surveys.

We want to stress that we view the results of our surveys as highly suggestive, but very preliminary. The information discussed in the next several sections should not be viewed as the results of a comprehensive scientific study, but rather as exciting indications that an unusual approach to computer science education can attract young women to the field and increase students' interest and engagement. We also want to explicitly acknowledge the fact that we did not focus on what children learned during this workshop. Our evaluation of earlier workshops examined learning questions [5]—whether we could introduce basic electronics and programming concepts through an e-textile construction kit—but we chose to focus on interest and motivation for this session.

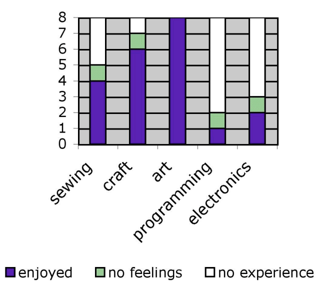

Table 1. The results of a survey taken before the workshop of students' previous experiences. The y-axis shows the number of students.

Our initial survey asked students about their previous experiences with programming, electronics, sewing and art. We also asked participants to tell us their anticipated college major and describe why they had signed up for our course. The previous experience responses are shown in Table 1. It's interesting to note that only two out of eight students had any previous programming experience and only three out of eight had electronics experience; also, almost all of the students had (positive) experiences with arts and crafts.

In the survey at the end of the class, we asked students about their experience in the class, including whether they would be interested in participating in electronic fashion, computer science or electronics activities in the future. Table 2 shows a summary of the responses to these questions. We also have more detailed responses to these "interest" questions and others that we will discuss in subsequent sections. For now, it is interesting to point out a few things in the simple data. We were delighted by the fact that six students expressed an interest in participating in future electronic fashion activities, and especially happy about the fact that they were interested in doing these activities at home on their own time. However, it is remarkable that fewer students said they were interested in programming or experimenting with electronics at home, since electronic fashion requires programming and electronics work. We were also happy that five students said they would be inclined to take computer science and electrical engineering as a result of their workshop experience.

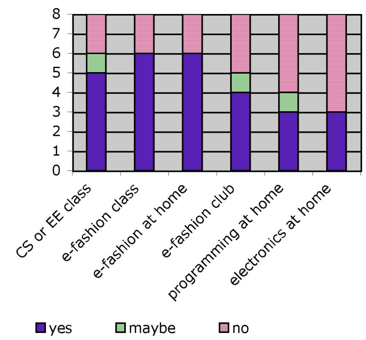

Table 2. The results of a survery taken after the workshop showing students' interest in future activities.

DISCUSSION

This section will delve more deeply into the results of our user studies, highlighting what we believe to be the most interesting implications of these experiences. We will begin with a discussion of what we believe to be the most important issue raised in our workshops, student engagement. We will then proceed to a discussion of two themes—related to engagement and each other, but worthy of independent attention—aesthetics and diversity.

Engagement

A recent study conducted by researchers at the University of Virginia indicates that early personal preference and interest are more predictive of career choice than performance on traditional measures of achievement like standardized tests [18]. The study found that students who, as eighth graders, expected to earn degrees in science or engineering were almost 3.5 times as likely to earn degrees in the physical sciences and engineering than students who did not express an intention of majoring in the sciences in eighth-grade.

Csikszentmihalyi's research has shown that personal motivation and enjoyment are highly predictive of achievement but, sadly, mostly neglected by our educational system. In a ground breaking study, he followed a group of "talented teenagers" for five years to assess what made them choose to either develop or abandon their talent [6]. Among his findings are the fact that students will seek out and continue to participate in activities they enjoy, and that a peer culture, which does not support achievement, can have a strong negative affect on achievement.

A foundation of our work is the belief, influenced by the research cited above, that society needs to devote more attention to making educational experiences intrinsically motivating and relevant to youth culture. We need to develop intellectually rich artifacts, activities and communities—ones that inspire independence, delight, and obsession. We have also been strongly influenced by the tradition of constructionism, which postulates that people are most likely to become engaged in an activity and learn things from it when they are active and creative participants [13].

The results of our surveys (and the loveliness of some constructions) indicate that several of the students in our last workshop became passionately engaged in the class and the medium. At the close of our workshop, we asked students to rate their feelings about the class on a five point scale from "ecstatic" to "miserable". Two participants rated their feelings as "content", two as "happy", one as in between "happy" and "ecstatic" and three as "ecstatic". We will now present short case studies of the three who rated their feelings the highest.

Figure 6. Susan's sweatshirt, front and back views.

Susan[1] was a 13 year old who had had some previous experience with both electronics and programming, but said, in the first survey, that she had neither positive nor negative feelings about those experiences. She had also had previous experience with art, craft and sewing and said she enjoyed arts and crafts. In the course of the class, she embellished a sweatshirt with an LED whose color changed in response to arm gestures. Photographs of her construction are shown in Figure 6. Gestures were captured by tilt sensors that Susan sewed into each wrist of her sweatshirt. As can be seen, the garment was beautifully crafted: conductive stitching was employed both functionally and decoratively. The tilt sensors were artfully concealed on the inside of the garment, and the battery and on/off switch were thoughtfully placed in a pocket where they were hidden yet easy to access. The RBG LED and LilyPad were displayed on the exterior of the garment which was further embellished with hand-cut patches of conductive fabric.

[1] All student names have been changed to preserve their anonymity

Susan was our most articulate and effusive survey respondent. Here are some of her responses to our post-workshop questions:

> Do you think you might take future classes in electronics or computer science because of your experience in this class?
> *For sure! I especially think that this class should happen again.*
>
> Would you take another class in electronic fashion if it were offered? Briefly explain your reasons.
> *YES! It was amazingly fun, I learned a lot, and we get a really cool garment out of the class!*
>
> Are you interested in building electronic fashion at home on your own time?
> *Oh boy, am I ever! :)* (a heart was drawn on the survey here)
>
> Are you interested in building or learning to build electronic devices at home on your own time?
> *Yes! It's amazingly fun!*
>
> Provide any additional comments you have about the class.
> *This was by far the most fun summer science class I've ever been in..*

"Lily" was a 12 year old with no previous experience with programming, craft or sewing. She did have previous positive experience with art and some electronics experience ("*In second grade we made circuits to light up a bulb*") that she also rated as positive. Lily decorated a handbag, shown in Figure 7, with a touch sensor and an RGB LED that it controlled. Again, one can see how carefully the project was constructed. She employed patches of conductive fabric to function both as decoration and as the touch sensor. The RGB LED is at the center of the touch sensitive flower and the LilyPad, battery and switch are hidden in the bag's interior. Lily provided less detailed answers than Susan in the survey, but she also said she was interested in exploring electronic fashion, programming and electronics at home on her own time. In response to the "Provide any additional comments you have about the class" section she wrote *"This class is awesome!"*.

Figure 7. Lily's handbag.

Also worthy of note, Lily did not complete her project according to her original design by the end of the workshop, and later voluntarily returned to our lab to spend an afternoon adding functionality to her bag. (At the close of the workshop, we invited all of the students to return to the lab to continue working on their designs. Lily was one of three students who accepted the invitation.) During this session, she, rather shyly, asked about the authors' plans for holding more electronic fashion workshops and expressed unsolicited interest in an after school "electronic fashion club" and a more in-depth semester-long class.

Figure 8. Christopher's hat.

"Christopher", the only boy who signed up for our workshop, was a self-described 10 year old computer expert. He had no previous sewing, craft or electronics experience, but, like all the kids in our class, had had positive art experiences. Christopher sewed a speaker and a pressure switch to a New York Police Department hat and programmed the speaker to emit siren sounds when the switch was pressed. His construction is shown in Figure 8. Christopher wasn't as concerned about the appearance of his construction as Lily or Susan; he was focused almost exclusively on its functionality. Like Lily and Susan, he was enthusiastic about continuing to explore electronic fashion, electronics and programming extracurricularly. He also provided this enthusiastic assessment of the class in response to the question "Do you think you might take future classes in electronics or computer science because of your experience in this class?": "*Science discovery camp rocks!*". But, most remarkably, Christopher sent an unsolicited email to the first author a few weeks after the end of the camp. Here's an excerpt from the email:

> *"...I just wanted to tell you that my friends thought my hat is soooooooooo cool...so i'm just sending you an e-mail to say I loved your camp so much!!!!!!!!!!!!!!!!!!"*

Susan, Lily and Christopher were the most enthusiastic participants, but most of the students had positive responses to the class. Table 3 shows a sampling of survey feedback (both positive and negative). As we mentioned earlier, six out of the eight students said they were interested in working on electronic fashion in their free time, indicating a remarkable level of engagement. These results, coupled with the glowing feedback of the "ecstatic" students, point the way toward the area we are most interested in: seeding and supporting e-textile hobbyist cultures. Referring back to the work of Csikszentmihalyi, our primary goal is to spark and support people's independent interest and motivation; we want to foster new, creative, and contentful youth cultures.

Some clear negative themes also emerged from the feedback. Many students wanted the class to be longer, and we heartily agree with them. One week is just not enough time to introduce people to programming, electronics, and sewing and then expect them to be able to produce sophisticated projects. Other unsurprising trends are the difficulty some students expressed with programming and sewing. The frustrations students had with programming are particularly noteworthy—for example, Elisa, a 10 year old, remarked that she had "*a ton of trouble computer programming*"—and point the way toward an important avenue for future research: developing user-friendly programming languages and environments for working with e-textiles.

In general, we believe that the survey responses and the student constructions validate the tools we've developed, and point the way toward areas for future investigation. Children ages 10-13 were able to successfully employ the kit to build e-textiles and most enjoyed their experiences with it; the LilyPad is useable. However, programming remained challenging for many students, and future research should concentrate on developing accessible programming tools that retain the social benefits of the Arduino system that we touched on earlier.

Now let us turn to the question of why students were engaged in the class and materials. We believe that e-textiles have several features that make them especially compelling to teens and "tweens" (10-12 year olds). Fashion plays a vital role in the lives of everyone, but particularly in the lives of young people, who are discovering and defining their identities, identities that are publicly announced through their clothes and accessories. Electronic devices—mobile phones, for example—are increasingly significant fashion accessories, functioning as status symbols both through their monetary value and their ability to advertise social connections. Craft can also play a significant role in developing identity; many wardrobes include carefully personalized items. Kids make elaborate drawings on their notebooks and backpacks, glue rhinestones to their mobile phones, and weave friendship bracelets to trade with their buddies. E-textiles are poised to take advantage of each of these trends, providing a cutting-edge technology that kids can personalize and integrate into their daily lives.

Of course, it is possible that students who rated the class highly were responding less to the course materials (to the LilyPad or e-textiles) and more to the enthusiasm of the instructors. First of all, we would like to make the point that even if this is the case, this is not a bad outcome; given

Question	Sample Responses
Do you have any suggestions for improving the class?	*Everything was very well done. I just think you need more time.* – Lily *A longer class would really help to insure the completion of projects.* - Sara (age 13)
Was there anything in the class you found particularly hard to do?	*I had a little trouble understanding the C language. I just had my dad help me a little.* – Lily *I've never sewn before.* – Christopher *I had a ton of trouble computer programming. It was very confusing for me.* – Elisa (11)
Do you think you might take future classes in electronics or computer science because of your experience in this class?	*Yes, because I intend to be an astrophysicist or a mathematician. Also, I am interested in fashion design and modeling.* - Ellen (12) *Nope. It does not incorporate itself with my interests.* – Shauna (13)
Would you take another class in electronic fashion if it were offered? Briefly explain your reasons.	*I think the first class was confusing but I think if I did it again I would understand much better.* – Elisa *Yes, because you make something that has technology but it still has the design aspect.* – Ellen
Are you interested in building electronic fashion at home on your own time?	*Yes. I think electronic fashions would be cool presents.* – Sara
Are you interested in writing computer programs at home on your own time?	*Never!* – Elisa
Provide any additional comments you have about the class.	*I had a great time in this class and I learned a ton I never new [sic].* – Elisa

Table 3. Additional survey responses.

the right environment, kids can become engrossed in and excited about e-textiles. Furthermore, we believe that some of the less positive survey responses provide evidence against that interpretation. Kids were free with their criticisms and a couple just weren't terribly excited by the class or e-textiles. Like all creative media, (again, the clarinet—or the robot for that matter—is a good analogy), e-textiles probably won't appeal to everyone, but they introduce the creative possibilities of computer science and electrical engineering in a unique way. By integrating aesthetics with engineering and explicitly fostering student creativity, we believe e-textile activities can attract a new and diverse group of people to these fields. We will expand on this issue in the next two sections, but before we move on, we would like to examine the relationship of e-textiles to another type of engagement.

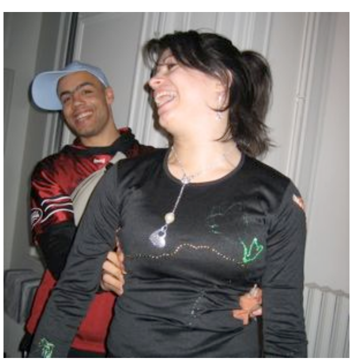

Figure 9. Teenagers enjoy the touch-sensitive wearables they've built.

Figure 9 highlights a different facet of engagement—the way in which artifacts that are integrated into our daily lives can enchant and surprise us. In the image (captured during our fifth workshop, taught to a group of teenagers and adults in the spring of 2007), two teenagers are caught in a flirtatious encounter centered around a touch-sensitive wearable built by the young woman. Her shirt makes sounds when someone squeezes her waist, and the teenagers were delighted both by the shirt and the excuse to touch one another that it provided. Christopher's comments about his friends' responses to his hat also indicate that hand-crafted e-textiles may be able to infiltrate and impact youth cultures in interesting ways. The role that e-textiles might play in people's lives once they are constructed is something we are very intrigued by and would like to focus on in future longer-term studies.

Aesthetics

Today, one does not typically associate art, or even design, with engineering (particularly not computer science and electrical engineering). Of course, historically, this was not always the case. Most famous Renaissance figures, for example, were renowned for—often intertwined—artistic and engineering accomplishments [8]. Our point is simply that art and engineering are not inherently distant from one another; there is no intrinsic reason why the two should not be investigated in tandem. We believe that the divorcing of aesthetics from engineering contributes to its lack of diversity. We mean "diversity" in two senses here: both the diversity of the practitioners—who becomes computer scientists and electrical engineers—and the diversity of the artifacts that are researched and produced by these practitioners.

Being a soft, multi-colored flower, the LilyPad simply looks and feels like no other technological device, and its affordances are correspondingly novel. It presents programming and electrical engineering as arts and crafts tools, encouraging the integrated exploration of art, design and engineering. There are other terrific research efforts aimed at presenting embedded computing as a creative/artistic medium. See for example Resnick et al. [15-16], Hartmann et al. [9], and Igoe [10] for wonderful examples of "physical computing" tools for different audiences. However, previous work has utilized devices that were developed for other purposes, usually robotics, or only slightly redesigned to facilitate a broader range of projects. In particular, hardware has remained hard, bulky and square. Our work differs in that it introduces a radically new tool specifically designed for the creative exploration of e-textiles.

Our students have clearly taken advantage of the aesthetic possibilities of the medium. As can be seen in Susan and Lily's designs (above in Figures 6 and 7), students devoted a lot of attention and energy to the aesthetics of their designs. The LilyPad patch was frequently utilized as a decorative element and great care was usually taken with the placement of electronic components and the paths of conductive stitching. Figure 10, shows additional examples of students' attention to design. The photograph on the left shows a shirt that was decorated by a woman in her early 20s during our fifth workshop and the photograph on the right shows another construction from our Science Discovery workshop, built by a 12 year old girl. We would like to focus the reader's attention on just how different these artifacts look from any other technology-related student projects.

Figure 10. Thoughtful design in student constructions.

There is preliminary evidence that students, particularly women (an issue we will examine in the next section), were attracted to our class and engaged in it precisely because it facilitated the exploration of art and design. Five out of eight students mentioned fashion, or a related theme, in their explanation of why they signed up for our class (Here is a representative quote: "*I thought it was interesting to combine both fashion and technology*" -Shauna). Several quotes from Table 3 point to interesting relationships between engagement and aesthetics. We find Sara's comment about electronic fashions making "*cool presents*" and Ellen's comments about being interested in another class in electronic fashion because it integrates technology and design especially suggestive.

Diversity

In the fall of 2005, the enrollment in the undergraduate computer science program at our university was 8% women [13]. Across the United States, computer science communities are overwhelmingly male dominated, and despite many efforts to address the problem, it is getting worse, not better. Nationally, women received 37% of the computer science undergraduate degrees granted by major research universities in 1985, but only 14% in 2006; the number of undergraduate women choosing to major in computer science declined 70% between 2000 and 2005 [12]. Clearly something is wrong, and current efforts at increasing diversity are failing.

Traditional research in this area has examined the academic and social hurdles that women struggle with when they attempt to participate in computer science or pursue it as a career. See [11] for a particularly detailed investigation of these problems and constructive and ambitious solutions to several of them. This and other studies have found that women students lack the communities and mentors that men have access to, and that computer science curricula are often (usually unintentionally) biased. Proposed solutions to these problems have included revamping computer science curricula and developing and supporting social networks for women in computing.

Undoubtedly, these efforts are productive and important, but our work suggests an approach to complement these efforts. In addition to asking "how can we get girls and women to participate in traditional computer science and support them once they are there?", we should ask: "how can we integrate computer science with activities and communities that girls and women are already engaged in?". Rather than struggle to build communities from scratch, we should take advantage of social structures and patterns of interest that already exist. We cannot claim to be the only researchers pursuing this angle (see [17] for a good example of work in this area), but our investigations of educational e-textiles extend this approach beyond its usual application to traditional computer science settings.

Though our results are preliminary, they are dramatic. We have been able to consistently attract overwhelming majorities of young women to our e-textile classes. (It is worth keeping in mind that these are courses in embedded computing, which women usually shun.) In three of our six workshops, people attended via invitations, but in the other three, participants were self selected. In each of these instances, we attracted significant female majorities. Our first workshop took place as an elective course at a local highs school and attracted five girls and one boy (we capped the enrollment at six students). Our second workshop was also an elective course at a local high school and it attracted 11 girls and four boys (again, our enrollment was capped at 15 students), and the workshop which this paper reports on attracted nine girls and one boy. Each of these classes was called "Learn to Build Your Own Electronic Fashion".

Most importantly, as the previous sections have described, young women participated in the classes successfully and enthusiastically. They completed working projects and, in many cases, were very excited about the class and the medium. What's more, there is some (very preliminary) evidence that girls who participated in our classes may have been inspired to continue exploring computer science and electrical engineering, both in their course work and in after-school projects.

We want to emphasize that our data is clearly preliminary and inconclusive. However, we feel these results strongly indicate that the emerging universe of (artistic) e-textiles has compelling contributions to make to technology education. It is a very young field of study that warrants attention and further investigation.

FUTURE WORK

The LilyPad kit is, in our view, a springboard for an extended agenda of future work. In particular, as we mentioned earlier, we would like to begin developing, supporting, and investigating e-textile hobbyist communities. We envision them as being similar in spirit to the marvelous First Lego League for robotics, and have several plans for near-term realization of this goal.

First of all, as we briefly discussed at the beginning of our paper, we recently developed a commercial version of the LilyPad Arduino. (It was released in October 2007.) This enables students to continue their e-textile experimentations after the conclusion of our workshops. It also enables educators around the world to conduct their own "Electronic Fashion" workshops and allows us to conduct large scale and long term educational/sociological studies. We are excited to take advantage of these opportunities. We also plan to develop a LilyPad Arduino website to facilitate the exchange of ideas, designs, programs, and construction tips. Other practical steps toward sparking e-textile hobbyist communities might include organizing regional electronic fashion shows with prizes awarded to especially dazzling designs.

More generally, there are many potential directions for research and continued development in promoting and empowering a hobbyist and student culture of creative e-textile crafts. First of all, we would like to investigate the development of software platforms specifically geared to the programming of e-textiles. Likewise, there are numerous recent technological developments that dovetail well with the capabilities of the LilyPad: for example, there are now textile substrates compatible with inkjet printers that could easily allow for a combination of (printed) graphical and electronic elements in the creation of e-textiles. Similarly, there are a host of new and novel materials (e.g., stretch-sensing elastomers) that could be incorporated into e-textile projects. In short, then, a creative "popular culture" of e-textile design is just at its inception; and the near future will, we believe, see a still-greater expansion of the notions of "computational media" and "human computer interaction" to accompany the imminent growth of this culture.

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