# Wearable Computing

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# The LilyPad Arduino: Toward Wearable Engineering for Everyone

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Electronic textiles, or e-textiles, are an increasingly important part of wearable computing, helping to make pervasive devices truly wearable. These soft, fabric-based computers can function as lovely embodiments of Mark Weiser's vision of ubiquitous computing: providing useful functionality while disappearing discreetly into the fabric of our clothing.

E-textiles also give new, expressive materials to fashion designers, textile designers, and artists, and garments stemming from these disciplines usually employ technology in visible and dramatic style. Integrating computer science, electrical engineering, textile design, and fashion design, e-textiles cross unusual boundaries, appeal to a broad spectrum of people, and provide novel opportunities for creative experimentation both in engineering and design.

Moreover, e-textiles are cutting-edge technologies that capture people's imagination in unusual ways. (What other emerging pervasive technology has *Vogue* magazine featured?) Our work aims to capitalize on these unique features by providing a toolkit that empowers novices to design, engineer, and build their own e-textiles.

## THE LILYPAD ARDUINO

Researchers, designers, students, and hobbyists can use the LilyPad Arduino construction kit to build soft, wearable computers. Figure 1 illustrates the most recent version of the kit—a commercially available product that we developed in collaboration with SparkFun Electronics. It contains

- a main board, which runs on 2.7–5.5 V and comprises an ATmega168V microcontroller, a reset switch, an indicator LED, 16 Kbytes of program memory, an 8-MHz processor, a 10-bit analog-to-digital converter, and 20 I/O pins, including 6 analog inputs and 6 pulse-width modulation (PWM) outputs;
- a 5 V power supply—with one AAA battery, an on/off switch, an indicator LED, and an NCP 1400 DC-DC step-up converter, and capable of supplying a maximum of 100 mA;
- a speaker;
- a vibrating coin-cell pager motor;
- an accelerometer with an ADXL330 3-axis acceleration sensor, +/–3 g in each direction, and an analog output of 0–3 V;
- an ambient light sensor, with an analog output of 0–5 V; and
- an RGB LED.

To build an e-textile, the user sews modules together. The "petals" on each flower-like module can be sewn through with conductive thread that creates both physical and electrical connections, attaching components to a design's background fabric and providing buses for power and data transmissions between pieces. The user can program the microcontroller in C with the popular open source, free, and relatively user-friendly Arduino programming environment, downloading programs to the board via a USB-to-serial adapter.

We based the commercial kit shown in figure 1 on the research prototypes we developed at the Craft Technology Lab. Although the commercial version uses traditional, hard printed circuit boards (PCBs), we based our research prototypes on soft, laser-cut fabric PCBs—a technology we developed that lets us implement complex circuitry on cloth.

Figure 2 shows a close-up of a fabric-based LilyPad microcontroller module sewn into a dance costume we made. In this version, the stitching goes directly through the PCB's conductive fabric, and embedded sensors control computer-generated music and lighting. (In the commercial version, holes in the petals allow for a similar kind of sewing.)

Table 1 describes several other devices that people have built with the kit.

Our motivation in developing the LilyPad Arduino was to build an accessible yet powerful and open-ended toolkit. We strove to develop a system roughly analogous to the popular Lego Mindstorms kit that introduces people to robotics. We wanted to create a medium that could engage a variety of people in creative experimentation with computing and electronics while teaching them basic skills in these areas. To evaluate our kit, we conducted user studies that have interesting implica-


*Published by the IEEE CS* ■ 1536-1268/08/$25.00 © 2008 IEEE

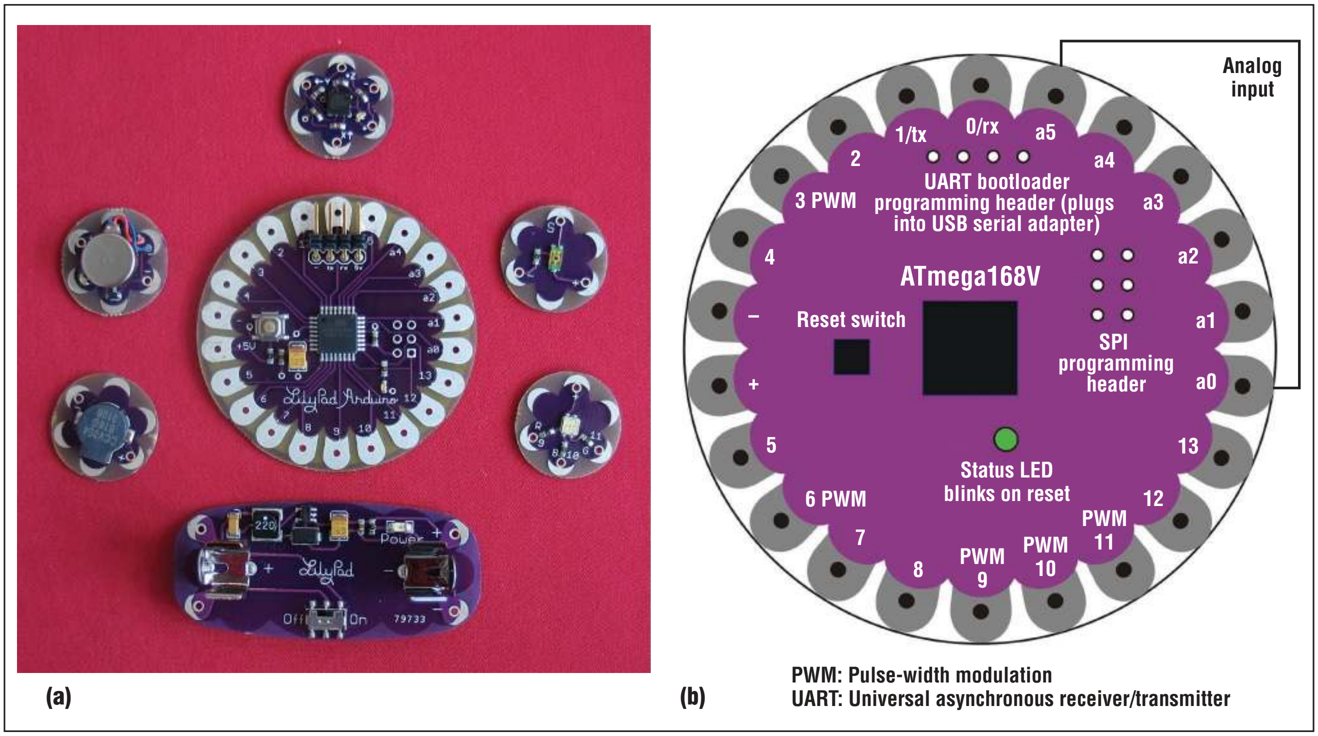


**Figure 1. The LilyPad Arduino kit. (a) The microcontroller is in the center. From the bottom going clockwise: power supply, speaker, vibrating motor, accelerometer, light sensor, and RGB LED. (b) Diagram of the microcontroller module.**

tions for pervasive computing, engineering education, and the technology world more broadly.

## USER STUDIES

So far we've conducted six user studies where people of various ages and backgrounds used versions of the LilyPad Arduino to build their own wearables. Each study was in the format of a workshop titled "Learn to Build Your Own Electronic Fashion" and had a similar structure. At each session's start, participants—most of whom had no previous programming or electronics experience—were introduced to these topics as well as to sewing techniques. Then, under an instructor's guidance, they designed and built a wearable. Each workshop culminated in a fashion show or exhibition that let the participants show off their work to friends and family. Figure 3 shows pictures from two workshops: in figure 3a, two girls work on their designs, while in figure 3b, two teenagers have fun with a project during an exhibition party. A touch-sensitive shirt—built by the girl in figure 3b—makes silly noises when someone squeezes her waist.

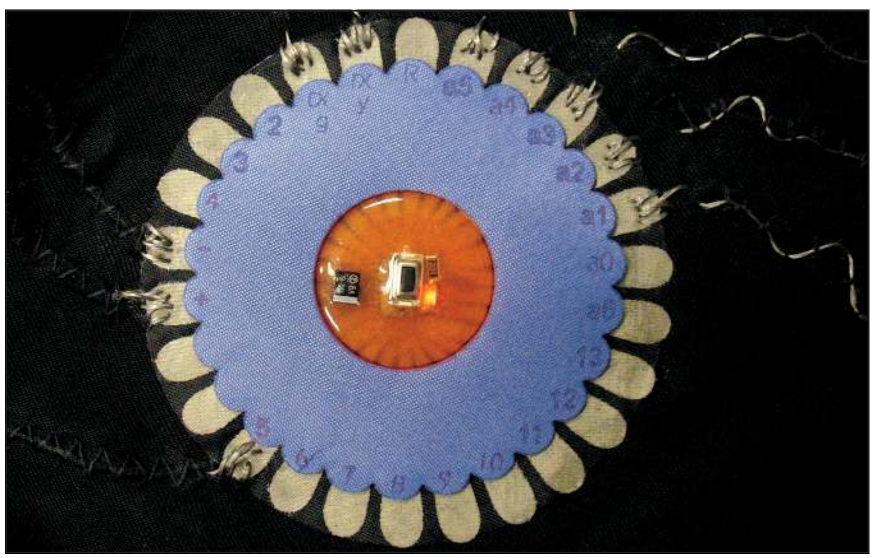

**Figure 2. A textile-based LilyPad Arduino module.**

We taught three workshops to middle and high school students (ages 10 to 17) in school or after-school settings. In each case, the workshop was listed in a course catalog and students signed up voluntarily. We taught the other three workshops to a mixture of teenagers and adults whom we invited.

The workshops provided us with settings that we used to iteratively improve our kit design and develop an e-textile course curriculum. In our final two classes, having developed a stable class

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**TABLE 1**
**Devices built with the LilyPad Arduino.**

| Description | Components | Creator, setting |
|---|---|---|
| Touch-sensitive shirt; makes silly sounds when it is touched in certain places. | Main board, power supply, speaker, skin resistance sensors built from conductive fabric | A 17-year-old girl, during an electronic-fashion workshop |
| Police hat that makes siren noises when a switch is pressed. | Main board, power supply, speaker, switch | A 10-year-old boy, during an electronic-fashion workshop |
| Fortune-telling shirt; when the wearer touches a button, the shirt answers a question by randomly lighting up an LED next to a phrase like "Most definitely." | Main board, power supply, LEDs, switch | A professional teacher, during an electronic-fashion workshop |
| Neural network quilt with squares that can be snapped together with different "weight" strips to form a simple neural network; LEDs show which neurons are firing. | Several main boards, LEDs, resistors | Graduate students, during an embedded-computing course |
| A hat that keeps its wearer awake: when the wearer's head falls to his chest, vibrating motors shake and speakers chime to keep him awake. | Main board, power supply, accelerometer, vibrating motors, speaker | A graduate student, during a physical-computing course |

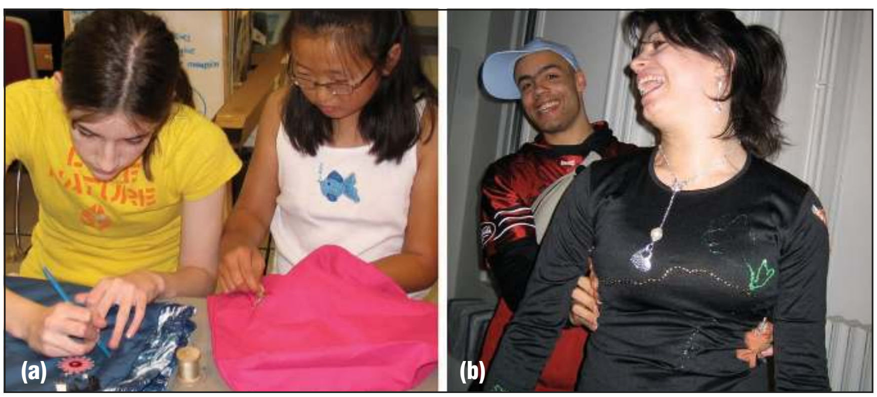


**Figure 3. Students at work during our user studies. (a) Two students work on their e-textile designs. (b) Students have fun with the wearables they built.**

structure and usable kit, we began to investigate more complex issues. We were particularly interested in motivational and affective issues: who chooses to participate in our courses, why they choose to do so, whether they become engaged in the experience, and what, if any, lasting impact participating in a workshop has on them.

Although our studies are preliminary, the results are suggestive and interesting. First, in the three workshops in which participants were (self-selected) middle and high school students, 25 out of 31 attendees were young women. In a remarkable reversal of traditional patterns, we were able to consistently attract overwhelming female majorities to what is essentially an embedded computing course. What's more, many of the students (though not all) expressed passionate interest and engagement in the class. Here is a sample of positive feedback from four students that we collected from surveys and an unsolicited email:

> *[The class] was amazingly fun, I learned a lot, and we get a really cool garment out of the class!*
>
> *[I would be interested in taking another class in electronic fashion] because you make something that has technology but it still has the design aspect.*
>
> *I think electronic fashions would be cool presents.*
>
> *My friends thought my hat [was] sooooooo cool … so I'm just sending you an email to say I loved your camp so much!*

Our data also indicates that the experience might have been an empowering and motivating one for some students. In the last workshop, five out of eight students who completed post-surveys reported that they'd be interested in taking future classes in electronics or computer science as a result of their experience, and one 15 year old wrote in a survey that she'd probably take future classes in computer science because "I thought programming would be a lot harder than it really is."

These results point the way toward interesting avenues for future investigation. E-textiles might well serve as an introduction to longer-term interest in computing and engineering. But beyond this, e-textiles might ultimately produce a sea change in the ways that students perceive computation and technology. After all, it wasn't so long ago when computers were room-sized "giant brains" and available only to a few elite practitioners in academia, government, and industry. Computing is certainly more widespread and accessible today; but as a field of study, it can still seem unnecessarily exclusive and daunting to the hobbyist or beginner. The image of the obsessive, reclusive hacker does have an idiosyncratic appeal; but at the same time, it conjures echoes of the removed fraternity of technicians from the earlier era.

E-textiles present an alternative look at computation—pervasive, soft, flirtatious, playful, theatrical. We can at least imagine such a style of computational design as an enticement to children or teenagers who would otherwise feel that technology is only for passive consumption. Our possibly utopian hope is that e-textile design can, over time, become a means through which hobbyists, craftspeople, and (perhaps most powerfully) children can become technologically fluent—and can express themselves creatively as well. P

## ACKNOWLEDGMENTS

We thank the US National Science Foundation for funding this research under grant EIA-0326054.

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