Chibitronics in the Wild: Engaging New Communities in Creating Technology with Paper Electronics

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ABSTRACT

We share a study on the public adoption the Chibitronics circuit sticker toolkit, an open source, commercially available hardware toolkit for learning and creating electronics on paper. We examine sales data over a two-and-a-half-year period from November 2013, when the kit was launched commercially, to June 2016. We also look at publicly available project documentation from users during this period. We find that the Chibitronics user community confounds norms for traditional technology-making communities, especially in gender demographics. We explore the artifacts and types of documentation produced by users to learn about the various backgrounds, values, and goals of subcommunities, which includes educators, Makers, and crafters. In particular, we focus on artifacts from the craft community as a surprising and distinctive subset of technology creators. The diversity in public engagement shows how paper electronics tools like Chibitronics can be an effective approach for engaging new and broader audiences to participate in technology creation.

Author Keywords
Paper electronics; paper circuitry; Chibitronics; circuit stickers; Maker Movement; do-it-yourself; craft; hardware toolkits; inclusion; education; STEM, STEAM

ACM Classification Keywords

K.3.0 [Computers and Education]: General

INTRODUCTION

The ability to design and create technology is ever more crucial as technologies become more ubiquitous and increasingly define the way we live. Formal educational settings are embracing engineering and design as fundamental learning goals for the 21st century [27] and informal learning communities like the Maker Movement have grown from small groups of hobbyists to a cultural movement celebrating do-it-yourself technology design and creation [2][36]. Despite this rising trend in the democratization of technology, many technology-focused communities are very homogeneous; participation by women and underrepresented minorities is limited. For example, 81% of MAKE magazine subscribers and 70% of World Maker Faire attendees were male in 2012 [25], and MAKE magazine features far fewer Makers who are women or underrepresented minorities [7]. In formal education, in the United States and Canada, 85.3% of bachelor's degrees, 71.3% of master's degrees and 81.1% of doctorates in the fields of computer science, computer engineering and information sciences were awarded to male students in the 2013-3014 academic year [16].

In one approach to diversifying technology related fields, researchers are developing new materials and tools to engage broader and more diverse communities of creators. The Lilypad Arduino is a toolkit for embedding electronics into textiles. Buechley and Hill's "Lilypad in the Wild" study [9], looked at the demographics of Lilypad Arduino customers and users to determine the kit's impact and found that a majority were female.

This earlier work inspires our current study of paper electronics—a medium that combines paper crafting and electronics building. For this study, we use customer and user data from a paper electronics toolkit called Chibitronics [11]. In our analysis, we find that paper electronics has indeed engaged new individuals and communities in creating technology. We find especially striking patterns of gender participation.

The remainder of this paper introduces the Chibitronics toolkit and shares our findings on the demographics of Chibitronics customers and users. We examine who is using the kit, how they are clustered into different sub-communities, and how they are creating and sharing. We also examine the unique values and practices of different subcommunities.

BACKGROUND

This work builds upon previous research in blending craft and technology as an approach to broaden participation in technology creation.

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Craft Technologies

Within craft technologies, we examine in particular tools and approaches that combine electronics building with traditional handcrafting mediums. Artists like Peter Vogel [34] and Leonardo Ulian [33] have long used standard electronic components and metal working techniques to make wire-based interactive and sculptural works. Electronic textiles (e-textiles) blends conductive thread, fabrics and fasteners with circuitry components to create functioning electronics that look and feel like traditional textile artifacts [8]. Buechley and Perner-Wilson have also explored how carving and painting techniques can be employed to fabricate electronics and bring technology making to new communities of practice [10].

Increasingly, researchers are translating their research into toolkits to bring techniques out of the lab and into creative communities in the wild. The sewable Lilypad Arduino [8] is one of the earliest kits for making e-textiles. ShrinkyCircuits use a common heat-shrinking craft polymer sheet and off-the-shelf conductive inks to produce handcrafted, expressive circuits that are made robust with miniaturization [24]. Conductive and nonconductive play-dough enables creators to sculpt circuits [21] in the Squishy Circuits toolkit. Finally, the littleBits and Makey Makey toolkits are pre-built electronic modules designed to integrate with craft materials, so that younger learners can create personalized technologies without the challenges of building the raw circuitry itself [3][4].

In this paper we focus on paper electronics, the blend of electronics and paper crafting. Researchers have explored building circuitry during the paper-making process [15], as well as techniques for building circuits on paper surfaces with gold foil [31], copper tape [29] and conductive ink [32]. Conductive inks and paints can be used to draw [30] and inkjet print [23] circuits on paper. These have matured enough to be in commercially available products like the Circuit Scribe [13] and Agic toolkits [1].

In short, newly available tools, both commercially and in the lab, are offering new approaches for blending craft and technology and making new on-ramps for creators to learn and build electronics.

Broadening Participation

E-textiles has been shown to be particularly successful in engaging more diverse audiences, especially girls and women, in designing and creating electronics as well as programming them [22][28]. The blend of textiles craft and electronics has also been successful used to disrupt gendered roles in both crafting and technology creation [35].

Current research in paper electronics largely focuses on the medium itself and *how* it can used to teach and make electronics [20] [6]. In this paper, we aim to shed light on *who* is actually learning and creating with it and their motivations for doing so. We investigate paper electronics as a medium to see if, like e-textiles, it can effectively apply crafting and personal expression as an approach to make technology creation more accessible and interesting to broader communities.

Chibitronics

Chibitronics is a paper electronics toolkit made up of sticker-based modules for building circuits [19]. These modules are a flat, flexible and paper-friendly alternative to standard electronic components. The kit includes LEDs, sensors and a programmable microcontroller that can be connected with copper tape. For introducing novices to paper electronics, the kit also includes an activity book with circuit explanations, templates and activities.

While it began as a research project, Chibitronics launched out of the lab through a crowdfunding campaign in 2013 [12]. It has since matured into a commercial product that is publicly available worldwide [11]. With unique access to structured and longitudinal data through sales and web analytics, we use this toolkit as a lens through which to explore the adoption of paper electronics in the wild.

The following sections share what we have learned about the paper electronics community over two-and-a-half years of observation.

CHIBITRONICS COMMUNITY

First we looked at who is purchasing Chibitronics products for a general sense of user demographics. In particular we focused on gender.

Data and Methodology

For early Chibitronics customers, we obtained the list of original crowdfunding campaign backers and pre-order sales from Crowdsupply.com. This list covers orders from when the campaign was launched in November 2013 to when Chibitronics switched to a custom online shop in October 2014.

For later customer data we analyzed individual orders from online shops at Chibitronics.com and Amazon.com, a general ecommerce website. These two vendors are the top two direct-to-consumer sales channels for Chibitronics, making up approximately 60% of sales by volume during our study. We obtained order data from when these shops from when they opened in November 2014 through June 2016 for both Chibitronics.com and Amazon.com. The remaining 40% of sales not covered in our paper is through wholesale distribution channels, such as international online shops and physical retail stores. We are not able to acquire end customer information from these sources due to privacy concerns.

For each of these sources, we compiled a list of names and countries of origin for the orders. Over 90% of orders on Crowdsupply came from the US, Canada and Europe. For Chibitronics.com and Amazon.com, over 90% of orders came from the US and Canada. To create the gender demographics sample, first we removed orders from institutions and distributors to assess individual users. We then manually hand coded the names by gender. For example *Jane* would be coded as female and *John* would be coded as male. Gender-ambiguous names like *Nat* and non-identifying accounts like *N.* were classified in a separate category labeled unknown.

Results and Analysis

Table 1 and Figure 1 show the results of this initial analysis. The number of samples from Crowdsupply.com (N=648), Chibitronics.com (N=1732) and Amazon.com (N=2872) are shown classified by gender with the ratios of the total samples from each website shown in parentheses. We were able to classify 98% of customers from Crowdsupply.com, 96% of customers from Chibitronics.com and 94% of customers from Amazon.com.

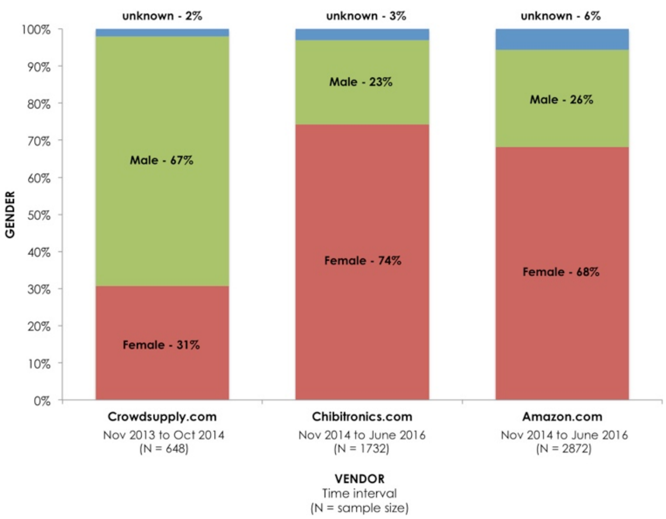

Figure 1. Gender of customers from Crowdsupply.com, Chibitronics.com and Amazon.com

Source	Female (%)	Male (%)	Unknown (%)	Total Sample
Crowdsupply.com	119 (31%)	436 (67%)	13 (2%)	648
Chibitronics.com	1287 (74%)	392 (23%)	53 (3%)	1732
Amazon.com	1956 (68%)	752 (26%)	164 (6%)	2872

Table 1. Gender of customers from Crowdsupply.com, Chibitronics.com and Amazon.com

On Crowdsupply.com, 31% of the orders were from females and 67% were from males ($\chi^2(1)=88$, $p<0.001$). However, on Chibitronics.com and Amazon.com this ratio reverses. 77% of the sample for Chibitronics.com ($\chi^2(1)=477$, $p<0.001$) and 68% of the sample for Amazon.com ($\chi^2(1)=535$, $p<0.001$) came from female customers while male customers made up 19% and 26% of the samples, respectively. We found the difference in gender for each sample to be highly statistically significant.

From this initial analysis we noticed the large reversal from majority male customers to majority female customers after the transfer from Crowdsupply.com to Chibitronics.com and Amazon.com. An explanation for this reversal may be in the difference in audience of each vendor as well as the different timing of the samples.

Crowdsupply.com typically focuses on emerging electronic products, which have largely male audiences, while Chibitronics.com was designed to engage more female audiences and Amazon.com is a broadly popular online retailer for a wide variety of products.

Since the Crowdsupply.com data covers the period when Chibitronics first launched as a toolkit, orders may have come from audiences that are particularly interested in emerging technologies. For example, press for the crowdfunding campaign mostly came from technology-related publications like *WIRED* [14], which have majority male audiences [37]. Chibitronics.com and Amazon.com data cover orders from later periods. By this time the toolkit had become better known, beyond the emerging technologies community, perhaps leading to more diverse audiences and thus more orders from female customers.

To learn about change in customer gender ratios over time, we combined the Chibitronics.com and Amazon.com samples, then split them into 6-month intervals and recalculated the gender ratios across these intervals. We used the following four intervals: November 2014 to April 2015, May 2015 to October 2015, November 2015 to April 2016 and May 2016 to June 2016. The last interval is shorter since the remainder of the data for 2016 was not yet available when the study was conducted. Table 2 and Figure 2 show the results of this second analysis.

From when the shops were launched through June 2016, on Chibitronics.com and Amazon.com the majority of people who purchased Chibitronics products have been female. Furthermore, there has even been a steady increase in the ratio of orders from female customers over this period. The percentage of orders from female customers rose from 66% to 78% and for male customers the percentage declined from 30% to 18% while orders from customers of unknown gender stayed steady between 4% and 5%.

In fact, we observed a statistically significant increase in the ratio of female to male customers from 70% in November

2015 through April 2016 to 78% in May 2016 through June 2016 ($\chi^2(2)=27.7$, $p<0.001$).

It is worth noting, however, that our results may be biased due to distribution and marketing strategies. For example, some online shops are targeted more toward female customers versus male customers. Even general online retailers may exacerbate gender biases through targeted marketing methods. For example, a retailer may categorize Chibitronics kits in such a way that it is advertised to more female buyers than male buyers. This would bias who is exposed to such products, and thus who makes the purchase.

Similarly, the buyer of a product is often not the user of a product, an inherent limitation in using sales data as a proxy for user participation. For example, a male educator could purchase a kit for a majority female classroom. In the next section, we attempt to address this uncertainty by examining public project documentation, to see who is making with Chibitronics. In addition, we use this analysis to further learn about the backgrounds of users, to see what communities they came from and their motivations for using paper electronics.

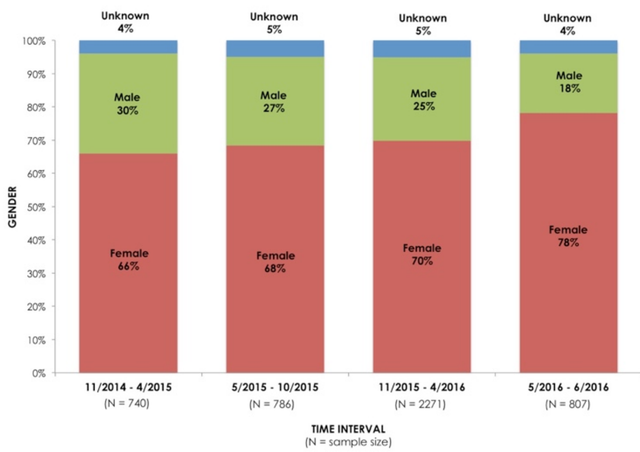

Figure 2. Gender ratios over time of combined order samples from Chibitronics.com and Amazon.com.

Interval	11/2014 - 4/2015	5/2015 - 10/2015	11/2015 - 4/2016	5/2016 - 6/2016
Female	488 (66%)	548 (68%)	1586 (70%)	631 (78%)
Male	223 (30%)	209 (27%)	568 (25%)	114 (18%)
Unknown	29 (4%)	39 (5%)	117 (5%)	32 (4%)
Total N	740	786	2271	807

Table 2. Gender ratios over time of combined order samples from Chibitronics.com and Amazon.com. Percentages of total sample are shown in parentheses.

SUBCOMMUNITIES WITHIN PAPER ELECTRONICS

We looked at public online documentation to learn more about the backgrounds of paper electronics users. To create our documentation sample, we used Google analytics to collect a list of all unique websites linking to the Chibitronics.com homepage and the *learn* and *education* subpages from when the webpage launched in November 2013 through June 2016. These webpages held the majority of Chibitronics online resources and thus were most often linked to.

With the help of an undergraduate research assistant, we cleaned the data set by removing expired and unresolvable website links and kept only websites that had original content, which are those that did not simply repost from another website. Multiple webpages by the same author on the same website, for example from a personal blog, were categorized as a single sample. Pages written by different authors on the same website, such as tutorials submitted by different users on Instructables.com, were categorized as separate samples. We came up with a total of 268 unique samples in our set, comprising largely of users documenting projects they created with the Chibitronics toolkit

We analyzed the sample by looking at what the webpage author created and how they created, what they used their creations for and how they documented their process (these are described in more detail in the next section). We also looked at how authors self identified on website profiles. Based on these factors, we created categories for the largest subcommunities that emerged from this analysis and used them to classify the sample. We found the following subcommunity categories: educator, Maker, crafter, artist, designer and other.

Those who used paper electronics primarily to teach others, such as teachers or librarians, were categorized as educators. Example posts include classroom activity reports and lessons plan resources to help others teach with paper electronics

Makers denote people who are part of a growing movement promoting hands-on creation rather than consumption of technology and a do-it-yourself approaches to making and inventing these technologies [2]. These individuals mainly engage in paper electronics as a personal pursuit and often focus on exploring the technical construction and functionality of their projects. They also typically use digital fabrication technologies like 3D printing or laser cutting during the process of building their creations.

We define crafters as those who created paper electronics projects as part of their own creative practice, often creating artifacts like personalized home decorations, memorabilia and personalized gifts for others. Crafters tend to value outward aesthetics of their creations most and spend the majority of their creative process on personalizing and decorating their projects. Many crafters incorporated predefined visual styles using tools like stamps and patterned paper.

Artists and designers refer to individuals who identified as such in their profile pages and typically used paper electronics for personal research and exploration purposes. We used "other" as a category for individuals who self-identify under other professions such as a mechanical engineer or baker.

It is worth noting that these categories are not mutually exclusive. For example someone can be both a Maker of paper electronics in their own work as well as a teacher of others. Or, someone may be a professional artist and also self-identify as a crafter. We tried to place authors into a primary category based on their own designation and based on the category of websites they linked to. As a result, these classifications are imprecise and fluid, offering only an approximation of the main subcommunities who are sharing online about their paper electronics experiences. The results of our analysis are shown below in Figure 3.

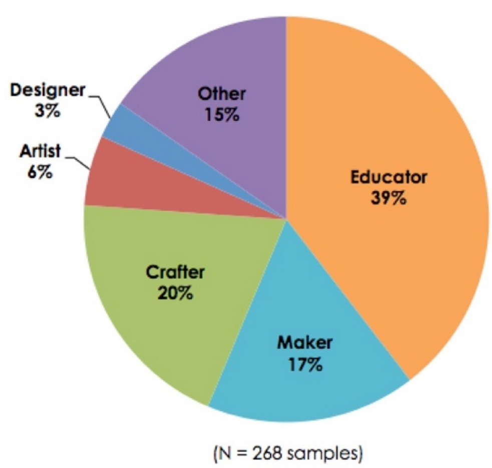

Figure 3. Sub-communities of webpage authors linking to chibitronics.com and resource pages.

After categorizing the webpages by subcommunity, we then subdivided the authors for each subcommunity by gender to investigate whether different communities resulted in varying gender participation ratios. We also wanted to see how the demographic data from online documentation compared to our sales order analysis. For this investigation we hand-coded the author gender based on author information provided on the webpage. We classified webpages whose author names are ambiguous, pages without specified authors, and pages representing organizations as "unknown." The results of this analysis are shown in Figure 4.

Our results show that educators, crafters and Makers are the largest sub-communities sharing online documentation about their paper electronics experiences, making up 39%, 20% and 17% of the total sample, respectively. Gender

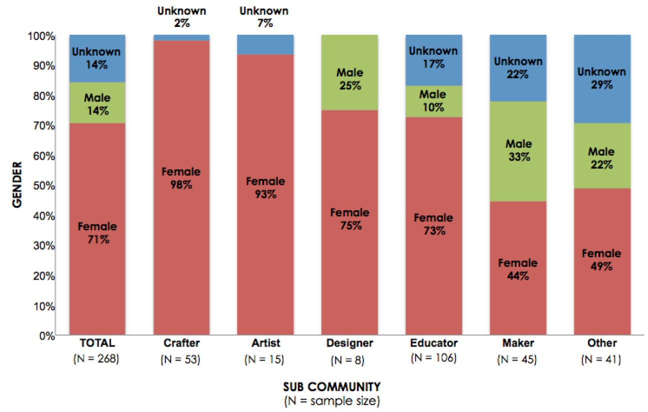

Figure 4. Gender of webpage authors linking to chibitronics.com resources by subcommunity

ratios also varied for each sub-community. 73% of posts from educators and 98% of posts from crafters were from female authors. While in the Maker community, only 44% of posts were from females authors.

Overall ratios found from the webpage contribution data approximately follows ratios found from sales data: 71% of overall posts were from female contributors, 14% were from male contributors and 14% of contributions were unknown while overall 70% sales orders for Chibitronics.com and Amazon.com came from female customers, 25% came from male customers and 5% were unknown.

It is worth noting that a higher ratio of website contributions came from authors of unknown gender. This may skew our findings. It is possible, for example, that more female authors than male authors (or vice versa) do not to include identifying information on their webpages. Furthermore, this sample of online submissions make up a small minority of users, further limited by our focus on google analytics data. This may bias our findings as certain demographics of users may be more likely to share their work through social media rather than webpage publications. Finally, certain demographics of users are more likely to publish their usage at all than others. For example, younger creators may not have access to social media and web publication, which biases to our results toward adults.

Analysis

Our initial study shows that a large majority of paper electronics creators and documentation contributors are female. This contrasts significantly from the demographics of typical electronics and engineering communities, which are mostly male-dominated fields [16][26]. Within the emerging Maker community, which is also male-dominated [25], we find more paper electronics contributions from identifiable female authors than identifiable male authors. These contrasting demographics come not only from engaging more women in male-dominated technology communities, but also from engaging individuals from outside engineering focused communities like, educators and crafters.

In the US, 87% of primary school educators and 67% of secondary school educators are female according to reports from the World Bank [38][39], which roughly reflects the gender ratios of paper electronics educator contributors. Furthermore, despite being a medium based on building circuitry and engineering practices, not only STEM (science, technology, engineering and mathematics) educators, but also those teaching humanities and arts are using paper electronics in their classrooms. We believe this shows that paper electronics kits like Chibitronics have the potential to widen perspectives, within the education community, of who can teach technology and engineering and in what contexts such material can be taught.

Meanwhile 72% of crafters in the US are female with median age between 35 and 44 according a recent report from the Craft and Hobby Association [17]. The overwhelming majority of crafters building paper electronics, 98% according to our data, are female. We find it especially striking and unusual to see engagement in paper electronics from mainstream crafters, as this is a community of adults who use high-tech tools but are often not considered or consider themselves technology creators. Their participation shows that paper electronics can appeal to creators with diverse backgrounds in terms of gender as well as age.

By engaging new communities in creating technology with paper electronics, we also observe new kinds of technologies and resources being made as a result. Now we shift the emphasis from who is creating to what, how and why they are creating.

PROJECTS, PROCESS AND PURPOSE

Our analysis of online documentation shows that the paper electronics community is made up of a multiple subcommunities – the biggest being educators, crafters and Makers. Each has their own unique values and approaches, which is reflected in what they create.

In this section we examine artifacts and documentation from websites that link to Chibitronics to learn more about how these subcommunities differ from each other, as well as how outputs from the paper electronics community differ from those created by typical electronics and engineering communities. We then look specifically at crafters, a new subset of the paper electronics community that is especially unique in terms of demographics and values.

Example Projects

For this study, we investigated webpage content from the online documentation study to find out the types of projects and resources, formats of documentation and platforms for publication that authors used. We chose a few examples of commonly observed types of artifacts for each subcommunity, which are shown in Figure 5. While these selected samples do not represent the entire subcommunity, we use them as starting points for discussion.

These and other paper electronics projects show how, in addition to electronic functionality, there is often a clear form and aesthetic that is unique to its creator. In fact, in many projects, the circuit functionality is secondary to the main purpose of the artifact. For example, it may be used as decoration or to highlight part of an image. This is very different from traditional electronics projects, which largely focus on technical functionality.

Many creators personalize their projects by adding text and images or incorporating their own tools and materials, making the artifacts further specific to the subcommunity as well as the individual creator. These customization practices are less common and often more difficult to do with traditional circuit building mediums, where customization is often limited to creating an enclosure around the electronics. Instead, with paper electronics, creators can create on or around the circuit or even use circuits to decorate the enclosure. By looking at the example images from students and educators, Makers and crafters, we see some clear differences between what different subcommunities create.

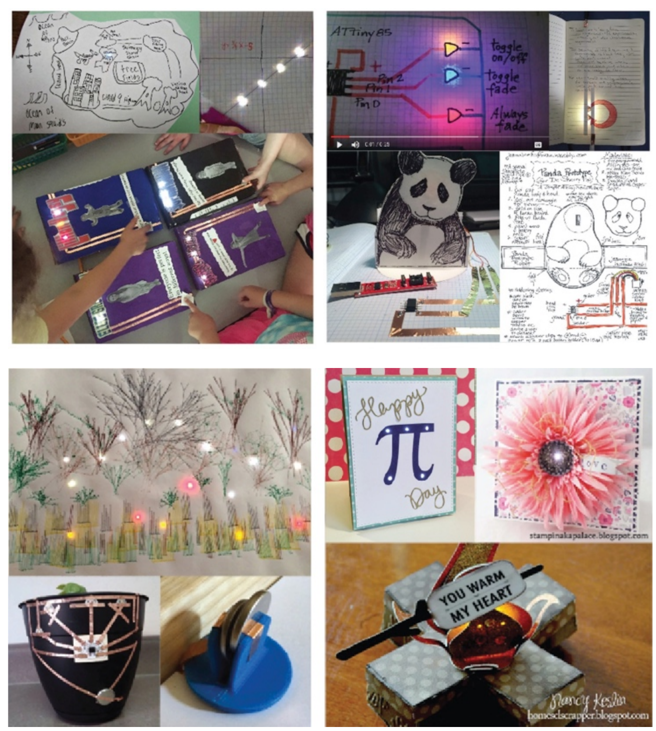

Figure 5. Paper electronics projects by students of Susan Watson, Lee MacArthur and Colleen Graves (upper left); educators Jeannine Huffman and Julie Willcott (upper right); Makers Josh Burker and Coercionette (lower left) and crafters Christina Hsu, Karen Jiles and Nancy Keslin (lower right).

Example projects created by students (Figure 5, top left) exhibit a wide variety of classroom applications, from an illuminated treasure map in geography class taught by Susan Watson, to highlighting points on the graph of a math equation taught by Lee MacArthur, to personalized journal covers created by middle school girls as part of the Circuit Girls group organized by Colleen Graves. Examples created by educators (Figure 5, top right) show educator Julie Willcott's notes while learning to program a microcontroller, prototypes for classroom activities and a hand-illustrated printable handout for a paper panda robot programming activity by Jeannine Huffman. The educators' approach is often to simultaneously teach circuitry while also using it to engage students in entirely different subjects like environmental studies or creative writing. It is also worth noting that many teachers often begin learning electronics themselves through paper circuits and move on to more traditional electronics tools—like wires and breadboards—as they advance their understanding.

Images on the lower left of Figure 5 show examples of projects shared by Makers. One project is from a tutorial for an electronic plant monitor that tells the owner when to water the plant, by Instructables user Coercionette. The other project is an illuminated computational illustration drawn by a robot, designed by Josh Burker. This piece also features a 3D-printed battery holder, also designed by Burker. These projects are examples of how Makers often create artifacts where technical performance and design is a core component of the project.

It is also common to see Maker projects integrate many technologies and processes, especially ones involving computation and digital fabrication, as it is often the technical functionality and inventiveness of a project that is highlighted. Interestingly, we have observed that though Makers may begin learning electronics with paper circuit tools like Chibitronics, like teachers many move on to more traditional electronic components and toolkits as they become more proficient. One reason may be that paper circuits have been designed primarily to introduce beginners and thus, despite having more complex capabilities like sensors and programmable microcontrollers in the Chibitronics toolkit, they may be perceived as technologically too simple to support the needs of advanced creators.

Finally, the images on the lower right of Figure 5 are example projects from crafters, which include illuminated greeting cards by Christina Hsu and Karen Jiles and a glowing gift box by Nancy Keslin. These artifacts tended to have a core function that is embellished by paper circuitry, but not defined by it. That is, in the examples above, the greeting cards and gift box would still function as elaborately decorated and personalized gifts even if the circuitry were not working or not present at all. Projects made by crafters also tended to have a sentimental value, for example as handmade gifts for others, souvenirs to commemorate a particular event or decorative pieces to inhabit the home. They are often made with a wide range of tools specifically to help ensure a visually pleasing outcome, like rulers and grids, stamps and stencils, patterned paper and pre-assembled collage accessories.

Paper electronics projects from crafters show a clear aesthetic that very closely preserves that of typical paper craft artifacts. They tend to show off traditional craft materials like paper and fabrics decorated with illustrations, graphics and text while the physical circuitry is generally hidden away and only the light shines through. Their projects have technology in them, but do not emphasize it. Instead light and interactivity take on a more symbolic role in support of the project's expressive theme, such as illuminating a highlighted character or representing the warmth of a fire.

Next, we examine how different communities document and publish their projects to learn more about the values each community.

How they shared

Access to personal publication tools on the internet has been crucial to the spread of ideas and inspiration within the paper electronics communities and the subsequent growth of these communities. While different communities often used the same social media channels like Facebook, Twitter, and Instagram to publicize their posts, there are differences in what educators, Makers and crafters document and publish. These differences reflect the unique needs and values of each community.

Educators often posted about their classroom experiences on personal websites and social media channels, celebrating their students' work while also providing inspiration for other educators. With paper electronics being new to many, educators documented their own learning process by sharing works in progress, insights, challenges and questions. In turn they received support from the community as they navigated these explorations. Educators also generated resource materials for themselves and others to use in the classroom, like lesson plans and circuit templates in the form of webpages, printouts and presentation slides. These resources included not only the materials and procedure for the activity, but also questions and rubrics for assessment, learning standards and goals and related activities for further investigation.

There is similarly a culture of open documentation and sharing within the Maker community, especially as creators are often learning by replicating others' projects or, once they have mastered the tools, building upon and remixing each other's work. Part of the culture of sharing and remix may come from the computational and digitally fabricated nature of many Maker projects. However, for paper electronics, since the making process is largely manual, we have seen Makers mostly document finished projects that show a particular electronic technique or invention, or share a project where paper circuitry is integrated with other digitally fabricated and computational mediums.

Crafters tend to share their projects on personal blogs with specific aesthetic and material genres that express their personal tastes and craft practice. Crafters are also more likely claim ownership of their work by imprinting their logo, names or web addresses onto images of their creations. A common way of documenting process is through video tutorials showing exactly how the project was made from beginning to end along with verbal explanations and captions. These resources tended to have polished, final outcomes rather than documentation of the exploration process.

Some of the posts featuring Chibitronics were created by professional craft bloggers who designed projects and shared tutorials in exchange for complimentary products, a common practice within the craft community. While these posts are biased toward polished and successful outcomes, the projects were created without any guidance and thus show authentic possibilities for paper circuits in the hands of expert paper crafters. Because the crafters are so different from typical technology creating communities, we decided to look more deeply at how and why they participate in making paper electronics.

CIRCUITS MEETS CRAFTERS

Crafters may have been excited about adding electronic functionality to their projects all along, but have not had the appropriate tools to do so until now. As blogger Susan Brown writes:

"The Chibitronics lights bring a whole new dimension to crafting and it was fun as I learned about electronics too!! I can't wait to use these in my papercrafts and handmade cards... watch out Hallmark... I have special effects too!"[1]

Participation in paper electronics from mainstream crafters is especially exciting to see as they have shown a particularly deep engagement with the material possibilities of paper electronics and while still preserving the strong aesthetic styles and themes authentic to the mainstream craft community.

Though the circuitry is generally the same—a single LED, several LEDs in parallel, a paper switch—we have seen very diverse project outcomes made by crafters. For example, they have taken paper electronics beyond flat illuminated images to create complex three-dimensional forms, such as the gift box on the bottom right of Figure 5.

[1] Brown, S. (2016). "Add Some Light to your #Cre8time with Chibitronics and Designers Craft Connection." http://sbartist.blogspot.com/2016/04/add-some-light-to-your-cre8time-with.html

Figure 6. From left to right: Circuitry embellishing a plastic cast resin charm by Susan Brown, a glass picture frame by Nadine Carlier and a gingerbread house by Ashley's Atelier.

Though we introduced the circuit stickers as a paper craft activity, crafters have also begun integrating circuitry into other materials and artifacts as decoration such as cast plastic charms, decorating picture frames or even an edible gingerbread house, shown in Figure 6.

Within the paper medium, crafters have integrated mechanical and paper-engineering techniques to add interactivity and enhance the narrative in their creations. For example, the top of Figure 7 shows a card where the bears' hearts glow when one bear slides close to another. The creator has designed a custom slide switch that uses foam to press a paper switch underneath the bears. The card is otherwise composed of decorative papers and stamp illustrations from standard paper craft kits.

Figure 7. Example cards showing slide switch (top) and integration sound (bottom) by Eiko Uchida

We also observed crafters incorporating new electronic technologies in their work, though still largely with a focus on embellishing a project with circuitry rather than making it the main function of a project. For example, the card on the bottom of Figure 7 uses a pre-made sound module that plays "Happy Birthday" when the bird slides close to the cat. This shows how the simple LED circuit cards may be acting as an on-ramp for crafters to try more technically complex creations.

Further evidence that crafters are expanding their paper electronics toolset is shown in Figure 8, which are stills from a video tutorial by a crafter explicitly titled, "LED Cards – without Chibitronics – cardmaking tutorial." In this video the creator shows how to make paper circuitry using surface mount LEDs, copper tape, aluminum foil and conductive silver paint. The title suggests that while crafters may be discovering paper electronics through the Chibitronics circuit stickers toolkit, deemed as default according to the title, it is acting as a gateway for them to begin exploring other methods of creating circuitry. This creator explored using more standard electronic components and alternative conductive materials, providing more affordable options than the Chibitronics toolkit and adding to the variety of aesthetic possibilities.

While these are early observations of crafter engagement with paper electronics, their depth and diversity of works shows promise for continued development and participation.

Figure 8. Video tutorial by titled "LED Cards – without Chibitronics – cardmaking tutorial" by Vanessa Amann

DISCUSSION

Our investigations into the paper electronics community reveal very different contexts and demographics of people producing very different artifacts from traditional technology-making communities. Paper electronics takes what Buechley and Hill call the "Build New Clubhouses" approach—creating new communities with different cultures and values around technology than typical engineering communities in order to broadening participation. We see this beginning to happen for example in humanities teachers using circuit building to teach literature and crafters using LED stickers to illuminate their scrapbook pages. Our hope is to provide ways for circuit making and engineering activities to be relevant and exciting to diverse communities, rather than the other way around.

However, if we are to change the dominant masculine narrative around who produces technology and what types of artifacts can be produced, we need to do more than show that approaches like e-textiles and paper electronics can get more diverse participants. Craft technology approaches like e-textiles and paper electronics can take advantage of existing craft practices to connect technology making to new communities, but it can likewise reinforce gendered views of aesthetics and the types of technologies that come from different creators.

As with traditional technical communities, existing craft practices and communities are often—problematically—also highly gendered. Even though creating glowing notebooks and illuminated paper craft requires a genuine understanding of electronic principles, some from traditional technical communities may dismiss it as introductory and not legitimate engineering.

The irony is that projects created with paper electronics may look simple, but their complexity is hidden or simply different from that of traditional electronics projects. For example, crafters need to design for the final visual presentation while also ensuring that the circuitry will work. In the same way that crafters use tools with pre-designed aesthetics like stamps to help ensure certain visual outcomes, Makers often rely on shields, which are pre-assembled and ready-to-use circuit boards, to simplify much of the circuit design and building process. For both, the focus is on having a working final project rather than creating the project entirely from raw materials or components. Yet, an electronics project created by plugging together many readymade circuit board shields may look more technically complex to build than a craft project made by integrating stamped shapes with fully hand-made circuitry.

The types of artifacts created using paper circuitry are extremely different and often not possible to create with traditional electronics tools and components. The aesthetic flexibility of working with the raw materials of paper electronics results in technologies that are can be more delicate, texturally diverse and expressive. Just as with electronic textiles projects, artifacts made with paper electronics challenge the norms of what technology can look and feel like. It may be this shift in the definition of what "high tech" can be that causes some individuals in traditional engineering communities to dismiss paper electronics, and craft technologies in general, as a means to protect masculine prototypicality in technology [18].

At the same time, by offering blended approaches to both electronics and craft, we may begin creating ambiguous spaces that disrupt traditional gender roles and binaries so that creators begin to explore and construct their creative identities apart from the forces of gender performance. We have seen this possibility with electronic textiles [35].

Bers stated that, "once installed into a society, a powerful idea naturalizes itself and appears as if it was always there" [5]. We hope that approaches like paper electronics will help make crafting circuits an everyday activity that is accessible to the general public. In small ways, we may already be seeing this. For example, crafters are using circuitry to decorate their projects as if it was just another embellishment activity. These creators, mostly women, are role models for the younger generations around them, showing how it can be both wonderful and totally ordinary for women to engage in creating technology.

CONCLUSION

In this paper we have shared an early look at how, like the e-textile community, the paper electronics community may offer new pathways to engaging more diverse participants in designing and creating technologies. We examined Chibitronics customers and users as a representative subset of the greater paper electronics creative community. As we continue this research, we are particularly are excited to learn more about creators from the craft community as an emerging node of technology creators and how their adoption may lead to insights for foster overall access, adoption and cultural relevance of crafted electronic technologies as an engineering practice.

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REFERENCES

1. Agic. Retrieved August 14, 2017, from https://agic.cc/en/
2. Anderson, C. (2012). Makers: The new industrial revolution. New York, NY: Random House.
3. Bdeir, A. (2009). "Electronics as material: littleBits." In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction* (TEI '09). ACM, New York, NY, USA, 397-400.
4. Beginner's Mind Collective and Shaw, D. (2012). "Makey Makey: improvising tangible and nature-based user interfaces." In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction* (TEI '12), Stephen N. Spencer (Ed.). ACM, New York, NY, USA, 367-370.
5. Bers, M. U. (1995). Blocks to robots: Learning with technology in the early childhood classroom. New York, NY: Teacher's College Press.
6. Brahms, L. and Crowley, K. (2016). "Making Sense of Making: Defining Learning Practices in MAKE Magazine." In K. Peppler, E. R. Halverson, & Y. B. Kafai*, Makeology: Makers as Learners. Vol 2.* Routledge, New York, NY, USA, 13-28.
7. Buechley, L. (2013). "Thinking and making." Closing Keynote Talk presented at *Fablearn 2013*, Stanford, CA.
8. Buechley, L., Eisenberg, M., Catchen, J. and Crockett, A. (2008). "The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '08). ACM, New York, NY, USA, 423-432.
9. Buechley, L. and Hill, B.M. (2010). "LilyPad in the wild: how hardware's long tail is supporting new engineering and design communities*." In Proceedings of the 8th ACM Conference on Designing Interactive Systems (DIS '10).* ACM, New York, NY, USA, 199-207.
10. Buechley, L. and Perner-Wilson, H. (2012). "Crafting technology: Reimagining the processes, materials, and cultures of electronics." *ACM Trans. Comput.-Hum. Interact.* 19, 3, Article 21 (October 2012), 21 pages.
11. Chibitronics. Retrieved August 14, 2016, from http://chibitronics.com
12. Circuit Stickers. Retrieved August 14, 2017, from https://www.crowdsupply.com/chibitronics/circuit-stickers
13. Circuit Scribe. Retrieved August 14, 2017, from http://www.electroninks.com/
14. Clark, Liat. (2013). "Circuit Stickers' creators want us to build stories using electronics." Retrieved August 14, 2016, from http://www.wired.co.uk/article/circuit-stickers
15. Coelho, M., Hall, L., Berzowska, J. and Maes, P. (2009). "Pulp-based computing: a framework for building computers out of paper." *In Proc CHI EA '09*. ACM, New York, NY, USA, 3527-3528.

16. Computing Research Association. *2015 Taulbee Survey: Doctoral Degree Production Dips Slightly data.* Retrieved August 11, 2016, from http://www.cra.org/resources/taulbee.

17. Craft and Hobby Association. (2012). 2012 State of the Craft Industry. Retrieved August 11, 2017, from https://www.craftandhobby.org/eweb/docs/2012.State.of.Craft.Industy_Key.Insights.pdf

18. Danbold, F. and Huo, Y. (2017). “Men's defense of their prototypicality undermines the success of women in STEM initiatives.” *In Journal of Experimental Psychology*. Vol. 72, 57-66.

19. Hodges, S., Villar, N., Chen, N., Chugh, T., Qi, J., Nowacka, D. and Kawahara. Y. 2014. Circuit stickers: peel-and-stick construction of interactive electronic prototypes. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*(CHI '14). ACM, New York, NY, USA, 1743-1746.

20. Huffman, J. (2015). “The Electric Notebook: An Open Source Innovation to Develop an Engineering Mind in Children through Making Simple Circuits, Simple Programming, and Simple Robots.” *In Proc. Fablearn ’15*. September 26–27, 2015, Palo Alto, CA, U.S.A

21. Johnson, S. and Thomas, A. P. (2010). “Squishy circuits: a tangible medium for electronics education.” *In Proc. CHI EA '10.* ACM, New York, NY, USA, 4099-4104.

22. Kafai, Y., Lee, E., Searle, K., Fields, D., Kaplan, E. and Lui, D. (2014). “A Crafts-Oriented Approach to Computing in High School: Introducing Computational Concepts, Practices, and Perspectives with Electronic Textiles.” *Trans. Comput. Educ.* 14, 1, Article 1 (March 2014), 20 pages.

23. Kawahara, Y. Hodges, S., Cook, B. S., Zhang, C. and Abowd, G. D. (2013). “Instant inkjet circuits: lab-based inkjet printing to support rapid prototyping of UbiComp devices.” *In Proc. UbiComp '13.* ACM, New York, NY, USA, 363-372.

24. Lo, J. and Paulos, E. (2014). “ShrinkyCircuits: sketching, shrinking, and formgiving for electronic circuits.” *In Proc. UIST '14*. ACM, New York, NY, USA, 291-299.

25. Maker Media. (2015). “Fact Sheet.” Retrieved August 14, 2017, from http://makermedia.com/press/fact-sheet/.

26. National Science Foundation. (2010). *Employed scientists and engineers, by occupation, ethnicity, race, highest degree level, and sex: 2010 (updated).* Retrieved August 11, 2017 from http://www.nsf.gov/statistics/wmpd/2013/pdf/tab9-37_updated_2013_11.pdf.

27. Next Generation Science Standards. Retrieved September 20, 2017 from http://www.nextgenscience.org/

28. Peppler, K. (2013). “STEAM-Powered Computing Education: Using E-Textiles to Integrate the Arts and STEM.” *Computer* 46, 9 (September 2013), 38-43.

29. Qi, J. and Buechley, L. (2014). “Sketching in circuits: designing and building electronics on paper.” *In Proc CHI '14*. ACM, New York, NY, USA, 1713-1722.

30. Russo, A., Ahn, B. Y., Adams, J. J., Duoss, E.b. Bernhard, J. T. and Lewis, J. A. (2011). “Pen- on-paper flexible electronics.” *Advanced Materials*, pages 3426-3430.

31. Saul, G., Xu, C. and Gross, M. D. (2010). “Interactive paper devices: end-user design & fabrication.” *In Proc TEI ’10. ACM*, New York, NY, USA, 205–212.

32. Shorter, M., Rogers, J., and McGhee, J. (2014). “Practical notes on paper circuits.” *In Proceedings of the 2014 conference on Designing interactive systems (DIS '14)*. ACM, New York, NY, USA, 483-492.

33. Ulian, Leonardo. Retrieved Jan 8, 2018, from http://www.leonardoulian.com/

34. Vogel, Peter. Retrieved Jan 8, 2018, from http://www.petervogel-objekte.de/

35. Weibert, A., Marshall, A., Aal, K., Schubert, K. and Rode, J. 2014. Sewing interest in E-textiles: analyzing making from a gendered perspective. In Proceedings of the 2014 conference on Designing interactive systems (DIS '14). ACM, New York, NY, USA, 15-24.

36. White House. (2016). “Nation of Makers.” Retrieved August 14, 2017, from https://www.whitehouse.gov/nation-of-makers.

37. Wired Circulation Demographics (2016). Retrieved August 14, 2017, from http://www.condenast.com/brands/wired/media-kit/web

38. World Bank Group. (2016). Primary Education, Teachers (% Female). Retrieved August 11, 2016, from http://data.worldbank.org/indicator/SE.PRM.TCHR.FE.ZS

39. World Bank Group. (2016). Secondary Education, Teachers (% Female). Retrieved August 11, 2016, from http://data.worldbank.org/indicator/SE.SEC.TCHR.FE.ZS