LilyPad in the Wild: How Hardware's Long Tail is Supporting New Engineering and Design Communities

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ABSTRACT
This paper examines the distribution, adoption, and evolution of an open-source toolkit we developed called the LilyPad Arduino. We track the two-year history of the kit and its user community from the time the kit was commercially introduced, in October of 2007, to November of 2009. Using sales data, publicly available project documentation and surveys, we explore the relationship between the LilyPad and its adopters. We investigate the community of developers who has adopted the kit—paying special attention to gender—explore what people are building with it, describe how user feedback impacted the development of the kit and examine how and why people are contributing their own LilyPad-inspired tools back to the community. What emerges is a portrait of a new technology and a new engineering/design community in co-evolution.

Keywords
LilyPad, Arduino, open-source hardware, long tail, electronic textiles, e-textiles, wearable computing.

INTRODUCTION: HARDWARE'S LONG TAIL
Web-based technologies have reshaped the way we work, communicate, and socialize in startlingly rapid and profound fashion. Anderson, in his 2004 article titled *The Long Tail* [2] and in his later book by the same name [3], beautifully articulated some of the new social and economic patterns that are emerging. He observed that when media is easy to create, publish and distribute, production and consumption decentralize. While the 20th century was dominated by large companies who mass produced media that was mass consumed by the public, the 21st century is emerging as a time where media is produced and consumed in an increasingly non-homogeneous fashion by niche groups. These niche groups, who comprise Anderson's "long tail", use the internet to construct, share, find, and consume material that fits their particular (sometimes very particular) interests.

We are at the beginning of a new chapter in this evolution as collaborative, open, web-enabled technologies extend their reach beyond the screen. For example, online marketplaces like Etsy [12] and Threadless [31] are making it easy for individuals to design, manufacture, and sell their own custom made physical goods. Digital fabrication devices like laser cutters, 3D printers, and computer-controlled knitting machines are allowing for "mass customization", enabling people and companies to quickly design and build personalized devices [16]. Businesses are employing tools like Innocentive to crowd-source complex scientific and engineering tasks that involve physical labor [19]. Ever growing communities of people are sharing advice on how to build real world stuff from dresses and rockets to robots and windmills on sites like Instructables [20]. Open-source hardware communities are growing around tools like Openmoko [26], the Chumby [11], and the Arduino [4].

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Most of these endeavors are happening in what one might term *The Long Tail of Hardware* or *The Long Tail of Things.* The goods sold on Etsy, the Arduino and the Openmoko phone are items that appeal to small but significant niches. These are all projects that would not have been undertaken by large companies, but that are collectively reshaping the way goods are produced and distributed. Surprisingly, very little scholarship has examined this new open and collaborative physical/digital movement. Several books touch on or mention related themes. Gershenfeld's *Fab* [16] discusses new design and manufacturing models; Tapschott and William's *Wikinomics* [30], like *The Long Tail,* describes economic and social implications of web 2.0 technologies; von Hippel's *Democratizing Innovation* [34] makes a case for the economic and societal advantages of supporting end-user innovation; recent articles have begun to discuss open-source hardware [32, 36]. However, no one has yet conducted an in-depth investigation of any of the new open and collaborative physical/digital communities.

This paper explores a project that illustrates what we believe are many of the most compelling and important features of this space. The LilyPad is a niche electronics kit that exemplifies hardware's long tail. Like Anderson's media niches, the LilyPad was made possible by the internet with the addition of hardware focused technologies. In particular, it could not have existed without online storefronts, media sharing sites, open source hardware and software, and rapid prototyping/ manufacturing technologies.

We will argue that the LilyPad in turn enabled a new and unique engineering community to develop and grow. The most noteworthy characteristic of the community is that it is engaging large numbers of women in designing and engineering technology, women who most likely never would have engaged in this kind of activity in the past.

The remainder of this paper explores the LilyPad community in detail. We introduce the LilyPad toolkit, examine the people who have adopted it, explore their creations, and investigate how they are employing open source tools to reshape and expand the kit in unexpected ways.

BACKGROUND: LILYPAD AND ARDUINO

In the past several years, a microcontroller platform called Arduino has come to dominate the landscape of interaction design. The Arduino is an inexpensive, open source, and relatively easy-to-use embedded computing platform that was developed by educators and students at the Ivrea Interaction Design Institute in 2005 [4,5,32]. Arduino is a marvelous example of hardware's long tail. It was created by interaction designers and educators who saw an unmet need—namely there were no low-cost easy-to-use hardware kits. The Arduino team developed the kit for their students but also distributed it online, where it was rapidly adopted by like-minded designers and engineers. Since Arduino was introduced over 80,000 boards have sold [18,32] and the platform is being used to teach interaction design, engineering, and computer science in schools and universities around the world. The project succeeded without the backing of a large company and without any traditional marketing or retailing.

Perhaps more compelling than Arduino's individual success however is the fact that it has inspired—and, by being open source, actively facilitated—countless extensions and variations. For example, the "Boarduino" is identical to the Arduino except for the fact that it fits onto a standard breadboard [6], the "Sanguino" is similar to the Arduino, but is based on an AVR microcontroller with more I/O pins and processing power [28], and the "Funnel I/O" is an Arduino that includes a built in XBee radio to facilitate wireless networking [15]. Each of these variations can be programmed with the open source Arduino software (or some slight variation of it), and draws upon and contributes to a shared body of knowledge and documentation that has grown up around Arduino.

This paper focuses on LilyPad, an Arduino variant we designed that enables people to create their own electronic textiles or "e-textiles" [7,23]. It consists of a spool of conductive thread and a set of sew-able electronic modules—including a sewable Arduino microcontroller, a temperature sensor, an accelerometer, and an RGB LED. Interactive textiles are constructed by sewing these modules onto cloth with conductive thread, which provides the physical and electrical connections between the pieces. The behavior of designs is specified by programming the microcontroller, the "LilyPad Mainboard", using the Arduino development environment. Figure 1 shows a picture of the kit and a sample e-textile that was constructed with it. As the figure hints, e-textiles occupy a design landscape that is strikingly different from that of traditional electronics.

Figure 1. Components of the commercially available LilyPad kit and a sample construction, a turn signal biking jacket.

The LilyPad project began as an academic research project in 2006 [8,9], but grew into a commercial endeavor when we collaborated with SparkFun Electronics [29] to design and produce a for-sale kit that was released on October 1, 2007. (SparkFun is an electronics retailer whose business essentially focuses on hardware's long tail. SparkFun designs, manufactures, and distributes, via an online storefront, niche electronic products like Arduino and LilyPad.) Since the LilyPad's introduction, the kit has been adopted by an unusual group of designers, engineers, students, and hobbyists around the world. We turn now to an exploration of this community.

LILYPAD COMMUNITY: PEOPLE

At its core, the LilyPad community consists of people who are building artifacts with the kit. However, it also includes people who are documenting projects and posting them online, developing LilyPad tutorials, developing new LilyPad boards, and contributing to user forums.

For these studies we were primarily interested in exploring the demographics of the LilyPad users to determine who was participating in the community. We were especially interested in determining if the demographics of the LilyPad community were different from that of traditional electronics/engineering communities.

Data and Methodology

To assess the differences between groups, we collected and analyzed data for both the LilyPad community and the Arduino community, using the Arduino community as an example of a more traditional electronics/engineering community. We focus here on two studies, investigations of: (1) the sales records of LilyPad and Arduino boards sold by SparkFun Electronics, and (2) project documentation—in the form of photos, videos, and text—that community members produced and posted online.

Study 1: Customers

We obtained records from SparkFun for all LilyPad Mainboard and USB Arduino (Figure 2) sales between October 1, 2007 (when the LilyPad was released) and November 30, 2009—13,603 records in total. Each record contained the customer's first name, country of residence, a unique customer identification number, information on whether the customer was a reseller/distributor, information on the item purchased, and the date of sale. We aggregated this data by customer to obtain sales histories for 11,335 unique customers, 82 (< 1%) of whom were distributors.

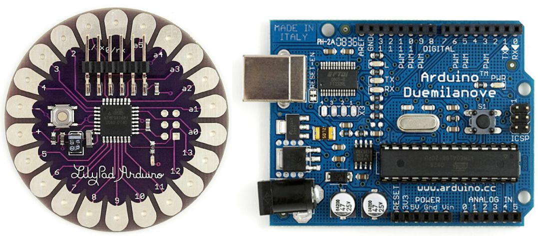

Figure 2. LilyPad Mainboard and USB Arduino.

Names were hand-coded for gender by the authors of this paper and several colleagues from around the world. Thus "Michaels" were identified as male and "Jennifers" as female. Since some customers were identified only as institutions and some names were gender ambiguous (i.e.: Chinese names written in the English alphabet, the names "Alex" and "Chris", etc.) we were only able to classify 87% of customers by gender.

While we do not claim that SparkFun customers are a fully representative sample of the Arduino community, SparkFun is one of the very largest microcontroller vendors for researchers, educators and hobbyists. Due to its size and importance, we argue that trends in SparkFun are likely to be indicative of trends in the larger communities. That being said, it is worth noting several limitations in our data including the fact that SparkFun is the sole manufacturer and primary distributor of the LilyPad, but only a reseller of the Arduino, which is manufactured by an Italian company. Thus, while the LilyPad sales data in our sample is comprehensive, the Arduino data is not. However, our data does account for a significant amount of total Arduino sales (approximately 30%) and a large percentage of US sales [18,32]. Furthermore, as we detail shortly, our results are consistent when we restrict our analyses to US customers for whom SparkFun was a primary source of both Arduinos and LilyPads during the window of our data collection.

Study 2: Builders

To build a sample of the community of people who are building artifacts with Arduino and LilyPad, we employed a group of anonymous workers through Amazon's Mechanical Turk system [1,22] to find LilyPad and Arduino projects that were documented online. We employed this method to build a sample representative of easily discoverable Arduino and LilyPad projects in an impartial manner. Contributors on Mechanical Turk were blind to the goals of this study and knew no details about the research.

We posted eight "HITs" (Human Intelligence Tasks) on Mechanical Turk—four for LilyPad and four for Arduino—each awarding workers $0.25 per submission. Six of the HITs asked people to find projects documented on Flickr [14], YouTube [37], or Vimeo [33] and two HITs did not specify a website to search for documentation. Each HIT asked people to supply the URL of the project and the creator's gender, age, and country of residence. Our HITs collected 175 LilyPad submissions and 202 Arduino submissions over seven days.

Mechanical Turk was used to generate our sample, and Turk submitters also made an initial attempt to collect basic demographic information on project creators. However, this data was double-checked and, in a number of cases, corrected after being examined by our research team. In particular, we eliminated inappropriate submissions (i.e.: submissions of irrelevant websites), eliminated duplicates, eliminated our own projects (whose inclusion or exclusion does not change our findings), and corrected obvious errors. Errors included erroneous submission of gender, age, or country information when such information was not readily available from the creator's profile/website and misidentification of age or gender when such information was available from the creator's profile/website. After making these adjustments we were left with 114 unique Arduino projects and 57 unique LilyPad projects, 88% of whose creators we were able to classify by gender.

Analysis and Results

The LilyPad and Arduino customers and builders in our sample were similar in several ways. Over 90% of customers from both groups were from North America and Europe and over 75% of builders from both groups were from these same regions[1]. We were able to obtain (self-published) age information for 40% of our builders. Within this group, the median age for Arduino builders was 27 (mean 30) and the median for LilyPad builders was 25 (mean 26). While the two communities had similar location and age demographics, they had very different gender distributions and the remainder of this section focuses on this relationship.

[1] The discrepancy between customer and builder populations is likely due to the fact that our SparkFun customer data does not include information on many sales made in non-US markets. For example, a Japanese distributor who purchased 500 LilyPads from SparkFun is counted as a single customer in our customer database, but the boards he purchased may be resold and then employed in several Japanese LilyPad projects.

Study 1: Customers

Figure 3 and Table 2 show the results of our analysis of customers by gender. 88% of our customers purchased Arduinos, 9% purchased LilyPads and 3% purchased both an Arduino and a LilyPad. Of the people who purchased Arduinos, 78% were male and 9% were female. In contrast, 57% of LilyPad customers were male and 35% were female. The gender balance of the group who purchased both boards was somewhere in between: 68% male and 21% female. These differences were highly statistically significant ($\chi^2(4, N=11335)=644$, $p<0.001$); there was a strong relationship between a customer's gender and the type of board they purchased.

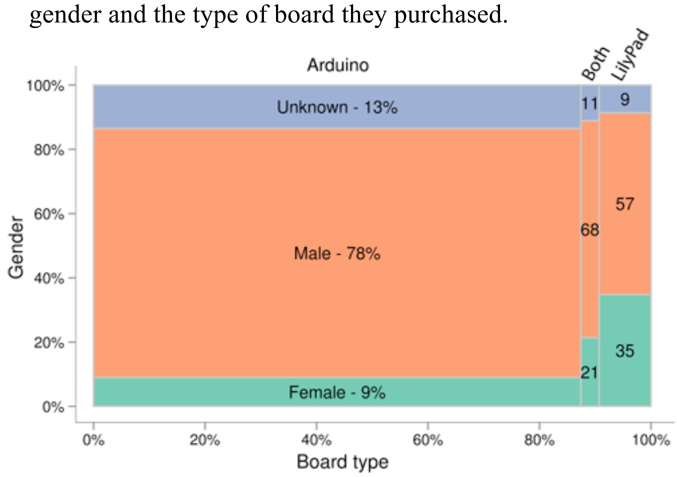

Figure 3. Mosaic plot of LilyPad/Arduino customers by gender and board type (N=11335).

Table 1. LilyPad/Arduino customer contingency table.

	Arduino	Both	LilyPad	
Unknown	1332	41	91	*13%*
Male	7687	250	598	*75%*
Female	890	79	367	*12%*
	88%	*3%*	*9%*	

Although our findings are very clear, there are several potential sources of bias in our data. For example, distributors who buy and resell many boards are likely to order both LilyPads and Arduinos but might not employ either for their own use. As a robustness check we reanalyzed our data on a dataset excluding distributers and found that the results were unchanged.

The large number of people of unknown gender in our sample, particularly among Arduino customers may in part be due to the individuals ordering from abroad. Additionally, Arduino is more readily available from retailers other than SparkFun outside the US than LilyPad is. Because of these potential biases, we reanalyzed our data on only US customers. The gender discrepancies actually widened in this subset: over 80% of US Arduino customers were male compared to 54% of US LilyPad customers. When we did this the percentage of customers with unknown gender shrank overall to 10% from 13%. Within this group, 9% of Arduino customers, 7% of LilyPad customers, and 7% of "Both" customers were of unknown gender. Table 2 summarizes this information.

Table 2. Customer contingency table, US data only.

	Arduino	Both	LilyPad	
Unknown	890	17	52	*10%*
Male	6724	178	382	*78%*
Female	810	61	279	*12%*
	90%	*3%*	*7%*	

It is interesting that in all of the cases we examined there is a higher percentage of unknowns for Arduino than LilyPad. We cannot definitively identify a cause for this, but one possible explanation is that popular gender ambiguous names in our sample, including Chris and Alex, are more likely to be men and men are more likely to purchase Arduinos.

What is clear from all of our analyses is that, within our sample, women make up a small minority of Arduino customers and a significantly larger percentage of LilyPad customers, though still a minority.

Study 2: Builders

Figure 4 and Table 3 show the results of our projects analysis. In our collection, 86% of Arduino projects were done by males and 2% by females. In contrast 25% of LilyPad projects were done by males and 65% by females. These differences were highly statistically significant ($\chi^2(2, N=171)=88$, $p<0.001$).

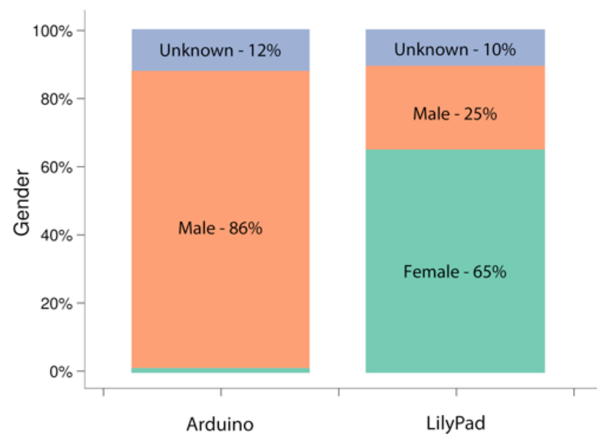

Figure 4. LilyPad/Arduino projects by gender. (Arduino N=114, LilyPad N=57)

Table 3. LilyPad/Arduino builder contingency table.

	Arduino	LilyPad	
Unknown	14	6	*12%*
Male	98	14	*65%*
Female	2	37	*23%*

Figure 5: LilyPad in the wild. Projects include interactive clothing, accessories, plush toys, dance costumes, sculptures, and biking accessories.

We find it especially remarkable that a significant majority of the LilyPad projects in our sample were constructed by women. Also compelling, this percentage is different from the percentage of women who purchased LilyPad kits: 65% of the projects we analyzed were built by women, but women made up only 35% of LilyPad customers. This discrepancy would support the explanation that female LilyPad customers are more likely to construct, document, and share projects than their male counterparts. It is possible that women and men are constructing LilyPad projects in proportion to their purchases and men are just less likely to document them, but this seems unlikely given the number of men who constructed and documented Arduino projects. Perhaps a more likely explanation is that women are more likely to actually employ their LilyPad once they've purchased it.

The data we have collected so far paints a portrait of the LilyPad community as one that confounds gender stereotypes and demographic patterns in electrical engineering and computer science—both overwhelmingly male dominated fields [10,13,17,24]. Women make up a significant percentage of the people who purchase LilyPad kits, and seem to make up a majority of the people who construct and document LilyPad projects.

There is a long history of systems and curricula designed to attract women to computing (cf [21,24] for wonderful projects in this arena), but to our knowledge in no instance have researchers documented an autonomous computing community that is—naturally and without external influences—dominated by women. It would be remarkable if LilyPad adopters were to grow into such a community.

LILYPAD COMMUNITY: PROJECTS

LilyPad enables people to build artifacts that were very difficult to build before the tool's introduction. Though people certainly designed and constructed e-textiles before the LilyPad (cf. [7, 23, and 27]), this was an activity largely relegated to professional researchers and engineers. The LilyPad makes the domain accessible to a much broader audience, and—as we described in the previous section—it is giving rise to a new and unusual community of developers. Tellingly, this new community is building devices that are very different from those normally built by electronics hobbyists and engineers.

To study what people are constructing with LilyPad and how this relates back to who the builders are, we examined the projects that were collected for the analysis in the previous section. We also collected documentation on additional LilyPad projects and conducted a small survey of 15 LilyPad community members. We selected members for our survey if they had (1) developed a new LilyPad board design or (2) developed what we believed to be a noteworthy LilyPad project. This second criteria is, we acknowledge, entirely subjective, so our survey results should be viewed more as a series of case studies than as a reliable representation of the community. Although we she be cautious in generalizing, the responses illuminate members' motivations and experiences and are helping to guide our ongoing research into the community.

Our survey included the following questions: how did you become interested in electronic textiles?, why did you chose the LilyPad for your project?, what did the LilyPad contribute to your work?, what if any problems did you experience with the LilyPad?, and what if any extensions would you like to see added to the kit?

Figure 5 shows some of the LilyPad projects collected for this study. What's immediately apparent from the photos is just how unlike traditional technological devices the artifacts are. To underline the comparison, a small selection of Arduino projects is shown in Figure 6.

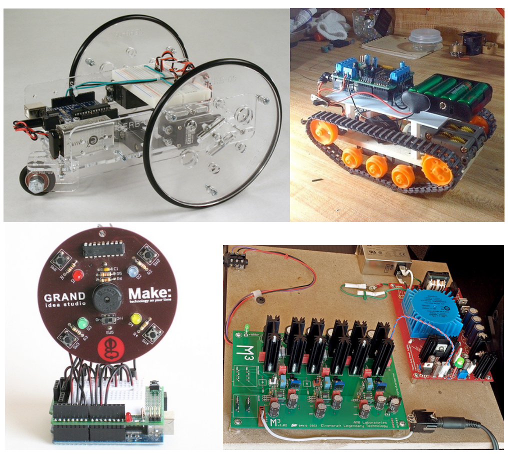

Figure 6. Arduino projects.

Most of the LilyPad projects in Figure 5 are textiles, many of them are wearable, and several have a design or artistic focus. They include dance costumes that record dancers' movements, interactive textile wall-hangings, and light-up cycling gear. It is worth taking a moment to look at a few of these projects in more detail.

The image in the center of the figure is of an interactive embroidered wall hanging. The piece includes light sensors, LEDs, and speakers and creates sounds that change as an observer approaches or moves away from the fabric. The embroidery is a good example of how e-textiles can integrate traditional crafts—in this case needlepoint—with electronics and computation. This piece was constructed by Rebecca Stern, a professional journalist and designer.

The stuffed teddy bear, shown mid-construction in the bottom row of the figure was constructed by Diana Hughes, a graduate student in Interactive Media at the University of Southern California. In this piece, sensors in the bear's body capture a person's interaction, and the LilyPad Arduino communicates this information to a computer via Bluetooth to control a Flash-based video game; the bear functions as a soft video game controller.

Finally, it's worth highlighting one of the non-textile projects. The book on the top row of the figure is part of an installation built by the artist Edith Kollath. In this piece, a group of books rest on tables and "breathe", gently opening and closing like small bellows. Each book in the installation is controlled by a LilyPad.

One of our ongoing interests in is determining whether or not projects like these are projects that would have been built before the LilyPad kit was released. We would like to determine if the LilyPad is sparking a new community or if it is simply providing a useful tool to an existing one. We believe that the LilyPad is actually helping to create a new engineering community, but this is a difficult phenomenon to verify. To explore the issue we asked people in our survey how they got interested in e-textiles and what the LilyPad had contributed to their work. Here are comments from three of our respondents:

"The LilyPad is a nice electronic system because it gave people the ability to realize e-textile projects…In all (of our) projects the LilyPad and the Arduino software gave us a fast way to do e-textile physical prototyping." (male designer)

"I had always been interested in textiles and garments, and also in creative art…but somehow I had never really thought of working in e-textiles because it seemed that it involved a huge skillset and also very specialized equipment...The Lilypad Arduino attracted my interest because it gave the promise that…something like this was doable by normal people." (female computer science professor)

"LilyPad and the related e-textile field made me brave enough to jump into hardware development…Before I started this project, I had absolutely no experience with electronics of any kind. I STILL can't solder to save my life, but it doesn't matter, because I can sew." (female media arts student)

These responses both support and add depth to our hypothesis that the LilyPad has sparked a new community rather than providing tools to an already existing one. We plan to examine this issue more deeply in the future by undertaking larger surveys that ask more direct questions about people's previous experience in electronics, computing, and textiles.

OPEN SOURCE HARDWARE CONTRIBUTIONS

The last two sections explored how the LilyPad sparked a new community of unorthodox developers. In this section, we will look at how that community in turn influenced the design and evolution of the LilyPad. In particular, we will examine how community members employed LilyPad's open source design to develop LilyPad extensions.

The LilyPad is an open-source hardware (OSH) project. This means we have released our schematic and board layout files under the creative commons license and people are free to copy and repurpose our designs as long as they cite our previous work and keep their designs open-source. In the course of our community research we discovered several toolkit projects that were based on the LilyPad. We included the developers of these projects in our survey, and this section will explore their contributions.

LilyPad Extensions

The first extension we will discuss is the TeeBoard by Grace Ngai and her colleagues at the Hong Kong Polytechnic University [25]. In this project, the designers used the LilyPad to build a textile prototyping platform that enables people to experiment with e-textiles without sewing. Their kit consists of a LilyPad-powered T-shirt where input and output modules can be snapped onto the garment at preset locations. The TeeBoard was designed for educational purposes and was deployed in several educational workshops. The focus of the activity around the TeeBoard is programming and understanding sensors and actuators. These developers felt that sewing was too time consuming and error prone and that it also distracted from their educational mission of teaching students about programming and electronics, so they designed the TeeBoard to overcome these problems:

"The LilyPad kit requires sewing to attach it to the garment…the TeeBoard solved our problems because it allowed a big degree of reconfigurability and reusability"

Maurin Donneaud, a Paris-based textile and interaction designer, developed a different kind of extension. He used the published LilyPad OSH board files to design a high-current LED driver board called the LilyPadaone, images of which are shown in Figure 7. These boards look like they could be members of the LilyPad kit. In contrast to the TeeBoard, the LilyPadaone was developed to be used in parallel with the LilyPad in much the same way as the original pieces—that is, it is also sewn to textiles with conductive thread. The contribution is also different from the TeeBoard in that it was designed for individual use by the designer himself rather than for educational applications. In short, this contributor had an entirely different set of motives and objectives and consequently contributed to the project in a very different way.

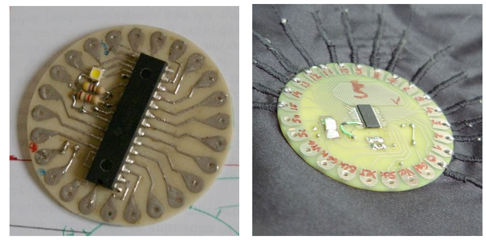

Figure 7. Different versions of Maurin Donneaud's LilyPadaone, a high current PWM driver.

Kate Hartman and Rob Faludi developed still another kind of extension. Like Maruin Donneaud, they made use of the OSH board files to design a component that wasn't yet part of the LilyPad kit, a wireless XBee radio. However they envisioned it being used in both their own projects and in educational settings:

"Human bodies don't like to be tethered, so most projects that involve sharing body data require some sort of wireless component…The main reason we developed the Lilypad XBee was because we repeatedly saw students strapping XBees on breadboards into their clothing and we knew there must be a better way."

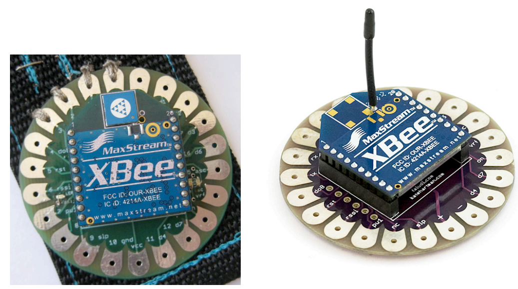

Figure 8. Kate Hartman and Rob Faludi's LilyPad XBee, a LilyPad for wireless communication.

The left image in Figure 8 shows the initial version of the LilyPad XBee sewn into a wrist-band.

Because their focus included an educational/outreach component, these designers weren't content to produce just one or two boards for their own designs. They saw their addition as an important improvement to the LilyPad kit and wanted their boards to be widely available. In November of 2008, after some collaborative re-designing undertaken by all of the stakeholders, the LilyPad XBee was released as an official part of the LilyPad Arduino kit. This official version can be seen in the right-hand image in Figure 8.

We believe that these examples, especially the last one, nicely illustrate the benefits and potential of open-source hardware projects. The LilyPad Arduino is a toolkit that can draw on the creativity and labor of a large group of designers and engineers. What we see in these instances is an OSH project evolving and growing in the same way that open-source software projects usually evolve and grow.

The fact that the source code/source design for the project is available allows an individual to solve her own particular problems independently. Once she has solved a problem she can contribute her solution back to the community and if the solution is something that is valuable to others, it gets adopted into the core distribution.

Of course, the entire LilyPad project is also an illustration of the same point. In designing our kit, we employed Arduino's open source hardware design, tailoring it specifically to fit our needs. Basing our design on the Arduino presented us with several advantages. It allowed us to leverage an existing body of software and hardware tools, documentation, and support and it provided us with an already established community of users who were capable of quickly adopting our kit.

LilyPad-Inspired Kits

Two of the developers in our survey group were inspired by the LilyPad to design and produce their own e-textile construction kits. In each of these cases, the developers—educational technology researchers—liked the idea of the kit, but preferred working with a different software or hardware platform, so they simply reinvented the kit.

The DaisyPIC, shown on the left in Figure 9, was developed by John Martin and Paul Gardiner. They created a PICAXE version of the LilyPad, explaining their motivations this way:

"For UK schools, programming in 'C' is not really viable. This is why we have engineered our own e-textile controller modules to use PICAXE controllers that are in quite widespread use in our schools and which can be programmed in flowchart or BASIC."

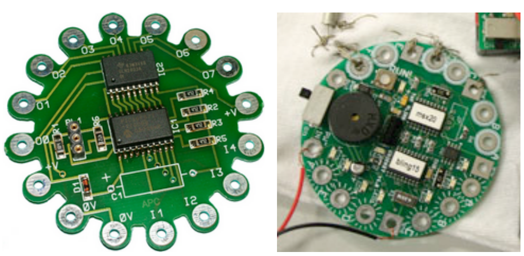

Figure 9: The DaisyPIC (left) and Bling Cricket (right).

Fred Martin at the University of Massachusetts Lowell developed the Bling Cricket, a LOGO programmable version, for similar reasons:

"We have a big investment in the Cricket platform and associated Cricket Logo programming language, so I borrowed ideas from the Lilypad in designing the Bling Cricket. Cricket Logo is not better than Arduino/C, it's just more familiar to my user community."

These examples show how the ideas and materials introduced by the LilyPad are being adopted and dispersed in a different, but potentially equally powerful way.

CONCLUSION

We have learned two important lessons in investigating the LilyPad user community, one which illuminates new strategies for broadening participation in computing and one which is prompting us to reexamine the relationship between HCI research and "the real world".

Broadening Participation

Margolis and Fisher's groundbreaking study on gender in computer science was titled "Unlocking the Clubhouse" [24]. This phrase provides a good description of the path that most projects aimed at broadening participation take. The story behind the research goes something like this: traditional computing culture is a boys' club that is unfriendly to women and we need to find ways to unlock this clubhouse, to make it accessible.

Our experience suggests a different approach, one we call *Building New Clubhouses*. Instead of trying to fit people into existing engineering cultures, it may be more constructive to try to spark and support new cultures, to build new clubhouses. Our experiences have led us to believe that the problem is not so much that communities are prejudiced or exclusive but that they're limited in breadth—both intellectually and culturally. Some of the most revealing research in diversity in STEM has found that women and other minorities don't join STEM communities not because they are intimidated or unqualified but rather because they're simply uninterested in these disciplines [35].

One of our current research goals is thus to question traditional disciplinary boundaries and to expand disciplines to make room for more diverse interests and passions. To show, for example, that it is possible to build complex, innovative, technological artifacts that are colorful, soft, and beautiful. We want to provide alternative pathways to the rich intellectual possibilities of computation and engineering. We hope that our research shows that disciplines can grow both technically and culturally when we re-envision and re-contextualize them. When we build new clubhouses, new, surprising, and valuable things happen. As our findings on shared LilyPad projects seem to support, a new female-dominated electrical engineering/computer science community may emerge.

Hardware's Long Tail Revisited: HCI Research and the "Real World"

HCI research encompasses the development of new interfaces and the study of the interactions between people and technology. Very often, advances made in both of these areas don't make it into commercial products. Commercial designers, engineers, and researchers may or may not communicate with academics; most of the novel interfaces developed by researchers are never commercialized; and large subsets of the HCI community bemoan the lack of rigorous in situ user studies.

New long tail social structures can profoundly reshape these relationships. As this paper demonstrates, it is now feasible for a small team to design, manufacture, and distribute new technology, even technology that involves hardware. Once a new technology is distributed the team has access to a group of real world users that they can study. This makes it possible to assess things like the relationship between a tool's design and its adoption and the formation and evolution of new technological communities. Perhaps most compellingly, these teams are uniquely positioned to study the impact of design decisions on patterns of use, since researchers have access to all aspects of the project from design to dissemination. Because of our new ability to rapidly produce and deploy systems, this style of research can now take place on relatively short time scales with small but significant user communities, even when hardware is involved.

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