The LilyTiny: A Case Study in Expanding Access to Electronic Textiles

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ABSTRACT

The LilyTiny sewable microcontroller was created ten years ago, in an effort to make electronic textiles more accessible. At the time, e-textiles was gaining traction as a means to invite more diverse participation in computing, but financial and instructional barriers stood in the way of broader adoption. In addition, there existed a scaffolding gap between projects involving lights, batteries, and thread – and those requiring programming (i.e. leveraging the LilyPad Arduino and/or additional sensors or outputs). In an effort to expand access to electronic textiles, we designed the LilyTiny, an inexpensive, pre-programmed sewable microcontroller which controls assorted LED patterns, and which later became available for purchase through SparkFun. Alongside the LilyTiny, we released a free workshop guide for educators which details five low-cost activities that can be taught without any prior electronics experience.

This paper summarizes our development of the LilyTiny and companion curriculum – and reflects on whether we met our stated goal of expanding access to electronic textiles in the decade since. We share and discuss some measures of impact, including a survey of derivative products and a multi-year analysis of sales data from the LilyTiny's sole distributor SparkFun Electronics.

CCS CONCEPTS

• **Hardware → PCB design and layout**; • **Social and professional topics → Informal education**; **K-12 education**.

KEYWORDS

Electronic textiles, e-textiles, computational textiles, computer science education, K-12 education, gender and diversity, broadening participation, open hardware, curriculum, LilyPad Arduino, LilyTiny, LilyTwinkle

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1 INTRODUCTION

Electronic textiles, also known as "e-textiles" or "soft circuits", are electrical circuits created using flexible conductive materials (such as conductive threads and fabrics) in conjunction with discrete electronic components (such as lights, batteries, switches, and sensors). This domain has long been gaining traction as a creative and approachable avenue into computing; utilizing craft materials and techniques, it invites diverse participation, broadens perceptions of what electronics and computing are "good for", and supports the creation of a very different kind of artifact when compared with traditional electronics prototyping materials [4].

The LilyPad Arduino was introduced in 2008 as a commercially available e-textile toolkit, enabling novices to build their own soft, wearable, sewn – and programmable – circuits [1, 2]. In the years to follow, Adafruit released a similar toolkit, known as the Flora [38]. In addition to supporting individual artists and makers in realizing personal projects, these toolkits also opened up the possibility of teaching electronics and programming with e-textiles. Indeed, research has found this to be a fruitful avenue for broadening participation in computing, teaching electronics and programming, and inspiring a new class of beautiful, computational, and personal artifacts [12].

Despite these successes, we observed critical resource gaps preventing widespread adoption of e-textile learning activities, particularly at the K-12 level. In particular, we noticed that many educators did not have access to the budget required to secure relevant tools and materials at scale. Additionally, we noted a lack of instructional materials to support educators in preparing for and facilitating such activities. We also noticed a scaffolding "valley" between simple projects involving only lights, batteries, and sewn connections – and more advanced projects leveraging the programmable LilyPad Arduino. We designed the LilyTiny in an attempt to bridge this valley; each LilyTiny is pre-programmed with several LED behaviors, inviting conversation about the power of computation without requiring students to write (or even understand) code.

This paper summarizes our experience developing a low-cost sewable microcontroller, known as the LilyTiny, and a workshop guide to support it – work undertaken to address the aforementioned resource gaps in hopes of broadening access to e-textiles. We also share the results of our inquiry into the impact of this work, several years having elapsed since we created the LilyTiny – now a commercial product sold by SparkFun Electronics. Our investigation includes a survey of derivative products and a multi-year analysis of sales data.

2 RELATED WORK

The development of the LilyTiny was made possible by years of prior research in physical computing, electronic textiles, and education.

2.1 Physical Computing

In the realm of physical computing, two projects in particular directly paved the way: the Arduino electronics prototyping platform and, later, the sewable LilyPad Arduino. Arduino was initially developed to enable rapid prototyping without specialized engineering expertise [24]. The LilyPad toolkit extended this functionality to a textile context, thereby inviting participation from diverse populations as well as enabling the creation of soft, beautiful, computational artifacts [1, 2, 4]. Both of these projects pioneered the now-ubiquity of physical computing – not only by their very design, but also by their mass availability and pricing suitable for hobbyists, artists, and students. They both leverage an open source hardware (also known as "open hardware") model, allowing others to modify the PCB layouts for personal use or derivative products. Our work extends these efforts, attempting to make e-textiles more accessible and affordable to a broader audience.

2.2 Electronic Textiles & Computing Education Research

The LilyPad Arduino has been extraordinarily successful in leveraging handcraft practices and materials to draw in demographics historically excluded from engineering (most notably, women). This has been evidenced by a much larger proportion of the LilyPad Arduino market share being female purchasers when compared to the classic Arduino – and by an emerging design community at the intersection of aesthetics, craft, and computation [4].

Significant work has also gone into the development of curriculum to support adoption of the LilyPad Arduino [1, 3, 11, 14, 15, 34]. This work affirms how highly we prioritized developing curriculum to support the LilyTiny hardware.

Ngai, et al. have also developed two modular platforms for wearable computing, TeeBoard and i*CATch, to bring computational textiles into the classroom and teach basic programming [27–29]. More recently, Hill, et al. introduced the ThreadBoard, for rapid prototyping of e-textile circuits [10]. These projects represent critical strides in the mission to expand educational access, although these tools are not yet available to the general public.

In parallel to the development of new e-textiles tools and kits, there has been a great deal of research into the impact of teaching with e-textiles. For example, studies have demonstrated the utility of e-textiles as a means to develop students' STEM/technological self-efficacy, teach debugging, develop computational thinking, experiment with aesthetics, and create culturally relevant artifacts [8, 13, 14, 16, 23, 35]. This body of work has inarguably established the value of e-textiles as an avenue for effectively broadening participation in computing, especially at the K-12 level and in after-school settings [5, 12]. The broader impact of this work has been limited, in part, by the funding required to secure necessary tools and materials, as well as access to a variety of instructional resources to support educators. We directly sought to address these limitations.

2.3 Instructional Design for K-12 STEM

Experienced educators and organizations have been disseminating resources for STEM learning long before e-textiles activities came to be. In particular, WGBH (a PBS affiliate, now known as GBH) has a long history of publishing K-12 activity guides for use in classrooms and at home. (The Design Squad guides are an excellent example of this [32, 40].) The National Center for Women & Information Technology (NCWIT) also offers "in-a-box" programming on topics including computer science "unplugged" (in-person, off-screen activities), outreach, and pair programming [26]. The design of our workshop guide drew heavily on the format of these successful resources, expanding their domain coverage to include e-textiles. (NCWIT has since released an "e-Textiles in-a-Box" program [25].)

2.4 Independent Learning Resources for E-Textiles

In addition to resources for educators, there has been an explosion of resources for individuals to independently learn new skills or complete projects related to making, crafting, and prototyping. At the time that we developed the LilyTiny, a handful of project-based e-textiles books had been released: *Fashioning Technology, Switch Craft, Fashion Geek, and Open Softwear* [7, 21, 30, 31]. Around the same time, MAKE Magazine – and the shorter lived CRAFT Magazine – were gaining popularity as monthly publications, containing example projects, relevant news/products, and profiles of prominent makers/crafters. Since the development of the LilyTiny and accompanying curriculum, two additional DIY e-textiles books have been released: *Make: Wearable Electronics* and *Sew Electric* (the latter containing an activity featuring the LilyTiny) [6, 9].

In addition to print resources, the internet has been host to a number of free, digital DIY resources over time; websites like Soft Circuit Saturdays and How To Get What You Want have reflected independent efforts to share e-textiles resources [17, 36], while structured tutorials have offered guidance to independent learners in the craft/technology realm [19, 20, 22]. Instructables has served as a valuable platform for many of these, especially as leveraged by prominent e-textiles artists/makers like Becky Stern and Hannah Perner-Wilson [33, 39]. SparkFun Education has expanded these offerings in recent years, in particular supporting the LilyTiny with detailed documentation and tutorials [37].

Our work builds on the success of many of the aforementioned projects, with an emphasis on lowering prevailing barriers of cost and know-how, while uniquely striving to support educators guiding many learners in parallel.

3 DESIGN & DEVELOPMENT

The LilyTiny and accompanying workshop guide were created to address known barriers to broader adoption of e-textiles in educational settings. In designing these materials, we sought to overcome challenges of cost, know-how, and also to provide a bridge to integrating computation and learning about microcontrollers without having to program. It was our hope that this work would expand access to electronic textiles as a creative way into computing.

3.1 The LilyTiny

Our goal for the LilyTiny was to create a sewable microcontroller at a much lower price point than the LilyPad Arduino, and one which arrives pre-programmed, allowing users to incorporate computation in their projects without writing code. We designed around the ATtiny85 microcontroller because it is very inexpensive, yet is powerful enough to support pre-programmed behaviors such as light patterns. Our breakout board was based on the LilyPad Arduino accelerometer board layout, which is open source and available under a Creative Commons License. The LilyTiny is about the size of an American quarter.

A milling machine was used to make the first prototype of the breakout board (see Figure 1). ATtiny chips were soldered by hand to each milled board, after which the broken out pins ("petals" in LilyPad terminology) were color-coded with permanent markers. These early prototypes were programmed one-by-one using an early prototype of SparkFun's Tiny AVR Programmer which attached to the petals of each board using alligator clips. After these boards were manually tested and successfully used in a pilot workshop, we placed a custom order with a circuit board manufacturer. This version included appropriately labeled pins and was more reliable than the first. This time, we used batch reflow soldering to affix the ATtiny chips, after which the boards were again programmed individually with a Tiny AVR Programmer prototype. Following testing and an additional pilot workshop, we partnered with SparkFun Electronics to release the LilyTiny commercially as part of the LilyPad Arduino toolkit line of products.

All versions of our prototype were programmed with the same Arduino code, allowing a user to access four different light patterns depending on which output pin/petal they sew an LED to. These include: blinking on/off, a breathing pattern, a heartbeat pattern, and a random twinkle pattern. We chose to pre-program the boards in this way to invite discussion of computation without the user having to write or understand code, meanwhile offering out-of-the-box access to creative and computationally interesting behaviors. This filled a gap at the time between lower-tech projects involving only LEDs and batteries – and more complicated projects leveraging a LilyPad Arduino which must be programmed before use.

For more advanced users, the LilyTiny offers a lower-cost means of incorporating computation into a project, as it can be reprogrammed using a Tiny AVR Programmer and the Arduino software. The LilyTiny debuted for sale through SparkFun in 2012 for about $10, but its price has hovered closer to $5 for the majority of the years since introduction. This makes it possible for educators to consider purchasing in bulk for workshops or classrooms.

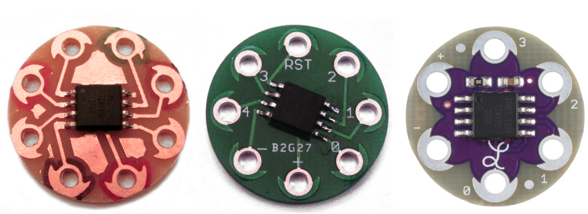

Figure 1: LilyTiny prototypes, from left to right: initial milled circuit board, custom-ordered factory board, final commercial product (sold by SparkFun Electronics).

Figure 2: Sample activities from our workshop curriculum.

3.2 Companion Curriculum

To support adoption of the LilyTiny, especially amongst our target audience of educators, we developed and self-published a companion workshop curriculum entitled *Getting Hands-on with Soft Circuits*. We made this curriculum available for free on the internet and also for ordering in hard copy format. This curriculum was designed as a standalone resource, providing just enough on-demand information for educators/facilitators to guide students through an informal activity.

The curriculum includes a series of five workshop activities leveraging e-textiles as a means to explore circuits and computation, some of which are shown in Figure 2. Each activity includes a photo of an example project, a list of tools and materials, a summary/overview, a list of learning goals, and directions on how to prepare for and facilitate the activity. Each project was designed to be doable in a two or three hour session, with the exception of the final activity which is better suited to a half-day workshop.

Activities 1 through 3 build foundational e-textile skills: an introduction to circuits with conductive thread, a primer on switches and how they control electrical flow, and an overview of parallel circuits and how they enable one battery to power multiple lights.

Activities 4 and 5 provide a high-level introduction to microcontrollers and the concept of programmability – without having to read or write code. In these activities, participants create light-up patches, using the pre-programmed LilyTiny to control the behavior of an LED (blinking, fading, twinkling, or heartbeat). This is first done individually, and then as part of a collaborative electronic patchwork quilt.

All of the activities were designed around low-cost, easily obtainable materials. These include craft notions (acrylic felt, sewing needs, snaps, beads, etc.) as well as off-the-shelf electronics components (such as through-hole LEDs, coin cell batteries, and battery holders). These items can all be sourced for less than 50 cents apiece. The only tools required for these activities are readily available, such as needle nose pliers, scissors, and hot glue guns.

The workshop guide also includes a troubleshooting flowchart, a curated list of low-cost tools and materials, and pointers to additional print and online resources relating to soft circuits.

After the release of the workshop guide, we co-developed one more LilyTiny-powered activity with a couple of collaborators, entitled *Plush Monsters: Creatures with Character*. The activity may be used as an add-on or independent of the workshop guide, as it includes its own curricular materials as shown in Figure 3. (The layout of the workshop guide is very similar.)

3.3 Pilot Testing

Design of the LilyTiny and curriculum were guided by two pilot workshops run in parallel with our development process. These workshops were arranged in collaboration with an outreach center

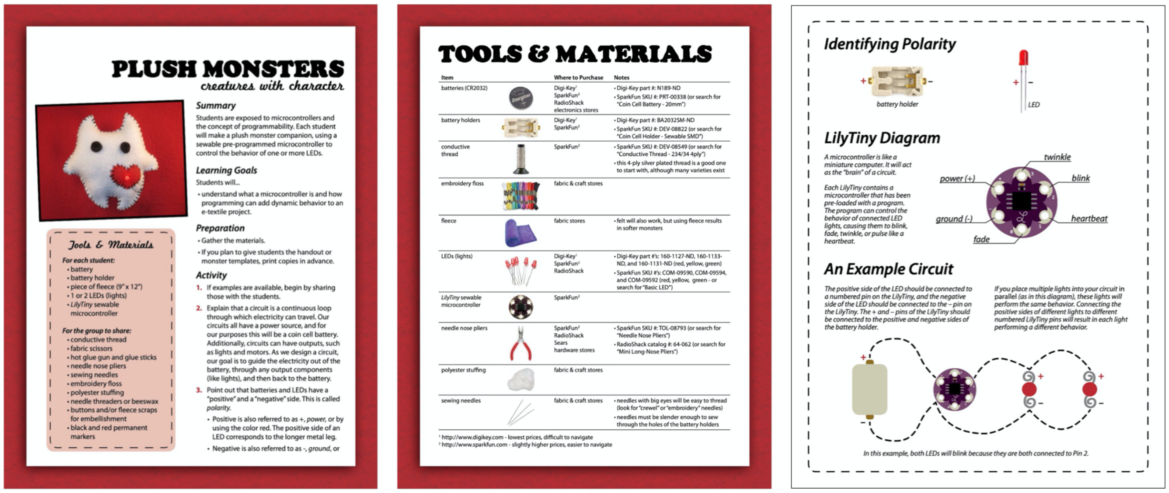

Figure 3: Select pages from our Plush Monsters activity, which utilizes the LilyTiny.

on our campus and enrolled volunteer homeschool students who were already familiar with basic circuits. Over a two-hour session, facilitators taught students to create a light-up patch with an LED whose behavior is controlled by a LilyTiny, using Activity 4 from the workshop guide.

The first workshop was taught by one of the authors using the earliest milled version of the LilyTiny. A total of 16 students between the ages of 11 and 16 participated (10 female, 6 male). 12 of the 16 students were successful in getting their LilyTiny to control an LED. This workshop revealed a few areas for improvement – for example, sourcing more durable materials and fine-tuning techniques for novice sewing with conductive thread. These informed a revision of the curriculum and during this time, we also procured the second version of the LilyTiny circuit boards.

In order to test the usability of our materials by a third party, the second workshop was taught by an outside educator. We provided all of the physical materials, but asked the educator to teach the workshop using only our curriculum as a guide. 10 students participated in this workshop, between the ages of 11 and 14 (4 female, 6 male). One of the authors was present to observe this workshop. In this workshop, all of the participants were successful in sewing a patch containing a LilyTiny-controlled LED. Additionally, several students went beyond connecting one light to their microcontroller, adding additional lights with alternate behavior. This second workshop was reassuring that our curriculum adequately supported an accessible and scalable learning experience using the LilyTiny.

In addition to our own observations, we solicited extensive feedback from the educator who taught the second workshop, as well as from an expert STEM activity guide developer. This was invaluable in making revisions. We also solicited feedback from students through surveys at the end of each workshop. Responses indicated consistency across the two workshops in terms of length, difficulty, and pace. This was preliminarily indicative that the instructional materials were transferable. When asked about future workshops, several students indicated specifically that they would like to learn how to program the microcontrollers themselves, or suggested projects that would likely require programming.

4 MEASURING IMPACT

In an effort to understand the impact of the LilyTiny in the years that have elapsed since it was first introduced, we conducted a followup study involving a survey of derivative products and analysis of sales data. Although SparkFun has repackaged our hardware in various ways, we have done little to promote adoption of the LilyTiny; thus we believe our findings to be a true reflection of whether our research innovations met an educational need and had impact in the wild.

4.1 Derivative & Follow-on Products

We surveyed the marketplace for low-cost sewable microcontrollers released over the past ten years. In particular, we took note of related and derivative products; these are shown in Figure 4.

At the time that the LilyTiny came to market through SparkFun, a sister product was also released, known as the LilyTwinkle. The LilyTwinkle hardware is identical to that of the LilyTiny; the only difference between the two products is that the LilyTwinkle ships with a different Arduino program. Instead of each Lily petal offering a different light behavior as with the LilyTiny, all of the petals twinkle lights at different rates. While the LilyTiny was designed to invite conversations about computation in educational settings, the LilyTwinkle is nicely suited to creating sparkling wearable projects. In addition to these standalone products, SparkFun bundled the LilyTwinkle into a few different kits and form factors, including: a "Firefly Jar" kit to create a twinkling felt mason jar, a ProtoSnap kit allowing testing of the board prior to sewing, and an E-textiles Basics Lab Pack to support classrooms.

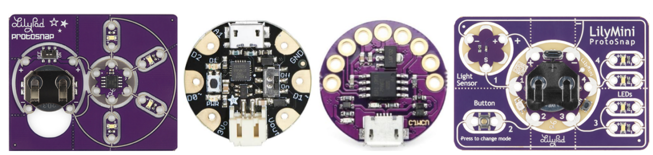

Figure 4: Derivative and follow-on sewable microcontroller boards. From left to right: LilyTwinkle ProtoSnap, Gemma, an unbranded clone, and the LilyPad LilyMini.

A little over a year after the release of these two products, Adafruit released the Gemma sewable microcontroller [18]. Like the LilyTiny, the Gemma also aims to be a smaller, more affordable version of its full-scale, higher-priced counterpart, the Flora. The Gemma has undergone several revisions, evolving to focus on reprogrammability and now featuring an upgraded chip, mini-USB connector, on-board on/off switch and RGB LED. It currently retails for about twice the cost of a LilyTiny, at around $10. The pre-loaded code is not well-documented nor marketed as a selling point, but it does ship with example code.

More recently, in 2016, SparkFun released the LilyPad LilyMini, another small sewable microcontroller which arrives pre-programmed, uses an upgraded chip, and includes an on-board coin cell battery holder. Although the program it ships with offers more interactivity than the LilyTiny and LilyTwinkle, it is sold at a higher price point ($16) and is much more difficult to reprogram.

A number of other sewable ATtiny85 breakout boards have been released in recent years. These boards are similarly bite-sized and typically manufactured using purple solder mask, like the original LilyTiny. However, these products feature a somewhat different arrangement of pins/petals and an on-board USB connector. They are sold under a variety of unbranded names such as "LilyTiny ATtiny85 Development Board", "MicroUSB LilyTiny", and "CJMCU LilyTiny". Although we were not involved in their development, the choice of naming leads us to believe they were directly inspired by our work. These boards do not necessarily ship with any example code installed, requiring the user to make some modifications to the Arduino IDE in order to initially program them. These boards retail for $1-15 and are widely available from a variety of sellers on eBay, Amazon, and Alibaba.

The LilyTiny was born out of open source hardware development, as were all of the aforementioned related boards. While it is not uncommon for someone to clone or create a derivative version of a useful circuit board, we believe that the number and variety of products following in the footsteps of the LilyTiny are testament to a market need for a small, low-cost, sewable microcontroller – especially when compared with the more full-featured LilyPad Arduino and Flora. It is worth noting, however, that the only boards advertised with their pre-loaded programs as a feature are the LilyTiny and LilyTwinkle. We believe this to be a particular asset and selling point for educational settings, as out-of-the-box functionality makes teaching time-constrained workshops/activities much more feasible. This feature also allows the introduction of computational behavior without the requirement to write code or navigate the Arduino upload/reprogramming process.

4.2 Sales Data

Next, we set out to understand the LilyTiny's impact on users. We use sales data as a proxy for adoption and investigate the LilyTiny's position within the market; whether it has been successful since its commercial debut, and whether this has shifted with the release of similar products. We obtained eight years of sales data directly from SparkFun, dating from the release of the LilyTiny and LilyTwinkle in July 2012 through the start of this investigation in June 2020. Because SparkFun is the only manufacturer of the LilyTiny and all LilyPad Arduino products, this data encompasses all sales, including those made direct-to-consumer and those made to distributors/resellers.

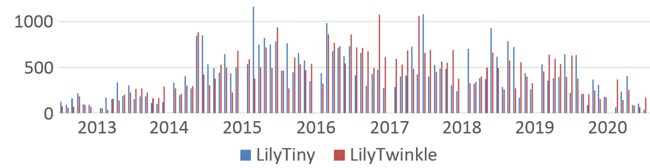

Figure 5: LilyTiny and LilyTwinkle monthly sales by year, measured in units sold. Note the sustained market interest over several years.

We first wanted to check whether our hardware has sold well as a commercial product. Indeed, it has; over this eight-year period, a total of 81,227 of our breakout boards (LilyTiny and LilyTwinkle combined) were sold. This includes boards sold individually as well those sold as part of a kit or lab pack. Our hardware shipped to 80 different countries across nearly 10,000 orders. The United States generated the highest number of orders, followed by Australia, Canada, and the United Kingdom in that order. Both products leveraging our hardware have sold steadily as shown in Figure 5, each averaging over 5,000 units sold per year. We think these numbers make clear that our breakout board is satisfying a real user need – and continuing to do so long past the introduction of competitor products.

Second, we wanted to check our hypothesis that a very basic board with pre-installed software is a useful intermediary between simple circuits and more complex boards requiring programming. To do this, we looked at sales data across the entire set of sewable microcontrollers offered by SparkFun. Figure 6 shows market share for each individual product, kit, or lab pack. To our surprise, the individually packaged LilyTiny was the single most ordered sewable microcontroller during the eight year time period that we examined. However, many products are related to one another through upgrades or repackaging, and thus we grouped these products into conceptual families. Even after grouping, the LilyTiny/LilyTwinkle board was purchased as often as boards in the much more capable

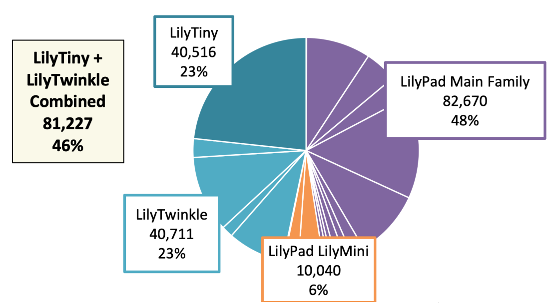

Figure 6: SparkFun sewable microcontroller sales, July 2012 through June 2020. Note that the LilyPad LilyMini was not introduced until 2016. Each *color* represents a different product family. Each *pie slice* represents a different product release (i.e. LilyPad Arduino 328 Main Board, LilyPad Arduino Simple Board, Firefly Jar kit, etc.). Kits are categorized by which board they include.

PRODUCT	AVERAGE UNITS/ ORDER	% OF ORDERS CONTAINING QUANTITY 5+	% OF ORDERS CONTAINING QUANTITY 10+
LilyPad Main Family	4.2	12.1%	7.7%
LilyPad LilyMini	5.1	14.7%	8.9%
LilyTiny	**9.8**	**34.1%**	**24.9%**
LilyTwinkle	6.7	18.0%	11.2%

Figure 7: SparkFun sewable microcontroller ordering patterns, after adjusting for lab packs which contain multiple boards. Notice that a much greater percentage of LilyTiny orders include quantities of the board suitable for teaching.

LilyPad Main family, with the LilyTiny/LilyTwinkle board representing 46% of sales. This seems to validate that a cheaper simpler board has value to a substantial number of users.

The data in Figure 6 also allows for comparison of sales between the LilyTiny and the LilyTwinkle. This is important to consider, as we designed the LilyTiny and its supporting curriculum with the intent of reaching educators – while the LilyTwinkle is likely to appeal to a more general audience. We had guessed that the hobbyist focus and additional marketing variations would have made the LilyTwinkle more popular. However, to our surprise, the LilyTiny has sold twice as many standalone boards as the LilyTwinkle – and about the same number of total units when considering all kits containing the LilyTwinkle. We believe this finding affirms that a board released with appropriate curriculum and pre-programmed code, supporting the introduction of computation, invites broad adoption.

Finally, we wanted to know if the LilyTiny is being used by educators. The sales data doesn't directly tell us who is purchasing boards, but it does tell us the quantity purchased in each order. Individual hobbyists probably buy a few boards at most, while educators typically buy in quantity appropriate for classrooms or workshops. (For this analysis, we excluded distributor orders since we are interested in individual purchasing patterns.) Figure 7 reports on order quantities for each product family. Indeed, a much greater percentage of LilyTiny orders include multiples of the product and the average units per order is higher, when compared to the LilyPad Main family, LilyTwinkle, and LilyPad LilyMini. This is true despite the fact that the LilyTwinkle and LilyPad Main boards were explicitly marketed in "lab packs" of ten units. We believe this provides evidence that the LilyTiny, with its choice of assorted programmed light behaviors and supporting curriculum, is likely being used for teaching more frequently than the more complex LilyPad LilyMini and LilyPad Main boards – or even its sister product, the LilyTwinkle.

Taken altogether, the sales data seems to support the ongoing impact of the LilyTiny. It is especially notable that the LilyTiny has undergone no major revisions, nor has it been sold as part of a kit or lab pack during its lifetime. While the lack of revisions may be attributable to the simplicity of the hardware and software, it is nonetheless rare to be able to purchase a device maintaining compatibility with any support resources developed in its lifetime. We believe that this stability is crucial for educational adoption.

4.3 Reflections

It is difficult to attain broad adoption with new hardware, especially adoption which persists over time within a shifting technological landscape. We believe that some of the LilyTiny's market success is attributable to our design goals and decisions, but also that there are ways in which we got lucky – and also, ways in which we could have done better. In this section, we share some of our lessons learned, in hope that they may be useful to others starting down a similar path.

Launching a hardware product is dependent on physical manufacturing and retail pipelines, and may also rely upon firmware or interfacing software to function. We believe that the simplicity of the LilyTiny has made it very easy to maintain. We deliberately leveraged a well-known, inexpensive, and widely available chip (the ATtiny85) and designed the LilyTiny to ship pre-programmed, necessitating no additional software interaction unless desired by the user. Because it does not rely upon a computer, the LilyTiny will continue to function indefinitely, despite updates to computer operating systems, programming languages, or even the Arduino IDE. Additionally, we were able to piggyback on existing manufacturing and retail infrastructure by partnering with SparkFun Electronics, who already had established a production workflow and market for the closely related LilyPad Arduino products. While not always possible, we believe that designing hardware around an existing market can support a rapid launch and a successful, sustainable product – even if at the cost of greater innovation.

We also believe that the LilyTiny benefited from our membership in the community we wished to impact. As educators ourselves, who were teaching e-textiles workshops both directly with students and also to train other teachers, we had ample opportunity to observe their needs. Being embedded in the educational community also allowed us to receive timely, straightforward feedback on our materials – from early in the design process through pilot testing. We believe that releasing our product into an established community (of which we were a part) also aided in successful adoption, as did publishing free teaching materials to support it. While this may be obvious to many, it is much easier to design for a community you belong to than for one beyond your reach.

There was also an element of luck to our experience; we were fortunate to have a pre-existing relationship with SparkFun Electronics and to be designing low-cost e-textiles resources at a moment in time when the discourse on access and inclusivity in computing was expanding.

In hindsight, one area in which we could have done better is to more carefully consider pathways of use. We had hoped the LilyTiny would serve as a stepping stone to Arduino programming, but in reality we did little to support this path; we put a lot of thought into making the LilyTiny easy-to-use for those with minimal electronics experience, but much less thought into how to encourage and support reprogramming the board. The derivative boards surveyed earlier in this paper are a testament to this need, as most of them feature USB ports to enable easier reprogramming. SparkFun has released a couple of tools to aid in programming ATtiny chips, along with tutorials to support this, but in practice this is attempted mostly by advanced users. If we were to go back in time, we might design additional curriculum to support this process and/or collaborate with teams already working to lower the barriers of entry to Arduino programming (for example, through block-based IDE add-ons). In sum, when designing for educational use, we think there is a lot of value in considering learning pathways and how you might support them – both where users may be coming from and where you would like to help them go next.

5 FUTURE WORK

While this paper provides an overview of market impact, we plan to continue our investigations to paint a richer picture of how our hardware and curriculum are being used. A survey of follow-on curriculum and academic research will deepen our understanding of educational use at the macro level, complemented by surveys or interviews with those who have personally used our materials for teaching. We will also analyze customer reviews of the product, offering a window into individual experiences. Lastly, we are working on an analysis of LilyTiny artifacts, to better understand the character of projects enabled by this work.

6 CONCLUSION

Ten years ago, we set out to develop, pilot, and release a hardware tool and curriculum to support broader educational adoption of e-textile activities. This case study affirms that our hardware has addressed a pressing market need, as evidenced by a variety of follow-on products and several years of sales data. Additionally, our exploration of ordering patterns suggests that the LilyTiny is being used in educational settings.

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