Making Grooves With Needles: Using e-textiles to encourage gender diversity in embedded audio systems design

Rebecca Stewart
School of Electronic Engineering and Computer Science
Queen Mary University of London
London, UK
rebecca.stewart@qmul.ac.uk

Sophie Skach
School of Electronic Engineering and Computer Science
Queen Mary University of London
London, UK
s.skach@qmul.ac.uk

Astrid Bin
Adam Lab & Center for Music Technology
Georgia Institute of Technology
Atlanta, Georgia, USA
a.bin@gatech.edu

ABSTRACT

Historically, women have been excluded from engineering and computer science disciplines, and interactive audio is no exception. Relatively few women are involved with the designing and building of embedded audio systems with traditional tools such as microprocessors, but when embedded audio systems are built using e-textiles, much larger proportions of women become engaged with technology. In this paper we review theories for this gender disparity and the barriers women face in working with audio technology, and then present a comparison of survey data between an e-textile audio workshop and an audio platform user group. Extrapolating from the case study and the surveyed literature, we propose that flexibility in learning, communal dissemination of knowledge, and gendering of tools are prominent reasons why women engage with technology via e-textiles.

ACM Classification Keywords

H.5.5 Sound and Music Computing: Systems; J.5 Arts and Humanities: Performing Arts; K.4 Computers and Society; K.7 The Computing Profession

Author Keywords

Embedded audio; e-textiles; gender

INTRODUCTION

Significantly fewer women than men participate in the designing and building of embedded interactive audio systems [31, 14, 11, 16, 4, 3, 15]. Contrastingly, electronic textiles (e-textiles) such as the sensor in Figure 1 have historically attracted the engagement of proportionally more women and girls than men and boys, particularly within hand-crafting contexts [6, 7].

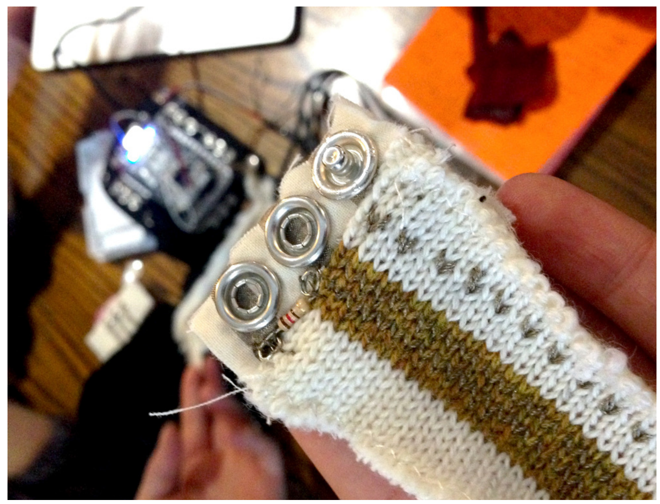

Figure 1. E-textile stretch sensor.

Despite a lack of women involved in building audio applications, e-textiles — a practice that includes far more women — have a long history of being used for building audio applications. Noting this disparity, we are examining e-textile practices in order to increase the participation of women in building interactive audio applications.

This paper is in four parts. First, we explore the barriers to participation faced by women in audio technology, in order to understand why this gender disparity exists, and how e-textile practice has the potential to effectively address it. Second, we survey e-textile practice, and consider the nature and history of e-textile practice through a gendered lens. Third, we present a case study of an e-textile audio workshop, and consider the outcomes reported through participant surveys. Finally, we discuss why women may choose to participate in audio technology through e-textiles due to its knowledge formation,

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community, and tools, and how this can inform strategies to encourage wider diversity of participation.

BARRIERS TO WOMEN IN AUDIO TECHNOLOGY

Audio technology refers to the intersection of computer science and electrical engineering with sound generation, analysis, and transmission. This term is also more generally used to describe all sounds, while *music technology* usually refers to only musical sounds (excluding sounds like speech or sound effects). However, both terms are often used interchangeably to refer to the same tools and communities, and both denote interdisciplinary fields drawing on music and engineering. Examples include human-computer interfaces for digital musical instruments, the design of algorithms that create sound, and using software and hardware to control sound. Within academia, university degrees and research labs addressing the same topics could be found in either music or electrical engineering and computer science departments [3].

Women and girls are underrepresented in every aspect of audio technology including academic communities [14, 11], professional music production [16, 31], students enrolled in music technology degrees [4, 3, 31], composers utilising music technology [15] and semi-professional or professional developers of audio technology outside academia [1].

Audio technology is not immune from the social context shaping the broader fields of engineering and computer science, and there is a large body of science and technology studies (STS) documenting ways in which young girls through to grown women are discouraged from being the designers and builders of technology. For example, the way programming is taught can discourage women if they don't conform to certain cultural norms [38]. These do not have to be intentional actions; even the placement of objects in a shared space can discourage women if those objects are associated with a culture that women do not identify with or belong to [10]. This effect remains in place even if there are only women in that shared space.

As audio technology has matured as a field in its own right, STS has focused directly on the gender imbalance that pervades every aspect of it. Born et al. [4] present a thorough analysis of music technology within higher education, and lay out a number of explanations for why girls choose not to even apply to universities to study music technology (such as the explicit and implicit messages that girls are less technically-adept than boys and technology is a masculine pursuit).

Within audio technology culture, there are still gendered cues that indicate women don't belong there, from the language used to describe technical concepts ("punch in", "kill a track") to the violent and sexualized content of advertisements for audio equipment [17]. Far more overt forms of sexism still exist, as well such as sexual harassment and assault [16].

ENGAGEMENT WITH ELECTRONICS AND COMPUTING THROUGH E-TEXTILES

We will first introduce core e-textile technologies along with the community of e-textile practitioners. We will then look at the field's relationship to audio technology.

Introduction to E-Textiles

E-textiles are electrical circuitry made of conductive threads and/or fabrics. The most commonly used threads are metallized by nano-plating or wrapping non-conductive core threads, but yarns can also be constructed by spinning staple fibers with metal fibers similar to how wool yarns are produced. Conductive polymers electro-spun into fibers or used to coat non-conductive textiles are another method commonly employed [28]. There are a number of resources that more thoroughly document the state-of-the-art of e-textiles than is possible here, including [37, 12, 30].

Conductive textile structures can be formed from these yarns by undergoing traditional textile processes such as weaving or knitting. These more complex structures can exhibit particular electrical properties that mean they can be used as sensors, such as a change in resistance when a knit is stretched [36].

Capacitive sensing to detect touch or proximity is another popular sensing technique as it can be constructed using a variety of textile processes. It is particularly effective when combined with digital embroidery where a computer-controlled sewing machine can precisely place conductive threads on non-conductive fabric (see [27, 21]).

E-textiles are more commonly found as sensors or the interconnections between components in a circuit, but they can also perform as actuators. Two such examples are fabrics dyed with thermochromic dyes that change color when electrical current heats the underlying conductive yarn [2] and conductive threads or fabrics acting as voice coils within loudspeakers [25].

Currently, non-textile components are included in e-textile circuitry. Components such as batteries and microcontrollers are not yet available in textile form factors (though there is ongoing work to adapt electronic packages to better integrate directly into yarns [29]). As a result, a number of applications have emerged to make the integration of hard components and soft circuity easier, such as the Arduino Lilypad, a microcontroller that can be sewn into textile applications and runs on a small 3V battery.

The Lilypad Arduino by Buechley introduced sewable pads on PCBs (Printable Circuit Boards) for connections to components like microcontrollers [6]. Its adaptation of traditional PCB manufacturing to accommodate sewn conductive thread allowed it to be produced at scale and be commercially available to professional and hobbyist embedded electronics engineers, opening up e-textile development to those outside academic research labs [7]. The core features of the sewable pads of the Lilypad have been integrated into other e-textiles products such as the Flora by Adafruit, seen in Figure 2.

E-Textile Practitioners

Women have been active researchers in e-textiles since its founding, with the research by Orth and her colleagues recognized as the first publications in the field. They developed novel applications for textile interfaces embroidered with conductive threads and adapted existing fabrics that happened to have conductive properties into circuit substrates [26, 27].

Figure 2. Adafruit Flora microcontroller in an e-textile circuit with conductive fabrics and thread. The Flora iterates on the open source design of the Lilypad using the same sewable connections on the PCB.

Buechley's pioneering contributions through the design and sale of the Lilypad greatly expanded the demographics of who was working with embedded electronics. The Lilypad was created with diversity, and gender diversity in particular, in mind [6]. It built on the Arduino platform, an open source and low cost microcontroller platform designed to be accessible for those with little or no formal education in electrical engineering. The Lilypad made it simpler for users to connect e-textile sensors to a microcontroller allowing those who already worked with textiles such as fashion designers or artists to integrate electronics into their projects with greater ease than ever before.

The Lilypad was immediately successful at engaging women in building and designing their own electronics. Within a few years of the commercial release, Buechley and her research team investigated who was buying and using Lilypads. They found significantly more women were working with Lilypad than the standard Arduino board [7]. When looking at Arduino projects documented online, they found that women were the creators behind 65% of the projects using the LilyPad and only 2% of the projects using an Arduino board other than the LilyPad. When looking at sales figures from the primary retailer of the Lilypad, they found that female customers were more likely to purchase a Lilypad, when buying an Arduino microcontroller board.

On the back of the mainstream success of the Lilypad, e-textiles were quickly becoming a pedagogical tool within schools for teaching engineering and computer science coupled with art and design. The topic was found to attract more girls in after-school clubs such as the one described in [6]. The 10 participants that volunteered to take part consisted of 9 girls and 1 boy, with the boy having more previous computing experience than the girls. This proportion of female to male participants and their respective prior experiences with technology were repeatedly found in other workshops, whether with students in formal educational environments or adults outside of universities [40, 9, 8].

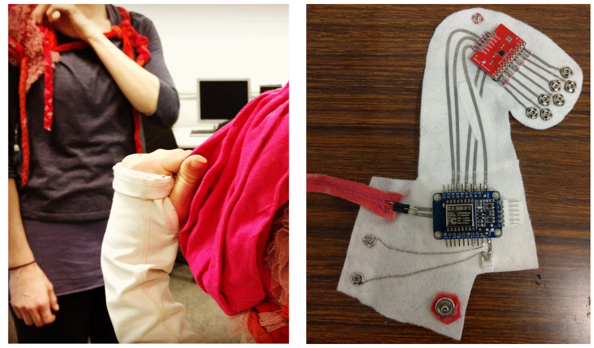

Figure 3. (Left) Touch-detecting wearable audio interfaces integrated into dancers costumes and (right) a portion of the embedded e-textile circuitry from the same interface.

As the Maker Movement grew with technologies like the Arduino platform and domestic 3D printers, hobbyist and semi-professional engineers, designers, and artists were sharing their expertise and experimentation with e-textiles online. Artistic duo Kobakant [1] became significant organizers and contributors to the e-textile community. Their website "How to Get What You Want" and their series of eTextile Summer Camps are resources and networks that are central to the community [32].

E-Textiles and Audio

E-textiles have long been used to sense, control, and generate audio. Much of Orth's groundbreaking work creating e-textile interfaces centered around musical controllers, most notably her MIDI jacket which used capacitive sensing to detect when digitally embroidered motifs were touched [27]. Later work by researchers at Virginia Tech combined weaving with audio signal processing to build large lengths of cloth that could determine the location of passing objects like cars [23].

E-textiles are well-suited for wearable applications as they can be directly integrated into clothing more comfortably than PCBs. This makes them ideal for embodied audio performances as the electronics can form part of the costumes that the performers wear. One such example can be seen in Figure 3 where e-textile capacitive touch sensors are worn by dancers to trigger audio samples [34].

Alongside wearable applications, e-textiles have been a popular technology for creating malleable objects where the ability to stretch or squeeze the object controls the generated audio. Examples include a touch-sensitive embroidered map that plays sounds from that places the embroidery illustrates [21], a pressure and proximity sensitive fabric keyboard [41]; and a multi-touch cloth as a control surface for audio synthesis [13].

WORKSHOP CASE STUDY

Now that we have explored the barriers to participation faced by women in audio technology and the history of e-textile practice through a gendered lens, we present a case study of an e-textile audio workshop, and consider the findings from a series of surveys. In order to more closely examine the barriers for women wishing to develop audio interfaces, we

[1] http://www.kobakant.at

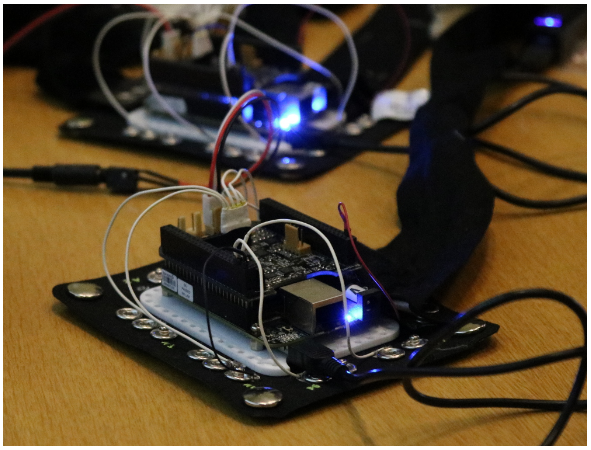

Figure 4. Bela on a fabric breakout circuit board as used in the e-textile workshop.

Figure 5. Group of workshop participants working together on their collaborative project.

examine the responses gathered via two different surveyed groups. Both sets of surveys look at using Bela[2] in embedded audio projects [19]. Bela is a computing platform designed for real-time embedded audio applications. Beginning as a university research project, Bela has evolved into a commercial product with a community of approximately 700 developers [22].

We will refer to as the first surveyed group as the *Bela community*. In June 2017 the Bela team conducted an online user survey to gather data on who was using the platform and how they were interacting with it. This survey was advertised online through the Bela user forum, mailing list and social media accounts and gathered 251 responses.

The second surveyed group will be referred to as the *e-textile workshop participants*. In November 2017 a one-day workshop was held during an electronic music and art festival in the UK [3]. The workshop was advertised as an e-textiles workshop for creating wearable audio interfaces using Bela and handmade fabric sensors. The workshop had 15 attendees in total; 11 of those attendees completed an online pre-workshop survey and 5 completed an online post-workshop survey. The pre- and post-workshop surveys were structured identically to the *Bela community* survey, with additional questions to account for working with textiles.

Workshop Activities

During the workshop the participants were introduced to some of the materials commonly used in e-textiles and taught how to build textile switches, stretch and pressure sensors. Conductive fabrics and yarns (e.g. silver coated fabrics or stainless steel fibers), as well as resistive materials were used to make textile circuits and sensors.

The participants were then shown how to use the data generated by the sensors to control sounds through editing the code running on the Bela, using the browser-based integrated development environment (IDE). Bela was connected to a fabric breakout circuit board so that conductive textile cables prepared for the workshop could be easily snapped into place to allow for rapid prototyping. (Figure 4 shows the Bela on a fabric breakout circuit board; a more detailed technical description of the system can be found in [35]. During the second half of the workshop, participants designed and prototyped projects using the provided kit and materials. They were encouraged to collaborate and to share different skill sets, helping each other with either textile-making techniques or programming skills.

As there were 5 Bela kits for the 15 participants to share, group sizes varied from 2 to 4 participants. Figure 5 shows one of the groups of four. Each group had the same equipment available, which consisted of fabric snap connectors to link the sensors to the Bela breakout board, as well as sewing needles and a variety of conductive yarns and fabrics. There was also a sewing machine and iron available for use. Participants were asked to bring their own laptops to work on the programming sketches that allowed testing of the sensors (these sketches were prepared in advance and shared with attendees by the workshop organizers).

Community Demographics

Though the *workshop participants* are a smaller sample set than the survey of the *Bela community*, we are able to compare their demographic and previous experiences to the larger audio technology community and to previously documented e-textile workshops. The age demographics of both the broader *Bela community* and the *workshop participants* were quite similar. Both ranged from 18 to over 55 years old, with representation from every grouping of five years. Both groups had slightly more representation from respondents in their 30s than the other age bands.

While there were similarities with age distribution, there were significant differences between the two surveys when comparing gender. The respondents to the *Bela community* user survey were overwhelmingly male with 92% (232) identifying as male, 4% (9) as female, and 4% (9) who preferred to not say. The survey did not ask if their gender matched the one they were assigned at birth. This roughly aligns with other measures of gendered participation in the audio technology community such as 3% of the board members and 6% of the

[2] https://bela.io
[3] http://algomech.com/2017/

authors of a prominent conference being women [11], though is lower than other reported figures of 15% women when considering audio technology within the entertainment industry [16].

Of the 11 respondents to the pre-workshop survey of the *e-textile workshop participants*, 82% (9) identified as female and 18% (2) as male with all but one respondent confirming their current gender is the one assigned them at birth. One respondent preferred to not say whether their gender was the same as the one assigned at birth. (Anecdotally, this is representative of the e-textile workshops that the first author has led and is similar to other workshops described in the literature [6].)

Prior Experience

From the pre-workshop *e-textile workshop participants* survey (N=11), no attendees indicated any experience working with the Bela platform before attending the workshop, but they did have experience with other electronics and coding platforms: 91% (10) had worked with Arduino and 27% (3) with the Raspberry Pi. 27% (3) had experience with audio-specific software, such as Max/MSP or PureData. One workshop attendee said they had no prior experience with coding or electronics, while 45% (5) had completed degrees or were currently university students in computer science or digital arts courses. The rest had limited experience with coding and electronics, largely through "tinkering" at home.

Generally, the *Bela community* had more experience with a variety of embedded computing platforms than the *e-textile workshop participants*, but a similar proportion had exposure to maker platforms: 80% (201) of the *Bela community* and 67% (10) of the *workshop participants* had used Arduino.

There were differences between the groups in self-reported expertise: 9% of the *Bela community* who had experience with Arduino considered themselves to be experts, whereas no *workshop participants* with Arduino experience considered themselves experts. Further, where one *workshop participant* considered themselves expert in Max/MSP (out of 10 suggested languages), 54% (137) of the *Bela community* considered themselves expert in at least one out of the same set of languages.

However, the *e-textile workshop participants* identified their expertise in e-textiles, with 64% (7) of survey respondents citing at least some experience. The skill sets that related to textiles focused on hand craft, such as hand embroidery, knitting, or crochet.

Even though 55% (6) of the *workshop participants* had formal educational qualifications in textiles at the undergraduate or graduate level, and an additional 27% (3) participants had years of experience in pattern making, weaving, printing, knitting or crocheting, only one person identified themselves expert in a textile-related discipline. Though this group had fewer formal qualifications in textiles than in computing, this was not reflected in their survey responses as their self-reported expertise tended to focus on textiles and not technology.

Additionally, 3 of the 7 *e-textile workshop participants* that confirmed they had previous experience with e-textiles had also taught e-textiles skills in other workshops.

Motivation

Both groups were asked to identify themselves from a list of descriptors, including musician, programmer, maker, instrument builder, researcher, visual artist, educator, hardware developers and visual artists. Respondents could select more than one descriptor.

The *Bela community* identified themselves as musicians (79%, 198), programmers (63%, 158), makers (55%, 139), instrument builders (54%, 136), researchers (43%, 109), educators (32%, 80), hardware developers (25%, 62), and visual artists (18%, 46).

Of the *e-textile workshop participants*, 33% (8) identified as makers, 21% (5) as researchers, 13% (3) as visual artists, 8% (2) as programmers, as well as 1 musician and 1 instrument builder. None identified as hardware developer. When asked why the attendees chose to attend the workshop, 90% (10) cited gaining skills (textile, technical or general) as their motivation for participating.

Workshop Outputs

The workshop's primary activity was to design sensors for an embodied sound performance. Most participants worked on accessories like a headband or glove instead of a larger garment. Two groups achieved their goal of creating a wearable sensor network that could be worn on the body, including the Bela attached via snaps or sewn pockets[4].

The sensors that were built on the day were mostly made in the first half of the workshop, when basic e-textile techniques were taught. To accomplish these basic skills and techniques (making switches and pressure sensors, as well as connecting sensors to Bela), *e-textile workshop participants* reported to having needed only little or no guidance. More guidance was needed when integrating the self made sensors in garments or accessories and working with Bela code to process the measured sensor data.

Discussion of Survey Results

There were significant differences in the survey responses of the two groups, but also notable similarities. Each group had a similar age distribution, and though the *Bela community* had more experience with different technology platforms, the *e-textile workshop participants* were experienced with two of those platforms most commonly used in maker communities.

The most obvious difference was gender, as the *Bela community* was predominantly male, and the *e-textile workshop participants* predominantly female. This imbalance suggests that though the outcomes of interactive, sensor-based audio applications are common to both groups, the Bela platform does not attract female users in the same way as a craft-based workshop.

[4]Different items of clothing for both upper and lower body were provided by the organizers.

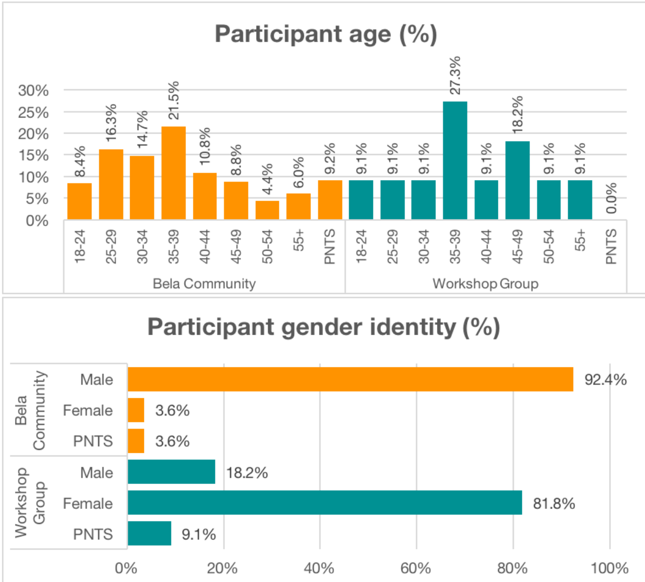

Figure 6. Visualisation of participant data, Bela community survey vs e-textile workshop participants. Top: Ages of participants. Bottom: Gender identity of participants. (PNTS = Prefer Not To Say)

The members of both groups also identified their motivations differently. Though a similar proportion of both groups chose the descriptor maker, the *Bela community* also predominantly identified as musicians and programmers. As well as makers, the *e-textile workshop participants* also identified as researchers and visual artists.

Though no detailed conclusions can be extrapolated from this data given the small sample size, it does suggest that the female-dominated *e-textile workshop participants* are motivated by exploration, while the male-dominated *Bela community* is motivated by task. This is not to suggest that music creation is not exploratory or creative, but rather that the Bela system is viewed more as a tool that can be used, rather than a starting point for open-ended exploration.

Overall the *e-textile workshop participants* did not express confidence in their expertise in any of the technical platforms listed in the survey (with the exception of one attendee who is a professional software developer), while showing more confidence in their textile skills. This did not correlate with the professional qualifications of the group as there were more individuals with university-level computing experience than textile. This could be indicative of women feeling less confident in expressing technical expertise, though this is again stated cautiously as this is a small sample size.

An interesting observation of the *e-textile workshop participants* is that though learning and skill development was listed as a motivator, we observed that participants tended to stay within the fields of practice in which they were already confident (knitters, for example, concentrated on making textile sensors rather than trying out new software to process sensor data), and few tried out techniques they hadn't used before. When experimentation did take place, it appeared that participants with more technical experience were willing to experiment with textile and craft related skills and techniques they had not yet mastered. However, those with craft experience and technical knowledge did not tend to extend their knowledge of software or programming.

Expecting to provide the participants with a sufficient grounding in an audio programming language unfamiliar to most of them is an overly ambitious goal for a single-day workshop, though this trend is still notable. It may be because those with craft skills consider technical skills to be intimidating or that they simply don't know where to start, and those with technical skills might consider crafting something that is low-risk and experimental and are therefore more willing to try. This is a particularly salient finding that requires more study, as understanding the perceptions of technical and craft skills by non-experts in both domains may provide important insights into how technical tools might incorporate styles of learning and using that support a user base with a more diverse range of experiences and abilities. This is examined further in the following section.

MOVING BEYOND 'WOMEN JUST LIKE TO SEW'

It has been demonstrated both in the workshop presented here and the many others that came before it documented in the literature [6, 9, 8, 40] that women and girls want to learn how to work with electronics and code to build audio interfaces of their own design. However, they are not easily found within the various academic, hobbyist and professional established audio technology communities. The introduction of e-textiles to audio technology drastically and consistently changes the gender representation with women outnumbering men.

In this section we explore why this occurs, and move beyond overly simplistic tropes such as "girls like to sew" or "women like knitting". Further, we examine the opportunities that textile practice presents and the barriers they may remove for underrepresented groups within audio technology. We identify three themes that have emerged: flexibility in learning; communal dissemination of knowledge; and gendering of tools.

Flexibility in Learning

Turkle proposes that one of the contributing factors to the lack of women in computer science is the stringent requirements in how skills like programming are learned [38, 39]. There is little accommodation for anyone who does not relate to computers in a way that aligns with the existing technical culture, and common pedagogical approaches. We propose that one of the attractions to e-textiles for women is that field is still relatively young; there isn't a 'right' or 'wrong' way, as long as the desired output is achieved.

Turkle and Papert argue for *epistemological pluralism* where different methods of thinking and learning are valued [39]. This fights against what is called in technology start-ups as "culture fit", where arriving at the correct answer is not sufficient if the steps taken to arrive at that answer did not follow the accepted model. They propose broadening computer science education by encouraging a *bricolage* approach to building knowledge by arranging and rearranging well-known concepts. They emphasize "playing around" and treating code elements as physical materials, sometimes literally by using code to alter the physical world through robotics. This pluralistic approach has directly impacted e-textile development, as Buechley et al. [6] reference the modular style of the robotics kit designed by Papert as a design consideration for the Lilypad, which brought bricolage to e-textiles and microcontrollers.

Epistemological pluralism addresses how an individual learns, but McCartney [18] discusses what feminist epistemologist Code calls "second personhood" within the context of electroacoustic audio. Code proposes that second persons inform how knowledge is created through empathetic knowledge and ecological thinking as opposed to "spectator epistemologies" — colloquially, "bouncing ideas off each other" as a method for the formation of knowledge. Hand crafting textiles are rooted in social interactions between women, and, as will be discussed in the next section, second personhood is a foundation of e-textile culture.

As women are less likely to pursue formal educations in computer science or electrical engineering fields, they need to use alternative educational routes to learn programming or circuit design. Resources like Kobakant's "How to Get What You Want" are one option, but peer-led community workshops are another. We saw this in our workshop attendees with the 3 of the 7 attendees with previous experience in e-textiles having already taught e-textiles skills in other workshop settings.

We suggest that women will engage with technology when it is taught in workshops set within social contexts where attendees are encouraged to interact with and learn from each other. Workshops should include activities that allow for creative exploration and which encourage combining presented concepts in new ways in order to facilitate a deeper understanding.

Communal Knowledge Dissemination

The communal nature of textile crafting is one that has directly influenced e-textiles. Kobakant have grown the e-textile community through virtual and physical activities. Their website "How to Get What You Want" and the eTextile Summer Camps described above have provided a set of central resources for both technical and social cohesion [32].

Workshops are an essential means of transmitting craft knowledge while reinforcing relationships, and can be used as a means to conduct research [33]. They have been used to evaluate e-textiles tools and pedagogy since the development of the Lilypad and continue to be a core research tool [6, 8, 32, 9]. Workshops also serve as a primary means to disseminate information on best practices. In our workshop, connecting with community was declared an important component and sharing knowledge, networking and acquiring skills were named by participants as a motivation for attending the workshop.

In discussing the growth of the Bela platform, Morreale et al. use the term *pluggable communities* to describe how the Bela community has grown by connecting multiple disparate communities already working with audio technology to Bela [22], and cite social experts as key to transferring knowledge between disparate communities. We have found this holds true in this work, and that holding workshops such as ours, where audio, technical, and textile/crafts experts are brought together, allows not only for social experts to meet but also for connections to form and knowledge to be exchanged between their associated communities, which might otherwise have very little interaction.

Tools

Pluggable communities, as discussed in the previous section, center around common tools and toolchains. When those communities are strongly gendered, the associated tools are as well. Electrical engineers have a wide variety of tools designed for precise, specialized tasks. Complex spatial transformations and in-depth understanding of materials are required to realize a physical circuit from its abstract circuit diagram. This is true whether working with fiberglass boards coated with copper or stainless steel threads embroidered onto fabric. However, the tools used with each of those materials are associated with gendered communities. One set of tools and materials are deemed more "serious" and "scientific" than the other. Even though e-textiles have only recently given a reason for a sewing needle or crochet hook to be placed in an electronics lab, handcrafting textiles have long been qualified as a frivolous activity because of its association with women [24].

The gendering of tools is easily seen within mixed gender e-textiles workshops. Buchholz et al. [5] found that during their after-school workshop that boys and girls worked with their historically gendered tools: The girls handled the textile crafting tools like needles and scissors 80% of the time, while the boys handled the electronics tools like the multimeter 75% of the time. We also observed this within two of the groups in our workshop where there was mixed gender collaborations. The men in both groups performed all programming activities while the women hand stitched or crocheted. For gender parity to take place, the gendered nature of tools needs to be challenged, and space needs to be provided for women to assert control over electronics and technical tools, as well as for men to feel comfortable with tools of sewing and crafting.

The tools available to complete a task have the ability to assist or hinder that task, and embedded audio for e-textiles has been limited by the available tools. The Lilypad microcontroller (along with its later iterations such as Adafruit's Flora) has limited processing power that is not designed for audio signal processing. It is only capable of simple tones and beeps unless peripheral hardware is used that can process mp3 files, for example, or the application is connected to a a computer where more complicated processing can take place. This lack of powerful e-textile platforms greatly limits the embedded audio technology systems that can be developed using textile practices.

We addressed this by creating a fabric breakout circuit board for Bela that was used in our workshop (see Figure 4). This breakout provided an easy way to embed a powerful system in a craft application. In this way, we are providing tools that encourage a wider diversity of techniques to be used in creating novel interactive audio systems, by providing a method of interfacing with a powerful system capable of much richer sound possibilities than those that are currently used.

CONCLUSION

Women have historically been excluded from engineering and computer science disciplines, including those involving audio. Relatively few women in proportion to men are involved with the designing and building of embedded audio systems, whether looking at students within school or university education, professionals, or hobbyists. However, the field of e-textiles regularly attracts women and girls in disproportionate numbers to other technical disciplines. When embedded audio systems are built using e-textiles, we see larger proportions of women becoming engaged compared to traditional code-based methods of creation. This implies that women are motivated to work with audio technologies, and we suggest that this is because the methods of working that e-textiles encourage remove, or let women overcome, the barriers that would otherwise prevent them from working with audio technology.

We began by reviewing explanations for this gender disparity and the barriers women face in working with audio technology. The culture surrounding engineering and computing both subtly implies and overtly states that they are inappropriate topics for girls. This influences what they choose to study and how to spend their free time. Outside of education, the environments where technology is designed and built are frequently unwelcoming — and sometimes hostile — for women. This is in contrast to textile-based communities of practice that generally are centered around women's work, even when technology is introduced via e-textiles.

We used an e-textile workshop as a case study to examine the demographics, previous experience, and motivations of the attendees. They learned how to design and build their own embedded audio systems with e-textiles, completing surveys before and after the workshop. We compared these responses to user survey responses from the Bela user community. Bela is the same embedded audio platform used in the e-textile workshop).

We found that the both groups had a similar age distribution, but that the *workshop participants* were overwhelmingly female with the *Bela community* almost entirely male. There were also differences in the way the two groups judged their expertise: the *Bela community* was more willing to consider themselves experts, while the *workshop participants*, despite significant formal education in electronics and computer science, only one participant identified as expert in any of the suggested programming languages or platforms. Further, the *Bela community* was far more confident in their technical abilities with more expertise in a variety of platforms, while the *workshop participants* felt their expertise was limited to textiles.

We identified three key themes from the observed workshop and the surveyed literature to aid in understanding what attracts women to engaging with audio technology within the context of e-textiles. E-textiles allows for multiple and more flexible methods of knowledge formation, brings technology to an already existing community, and utilizes gendered tools that provide space and confidence for women to exert expertise over men.

Both Buechley [7] and Turkle [39] discuss creating new communities around building technology that are designed for women, as opposed to asking women to fit into already established environments that work to exclude them. Focusing on materiality is one way to form these new technological communities. Paint, paper craft and woodworking can all be used to build circuitry, and these crafts each have their own communities and demographics. For example, painting and quilting workshops involving microcontrollers have drawn in an older demographic while for paper circuitry attracts women in similar proportions to e-textiles [20].

Though this study has produced intriguing findings related to gender, it only examines a narrow demographic. We have not discussed a multitude of additional factors that shape an individual's lived experience such ethnicity, immigration status, accessibility requirements, and a myriad of other influences. Future work should explore how the lessons learned from e-textile communities might be applied to encourage participation from other groups marginalised from technology, in order to increase the diversity of technical practice.

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