Interactive Bobbin Lace: Metal Thread History, Interviews with Lacemakers, and Material Explorations with E-textiles

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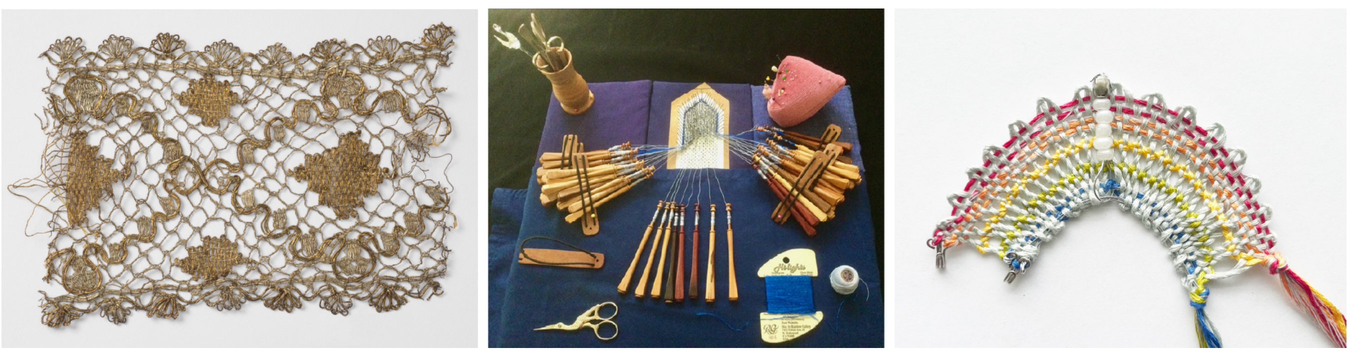

Figure 1: In this paper, we explore opportunities for e-textile bobbin lace with three contributions: (1) summarizing the metal thread history of bobbin lace for HCI audiences, (2) conducting interviews with contemporary bobbin lacemakers to understand their craft practices, and (3) creating e-textile bobbin lace samples with iterative feedback from members of a bobbin lace guild. Images courtesy (left to right) of the Smithsonian [15], Kathy Morgan, and potentiometer sample created by the research team.

Abstract

Hybrid crafts are increasingly repurposing the metal materials used in hand crafts for their conductive and interactive affordances. In this paper, we look to the history of metal threads and their use in the fine craft of bobbin lace to explore tensions and opportunities for leveraging bobbin lace techniques with e-textile crafting. First, we contribute an overview of the history of metal thread use in bobbin lace practices. Second, we provide insights on contemporary bobbin lace culture from individual interviews with 17 bobbin lacemakers. Third, to better understand how to integrate e-textiles with bobbin lace practices, we engaged in a Research-through-Design process of creating e-textile bobbin lace patterns and samples alongside two group feedback sessions with members of a bobbin lace guild. Together, these three contributions provide an introduction of the affordances and constraints of bobbin lace as a unique fabrication method for e-textile hand crafts.

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CCS Concepts

• **Human-centered computing → Human computer interaction (HCI)**.

Keywords

Hybrid craft, e-textiles, electronic textiles, lace, bobbin lace, textiles, metal thread

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1 Introduction

Bobbin lace is a form of weaving that has the potential to extend how smart materials can be interlaced into textiles, see Figure 1. Weaving has received increased interest in Human Computer Interaction (HCI) due to the ability to interlace novel interactions into cloth with electronic textiles (e-textiles) [116], as well as opportunities for digital fabrication with digital looms and patterns [42, 45]. One of the greatest strengths of woven technologies is that they reimagine what "computers" look like, how they are crafted [38, 122], and the applications and locations where technology belongs [114]. As Mark Weiser described in his influential paper on calm technology, *"the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it"* [131]. The craft of weaving enables researchers to interlace smart threads, materials, and components with interactive affordances into fabrics to design technologies that might blend into our lives. Weaving is a rich area of exploration due to the many weave structures [40], patterns [45], and challenges to address [116]. In this paper, we add to the diversity of weaving and interlacing techniques available to HCI researchers through an initial investigation into the maker culture of bobbin lace, and explorations into the coproductions with e-textile hybrid crafts [41].

1.1 Motivation: Why study bobbin lace in HCI?

Bobbin lace is a unique form of weaving "off loom" that enables the creation of diverse shapes and patterns that would not be possible on a traditional loom. Instead of holding threads in place with a loom, bobbin lace uses threads held with individual bobbins and temporary pins, which expands the directions that threads can be interlaced. There are several characteristics of bobbin lace crafting culture (including unique fabrication processes, material use, and applications) that make it an interesting area of exploration for HCI and hybrid craft researchers. E-textiles often leverage and repurpose the conductive abilities of metal threads [72], which have electrical and computational affordances when combined with increasingly small, wearable, and stitchable microcontrollers. Bobbin lace has a history of metal thread usage and design precedents that could inspire and inform current e-textile designs. It is also an opportune time to study lace, which has grown in recent years due to expansions in online lacemaking education and conferences [51, 60, 99, 101], exhibitions on contemporary and historical lacemaking practices [33], and innovations in digital pattern-making practices [106]. These directions have been able to expand the accessibility of lace making and lace education, which was previously limited to local guilds and in-person communities [79]. In this paper, we explore the material culture of bobbin lace (its metal thread history and current practices), and iteratively work with bobbin lacemakers on how e-textiles could be incorporated into these practices. This crossdisplinary exploration aims to make bobbin lace practices more accessible to HCI audiences, and to explore how e-textile patterns would need to be designed for use by bobbin lace audiences.

1.2 Contribution

This paper provides three contributions to e-textile hybrid craft:

(1) ***Introducing metal thread bobbin lace history for HCI researchers***: We summarize the history of metal thread use in bobbin lace practices and describe opportunities and applications for e-textile crafting.
(2) ***Understanding contemporary practices***: We interview 17 bobbin lacemakers to understand the contemporary maker culture of their craft including motivations and current challenges.
(3) ***E-textile sampling and feedback***: Using Research-through-Design, we iteratively explore how to combine e-textiles with bobbin lace practices and provide insights from feedback and discussion sessions with members of a bobbin lace guild.

Together, these contributions provide recommendations for creating e-textile bobbin lace with an understanding of its cultural history, modern uses, and fabrication and pattern-making practices.

2 Related Work

E-textile hybrid crafts combine crafting and computation to expand the creative opportunities, and mediums, for digital technologies. One area of this research overlaps with physical computing, where stitchable microcontrollers [31, 32, 95] are combined with metal threads for interactive dual affordances [72, 91, 112]. For example, using metal threads for stitching [75], but also leveraging the conductive affordances of these materials to create soft interactive devices [113]. This combination expands the customization and personalization opportunities available for computing [68, 105], and researchers are increasingly developing digital pattern tools to support these types of interactive hand crafting practices [45, 54, 92]. Here we discuss how lace, and specifically bobbin lace, has been used in computing.

2.1 Lace techniques in HCI

Lace is a broad category of textile techniques that are defined by their negative spaces and the "holes" in the textile. Though lace fabrics might be visually similar, the methods used to fabricate them vary to a great extent, see Figure 2. Most textile fabrication methods have ways of creating holes and lace patterns, such as stitches for knit lace, crochet lace, woven lace, netting, macramé, tatting, embroidery (cutwork) and needle lace. As a result, lace has popped up throughout e-textile research in different physical forms and across crafts. For example, researchers have explored how to combine textile pattern practices with e-textiles for lace crafts like crochet [83, 111], tatting [18, 19, 107], and needle lace [104]. Lace can also help e-textile technologies look more decorative and like something that belongs on the body, such as recent explorations into woven on-skin interfaces [59, 126]. Embroidered lace enables e-textile researchers to create digital embroidery designs with the potential for greater scale of e-textile lace [70], as well as interactive lace with 3D forms and shape change [47, 76, 97].

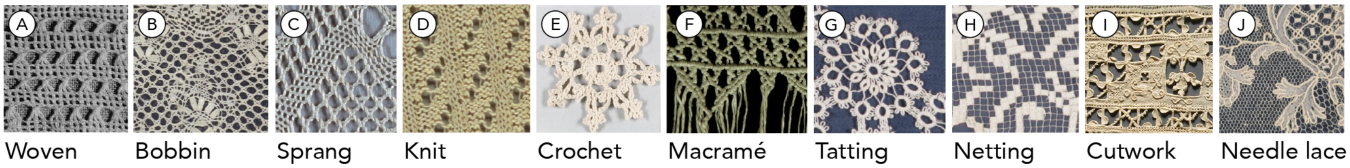

Figure 2: Laces are textiles defined by their negative spaces. Examples of lace fabrication techniques include (a) woven lace [16], (b) bobbin lace [6], (c) sprang [8], (d) knit lace [22], (e) crochet lace [12], (f) macramé [4], (g) tatting [11], (h) netting [13], (i) cutwork [3], and (j) needle lace [7]. Images courtesy of the Smithsonian and The Metropolitan Museum of Art.

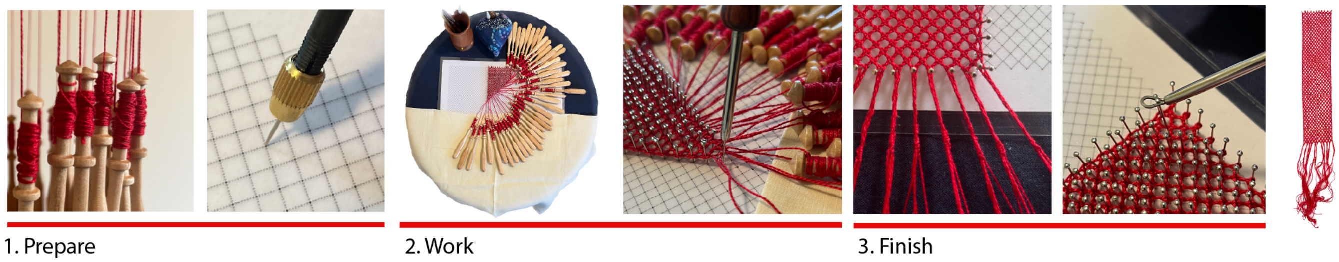

Figure 3: Making bobbin lace involves three phrases: (1) preparing the bobbins and pricking the pattern, (2) working the pattern by interlacing and pinning, and (3) finishing by tying off the threads and unpinning the pattern.

Laces provide unique opportunities for computing research due how they look and the "holes" in their design. These negative spaces and holes have fueled recent research in computer vision and image recognition of lace patterns [134, 135]. Lace designs are also used by HCI researchers for their ability to blend technologies into our home environment. For example, the History Tablecloth [46] and Digital Lace [120, 121, 127] projects used lace motifs (decorative patterns) to make interactive tabletop surfaces look less like "devices" and more like home furnishings. In this paper, we focus specifically on lace and e-textile affordances, leveraging bobbin lace's history of metal thread use.

2.2 Bobbin lace

Bobbin lace is a type of weaving "off loom" where instead of using a loom to hold threads in places, it uses temporary pins during the fabrication process.

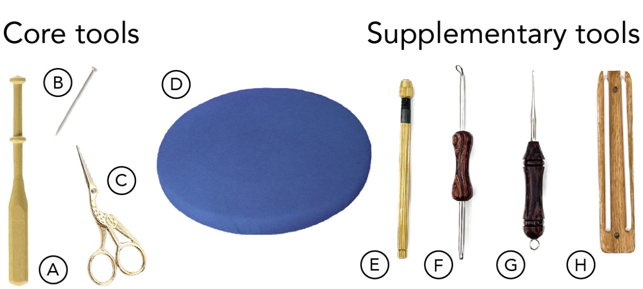

Figure 4: To make bobbin lace there are core tools including (a) bobbins, (b) pins, (c) scissors, and (d) pillow. There are also supplementary tools including a (e) pricker, (f) pusher/puller, (g) crochet hook, and (h) bobbin holder.

2.2.1 Tools. Bobbin lace is created with several core tools including bobbins that are wound in pairs, a pillow that lacemakers work the pattern on, and pins to hold threads in place on the pattern during the stitching process [43], see Figure 4. There are Do-It-Yourself options, such as replacing bobbins with clothing pins or creating your own with dowling and craft beads [52, 53], and replacing bobbin lace pillows with foam or cork. Beyond those core tools, many lacemakers use supplementary tools to make lacemaking easier [43]. A pricker is used to prick needle holes in their pattern for where the pins will go beforehand. A pusher/puller tool is used to avoid the calluses caused by repeatedly pushing pins into the pattern and pulling them out at the end. A small crochet hook is helpful for incorporating beads. When patterns utilize many bobbins, lacemakers also use bobbin holders to hold specific bobbins in place and out of the way when not actively stitching with them. Though advanced lacemakers often have an expensive full set of tools, the DIY options for core tools make lacemaking accessible for classroom and workshop settings.

2.2.2 Process. As summarized by Elberfeld [44], making bobbin lace involves three phases: (1) preparing the bobbins and pricking the pattern, (2) working the pattern by interlacing and pinning, and (3) finishing by tying off the threads and unpinning the pattern, see Figure 3.

(1) **Prepare:** Before a lacemaker starts lacing, there are preparation steps such as choosing your pattern (or designing your own), scaling your pattern to match your materials or choosing materials appropriate for the pattern, preparing your pattern by "pricking" where the pins will go, and winding the pairs of bobbins you will need for the pattern.
(2) **Work:** Lacing is the process of "working" the pattern, where a lacemaker follows the "pricking" and working diagrams,

and moves between interlacing the bobbins (stitching) and pinning to hold those stitches temporarily in place.

(3) **Finish:** Once the pattern has been worked, lacemakers finish off the pattern with knots (or "sewing" the end to the beginning in continuous patterns), then letting the lace "settle" for a period of time so that it will hold its shape, and then unpinning the lace so it can be removed from the pillow.

2.2.3 Stitches. Bobbin lace is a diverse practice with many geographic traditions. As a result, terminology for bobbin lace stitches differs depending on where you learn lace. A further area of tension for new lacers is that stitch terms can differ across interlacing techniques, for example a plain weave in weaving is often called cloth stitch in bobbin lace, though the end result is the same. To make patterns easier to read across cultural and making practices, pattern designers are increasingly focusing on the two stitch components (Cross[C] and Twist[T]), which together make up different bobbin lace stitches, see Figure 5. To further support this, working diagrams (which show individuals how to make a piece of lace and typically provide more information than the "pricking" pattern) are increasingly using International Colour Codes developed to annotate pattern instructions [25, 30].

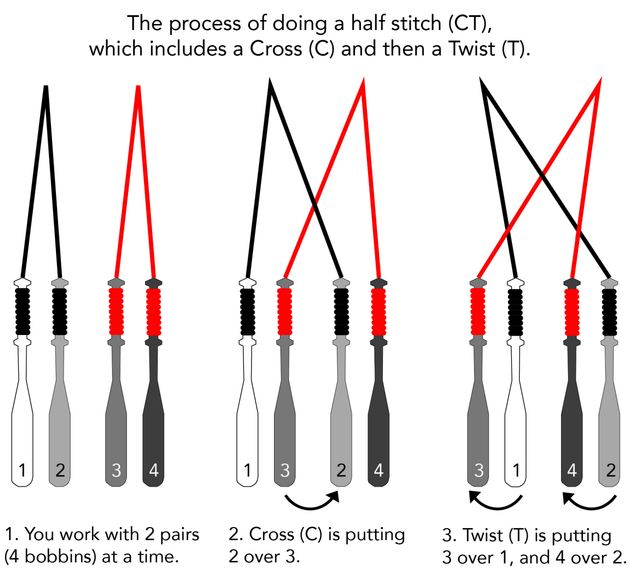

Figure 5: Bobbin lace stitches are made by working with 2 pairs (4 bobbins) at a time. Bobbin lace stitches are made from two stitch components: Cross (C) and Twist (T). Here we show the process of making a "half stitch" (CT).

2.3 Bobbin lace in computing

The unique stitches, tools, and processes for creating bobbin lace have received increased interest in computing in the areas of digital pattern making, digital fabrication, and automation. Digital pattern design further fosters and supports the hybrid craft ecosystem for hand crafting bobbin lace. Online design tools like GroundForge enable lacemakers to easily design lace grounds (repeating patterns) [106]. Researchers have also expanded possible bobbin lace patterns by developing mathematical models for bobbin lace [61, 62, 66], while also evaluating them to match practical design constraints (such as finding the patterns that can be stitched into lace [23, 64, 65, 67]). In the realm of handcrafting, researchers have explored how digital fabrication can support 3D lace with 3D "prickings" or patterns [17]. Researchers in architecture are increasingly exploring how automation with swarm robots can support large-scale bobbin lace [55, 78, 89, 132]. For example, replacing lace bobbins with robot bobbins for spatial lacing [128, 133].

Despite the history of metal thread use in bobbin lace, there are only a few examples of these materials being used for e-textile hand crafting, and all in the realm of media arts. For example, contributors to the E-textile Swatch Exchange have demonstrated the use of conductive thread as an inlay "gimp" thread that can be "woven" into bobbin lace [57, 80, 81]. Incorporating metal threads into bobbin lace can support new touch interactions, such as the pressure sensor dress series created by Anja Hertenberger and Meg Grant [56] or the star-shaped switch in Irene Posch's interactive e-textile book [108]. Novel materials, such as thermochromic colour-changing threads [84, 85] and electroluminescent wire [82, 93], enable lacers to make lace that visually transforms and responds to audiences. These projects demonstrate the expressive potential of bobbin lace for e-textile hand crafting, as well as the ability to craft interactive devices that look like they belong in our daily life and at varying scales (from small books to wearables to sculptures). In this current paper, we aim to dive into lacemaking practices (including culture, motivations for makers, and pattern design) in order to create more cross-disciplinary understanding of how HCI can leverage these expressive possibilities for future technologies.

3 Part 1: Bobbin Lace & Metal Thread

Researchers use a variety of methods to understand the material history of textile crafts. Understanding how metal threads were used in bobbin lace can give us inspiration for where, and for what, these materials might be well suited as well as how crafters collaborated and worked with the unique constraints of metal threads. For bobbin lace, researchers can trace the evolution of the craft through physical objects as well as through the analysis of wardrobe accounts [102], business records [21, 123], painted portraits [77, 94], fashion prints [36], and pattern books [34, 35].

3.1 Bobbin lace origins

Bobbin lace is unique compared to other laces in that it evolved from weaving and interlacing techniques, specifically braiding and passementerie, and as a result originally incorporated the silk and metal threads commonly used in those decorative applications [29, 90, 102]. Passementerie is a fine craft speciality that involved the creation of metal thread braids, cords, ribbons, tassels, and fringes that went on the edges of garments and soft furnishings [58]. Because bobbin lace evolved from passementerie, it was originally used in the same manner and with the same materials.

Figure 6: Examples of accessories with bobbin lace edges made of metal thread including: a collar [5], a pair of gloves [1], a purse [10], a embroidered box [2], and a nightcap [9]. Images courtesy of the MET Museum and the Smithsonian.

Figure 7: Pages from the first bobbin lace pattern book *Le Pompe* printed in 1557 in Venice, show bobbin lace patterns for creating lace borders and edgings. Image courtesy of the The Metropolitan Museum of Art [14].

3.2 Bobbin lace patterns

The rise of bobbin lace is intertwined with that of the printing press, which enabled bobbin lace patterns to quickly spread throughout Europe [77, 124, 125]. The earliest bobbin lace pattern books, *Le Pompe* (printed in Venice in 1557) (see Figure 7) [14] and *Nüw Modelbuch von allerley gattungen Däntelschnür* [1] (printed in Zurich in 1561) [118, 119], further demonstrate the use of bobbin lace for borders and edgings such as on cuffs and collars [34, 35] (see Figure 6). Importantly, compared to techniques like embroidery patterns, which could repurpose illustrations made for other purposes like illustrated books of plants and animals, bobbin lace patterns required an understanding of how bobbin lace is made, and therefore researchers can verify that these patterns were designed specifically for bobbin lace and its applications [125].

3.3 Bobbin lace in portraits

Paintings further demonstrate this use of bobbin lace as a decorative edging, and also the potential transferability of bobbin lace by evaluating the status of those who wore it. Early metal thread bobbin lace was mostly worn in portraits of secondary nobles or children, due to how bobbin lace edgings could be more easily reused and repurposed compared to the more advanced and desirable techniques of needle lace embroidery [117]. In this way, early metal thread bobbin lace was able to signify status and power in the same way that goldwork embroidery would have [77] but also provided flexibility since it was less permanent and could be transferred to other garments as needed.

[1] translates to "New Pattern Book of All Kinds of Bobbin Laces"

3.4 Value of metal bobbin lace

As bobbin lace patterns and techniques advanced, it became more desirable. In the 1600s royal wardrobe accounts increasingly mention items with metal thread bobbin lace edges of gold and silver [102]. This increased the demand and led to protectionist measures (defining where lace could be made) and sumptuary laws (defining who was allowed to wear it) in several European countries. For example, in England demand grew so great that there were complaints of individuals melting coins to make bobbin lace [90]. This metal lace was more valuable than the coins due to the slow process of making lace, and so metal thread lace created value both through the material and through the process of creation.

3.5 Summary and next steps

The history of metal thread use in the craft of bobbin lace points to unique opportunities for integrating metal threads into garments and furnishings. For example, the use of borders and edgings, as well as the potential re-use of these bands by transferring them between garments, could be useful design templates for e-textile designers to consider to support sustainability goals, as well as removable edges for laundering. At the same time, the history of the craft, and its unique pattern practices, demonstrate how it diverges from other crafts and has its own material culture of how it is made. As a result, it was important for us to dive into these cultural practices by interviewing lacemakers to understand how lace is made today.

4 Part 2: Interviews with lacemakers

Expanding on the history of metal thread bobbin lace, we interviewed lacemakers to better understand their current craft practices.

4.1 Method

Our research questions for this portion of the project included understanding what motivates individuals to create bobbin lace, and what they use the craft for.

4.1.1 Participants. We recruited participants by sending out a recruitment poster to a cross-country online bobbin lace guild with a request to disseminate it to their guild members. There was further snowball sampling [24] where members of the guild shared the study invitation with other bobbin lace groups or lacemakers. All participants had significant experience with bobbin lace. Before joining the study, they registered their consent to participate in research through an online survey that also asked them about their experience with bobbin lace **(see Appendix Table 1)**.

4.1.2 Procedure. The first author conducted individual interviews with bobbin lacemakers to understand how individuals use bobbin lace in their craft practices. These semi-structured interviews were conducted through Zoom and included questions such as: how individuals got into bobbin lace, what they make with the craft, and recommendations they have for beginners. Each interview lasted up to a maximum of 1 hour. We also had a photo submission form for participants to submit photos from their bobbin lace practice.

4.1.3 Analysis. The data included automatic transcripts and video recordings. We compared and verified the transcripts to the video to ensure that they matched, and then imported the anonymized transcripts into MAXQDA [48], for inductive thematic analysis as described by Braun and Clarke [26–28]. This involved coding the transcripts at the sentence level. Next, these codes were iteratively connected with relating codes to create subthemes and themes on what bobbin lacemakers enjoy about the practice (and their motivations for engaging in it) as well as challenges they experience. By analyzing the data in this way, we frame our findings as what HCI and e-textile researchers would need to know about current bobbin lace practices to engage in the craft.

4.2 Theme 1: Learning through making

Rather than using lace for specific applications, most participants discussed how they enjoyed lace as a textile puzzle to tangibly figure out. Their lace practice focused on discovering and learning through the process, rather than the end result. Most participants produced samples as tangible documentation of this process.

4.2.1 Enjoying the challenge of the process. Many participants were motivated to create lace to figure out how it is made and enjoyed the challenge of engaging in the craft. Participants described becoming interested in bobbin lace after seeing a lacemaker in action at *"a demonstration"* (P6) or seeing an example of lace that they wanted to further understand. The process of making bobbin lace was what drew them to the craft, and a fascination with wanting to comprehend how it was made. As P4 described the feeling of seeing a lacemaker in action: *"I was absolutely mesmerised. I thought: 'What on earth? How do you do this?'"*

Making bobbin lace involves *"figuring it out"* (P2), *"understanding where the threads go"* (P7) and interlacing them in a specific order. Participants enjoyed bobbin lace as this problem-solving process with *"complexity"* (P18), *"math"* (P9), and *"geometry"* (P11). As P20 described the precision involved: *"I think it's very pleasing how you could take what could very easily [. . .] become literally just a tangle of threads, and if it is tangled in exactly the right way it makes this pattern."* Though today there are more conventions on how to present patterns, participants described the puzzle of seeing older patterns and trying to decipher lace from historic sources such as the bobbin lace in painted portraits. The process of creating lace also has its own challenges. As P10 describes: *"You really have a lot of puzzles and a lot that you have to solve"*. Participants described enjoying the process because it is difficult – *"It has become my favourite activity because it's complex"* (P18). Lacemakers are looking to bobbin lace for a challenge, as P8 summarized: *"[It] fulfills that part of my brain that craves that challenge."* Within bobbin lace, due to the diversity of geographic practices and traditions, there are always more areas to explore and branch into. As P19 described wanting to continually expand their skills and challenge themselves: *"What can I make [bobbin lace] out of? What boundaries can I push? What different types of lace can I put together? So, it's all about trying to figure out, 'What can I do next?'"*

4.2.2 Sampling. Participants valued bobbin lace as a "process" – i.e., as an activity rather than a result. This was best exemplified by P21: *"For me, it's really about the process of making it, and less about the final piece."* While making bobbin lace, participants aimed to tangibly figure out how to stitch a pattern, as P9 described: *"I'm looking to have learned a technique usually. It doesn't matter if it's not quite right if I figured out what it was that I needed to figure out. Ideally it should be beautiful and pristine and perfect, and the joints shouldn't show and that sort of thing, but I'm quite happy if I've learned enough to do it right next time."* As a result, the most common activity participants engaged in was sampling to understand how the pattern and their materials worked together. As P19 described: *"I have to sample the pattern, because I always say that when I design something it's a theory until I've tested it out."* Participants tested whether the result would *"hold its shape"* (P17) and whether the material responds to the pattern as expected – *"Is it nice and equidistant, or is it bunched up?"* (P5). These samples were often stored in a binder with the pattern references and notes, as P17 explained: *"What I have produced mainly so far are samples [. . .] I put it in a sample book with the original pricking, any other notes, samples of the thread, and that sort of thing."* To do so, participants made bookmarks as a way of sampling a pattern at a manageable size. P11 made: *"bookmarks, bookmarks, and more bookmarks, because you can finish them and you can learn a technique"*. Even participants who made large-scale bobbin lace artworks would make small scale samples at bookmark size to test out the pattern before investing in it.

4.2.3 Bobbin lace is visually intriguing. Participants enjoyed *"the artistic side"* (P21) of bobbin lace. Compared to other textile crafts, bobbin lace was often used for artwork and aesthetic purposes rather than functional purposes (*"something pretty to look at"* (P5)). As P19 described how they engaged in the craft: *"You can make really beautiful things. That's what lace is [. . .] not exactly a functional item. It's just beauty, it's absolute beauty."* Finished pieces often went *"into a frame"* (P8) and then were hung *"on the wall"* (P10). As P21 explained how bobbin lace differentiated from other textile crafts: *"Bobbin lace is mostly a creative outlet for me. It's not necessarily always to make something useful. Knitting has been more useful (exploring how I can make my own clothing and that kind of thing). For bobbin lace [. . .] there is no purpose for this except the pleasure I take out of the process."*

4.3 Theme 2: An embodied practice

Bobbin lace engages the body including a lacemaker's concentration, eyesight, and other ergonomic factors.

4.3.1 Tangible enjoyment: lace making is addictive. Compared to other textile crafts, bobbin lace is a slow process – *"It's very slow and [bobbin] lace is probably at the extreme end of that spectrum"* (P9). Even experts who could stitch rapidly described the slowness of the craft, for example, P6 made artworks and their average progress was approximately *"an hour to do an inch"*. This is another reason why those who engaged in the craft emphasized enjoying the process of making lace – *"It's not something that's fast, so you've got to thrive on enjoying it in the moment* (P8).

Bobbin lace is a meditative activity that created a sensation where *"time flies"* (P7). As P20 described how it could engage them for hours: *"My brain is very happy to just sit down and do lace for hours and hours and hours, and then I look up and realize like, oh, I didn't eat lunch. I'm really hungry."* Bobbin lace, and its challenges, required enough concentration that it would keep lacers from worrying about other things. As P16 explained: *"It's very healing in its own way. If I've had a busy day [. . .] I can settle down. I don't have to worry about anything. I can just put time into this sort of thing. So, I just find it is a stress release."* Similarly, participants referenced the repetition in many bobbin lace patterns – *"it's highly repetitive, very beautiful, a lot of fun, and it's cool to see how it turns out"* (P19). Part of this experience is also auditory, where the bobbins chime together while being worked. As P6 talked about the movement and sound of making bobbin lace: *"There's a rhythm that goes into it so it's very relaxing once you get going on a project. Some of the bobbins I use make little clinking noises when you're using them, and so that gets you into a very relaxed state."*

4.3.2 Concentration. Lacemaking required concentration because it is difficult to fix mistakes that aren't caught right away. For example, when using thin threads, or threads of a similar colour, it can be tricky to reverse the stitches in the correct order while avoiding tangles – *"that's not worth trying to unpick"* (P19). If participants didn't notice a mistake in the moment, and it didn't impact whether they would have enough bobbins to complete the pattern, they would just continue. As P7 described: *"If it isn't too far back I will correct it, but if it is, just keep on going."* If the mistake impacted the number of bobbins available, then participants would need to correct to continue. P1 explained their thought process with this type of error: *"You have to reverse all of the [stitches] that you've put in, and sometimes it's very critical that you do go back and really follow along. So, you really have to be paying attention to what you're doing all the time."* Otherwise, lacemakers have to redo the entire piece, as P6 described: *"If I see it and I'm about an inch down, then I will probably take it out, but [otherwise] it either goes into the sample box, or I'll redo it. Depending on how important it is, it can be a little challenging, depending on the style of lace you're working on"*. Participants recommended analyzing your work as you are stitching it. As P8 recommended: *"I have always been a fan of admiring your work, and when I taught classes I would tell people: 'Take your time. This is not fast work. Admire it. If something looks off, then it probably is, and take a closer look and compare it to the surroundings'"*.

4.3.3 Lacing and the body. Bobbin lace pieces are often small with fine details, and as a result presented unique challenges for the crafter's body. The most frequent issue was awareness of one's posture, and avoiding hunching to see the details (*"my big problem is the hunching part"* (P5)). As a result, many lacemakers had a set up that supported seeing those fine details, such as having good lighting, tools to magnify their lace, and printing their picking patterns on a contrasting colour (or overlaying a contrasting contact paper) to make it easier to see their threads. Beginners often worked with colourful threads so they could more easily *"see how they move through the piece and get a sense of what the crosses and twists are actually doing"* (P10).

4.4 Theme 3: Innovation & experimentation

Lacemakers are increasingly exploring digital design, improvisational practices, and diverse materials.

4.4.1 Improvisational lace. Lacemakers discussed wanting to broaden into improvisational practices but many didn't feel ready (*"I just don't have enough experience to do it."* (P20)). Due to the complexity of lace, lacemakers often follow pricking patterns and stitch diagrams, though there were a few participants who already engaged in improvisational practices. For example, as their expertise increased, participants were able to recognize when they could swap certain stitches and begin to improvise. As P7 explained: *"You can take a pattern, and then change it to put different things in different elements."* A few participants designed their own patterns, where the improvisation happened before they started stitching. As P6 describes: *"I like to draft my own patterns and come up with my unique patterns. That part is very non-structured and sort of free form. When I get down to the actual making of it, that's where it's a lot more structured"*. On the extreme end, we had two participants who described doing bobbin lace over a picture. P5 described this type of improvisation: *"I'm just doing it free form, and by that, I mean I don't have a pattern or pricking to follow. I'm just using the picture itself, and I'm kind of winging it."* To support these practices, participants recommended using a grid, as P10 described: *"I have done a few where I take a photograph and put a grid over top of the photo"*. Having a grid structure helped participants to figure out what patterns might be possible and how many bobbins they might need to complete the lace. Overall, though most participants didn't currently improvise in their lace practice, this was discussed as an aspirational area they wanted to expand into.

4.4.2 Digital editing and pattern design. An emerging area of design exploration is digital patternmaking and editing (i.e. working with digital programs and vector-based design tools). Lacemakers used common tools, such as graph paper, photocopiers, and scanners, to support activities that previously would have taken a long time to edit manually. As P2 described: *"[You] do not necessarily need a computer, but the computer is just replacing other drafting techniques"*. A common pattern-editing activity is when lacemakers scale a pricking pattern to match the materials they want to lace. For example, using a thread with a thicker diameter than the original pricking means that lacemakers need to scale up their pattern, and vice versa. Most participants described doing this activity with a photocopier and many lacemakers still use this

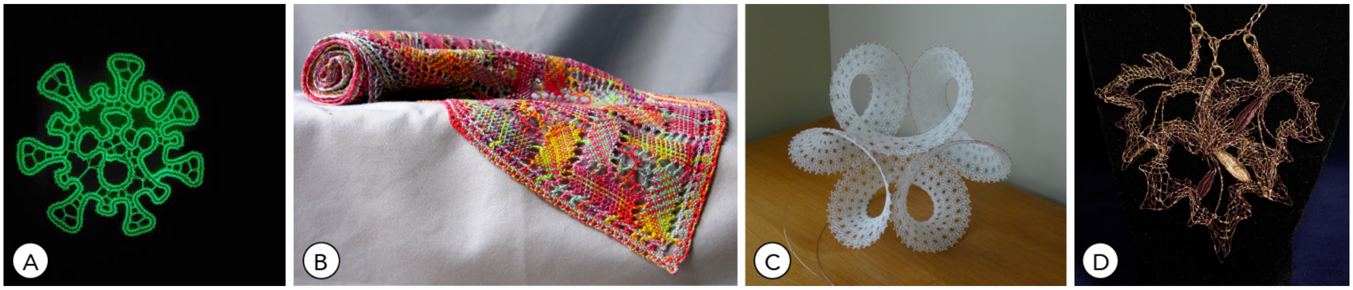

Figure 8: Today lacemakers play with materials and scale to bring bobbin lace to new applications, such as (left to right) (a) glow-in-the-dark threads, (b) yarn to create scarves, (c) wire to create sculptures, and (d) wire to create jewelry. Images courtesy of (left to right) Jenny Lyn Albers, Kathy Morgan, Veronika Irvine, and Josée Poupart.

Figure 9: Using a vector graphics program to design on an isometric grid can support more improvisation in the pattern design process. Image courtesy of Cajah Reed.

method for scaling. The benefit of vector-based tools (see Figure 9) was the ability to swap areas of the pattern, or grab portions of one pattern and combine it with another, and then scale them to match. As P19 described the importance of scale in bobbin lace patterns: *"the key is that it should be vector based so that you can make it bigger and make it smaller."* Participants who used vector patterns wanted to manipulate patterns, as P20 described: *"What I wanted to do is mirror part of the pattern, and then just make it sort of symmetrical. So, like manipulating the patterns, printing them, just changing the size of them. Like being able to say, I want this, but like 105% as big."* They described a collage approach, where patterns could be brought together in the software. As P21 described using GroundForge [106] for lace grounds and then combining those in vector tools: *"What I'll do is I'll import my GroundForge pricking. I'll import that into Inkscape, and then I'll end up printing that out and then doing the lace on that."* Vectors are also helpful for creating a symbol or pattern library that can be applied to new designs. As P19 described using vector design tools during a bobbin lace course: *"[The instructor] was talking about grid paper, and you need to draw this, you need to draw that. Instead, I'm going into [Adobe] Illustrator, and I'm going to create symbols. So, if I want this stitch, all I have to do is pull that symbol out, and it's already made correctly every single time."* From these vectors, it becomes easier to automate the manually intensive pricking process. For example, instead of pricking all the holes for a pattern you could send the vector file to create pre-pricked patterns with a cutting tool like a laser cutter. P2 knew a lacemaker who *"purchased a laser cutting machine, and she does her prickings, using the laser cutter"*. Though not part of the mainstream yet, participants discussed how bobbin lace was on the brink of a lot of separate digital innovations that when brought together would revolutionize the design process.

4.4.3 Material exploration. Bobbin lace as an artistic community is increasingly exploring diverse materials as bobbin lace increasingly blends with visual art practices. P19 noted this shift in their own practice: *"It has become something very different to me than when I began. When you begin, you're trying to figure out what [bobbin lace] is, [and] what you can do with it. And then, I began to think about lace as something that I could design, something that I could put my own personality in[to]. And more recently, as you can see with the grocery bags, it's 'What can I make lace with?'"* Artists are increasingly using bobbin lace for new purposes, for example, P6 used bobbin lace techniques with thick yarns to create scarves: *"I like to explore non-traditional yarns. So, how can I play with them and still create the same basic technique of bobbin lace."* Especially for artists who worked on more sculptural and 3-dimensional lace, they wanted to broaden the materials that bobbin lace could be applied to.

4.5 Summary and next steps

From these interviews we recognized many coproductions [41], and opportunities to blend the practices of bobbin lace and e-textile hand crafting. In particular, bobbin lace was described, and valued, by participants as a learning activity (a "puzzle" to figure out). Participants described themselves as individuals who enjoyed this process of figuring out the challenges of where threads go and how to interlace them. This growth mindset, of enjoying a craft as a learning activity, fits well with physical computing where making is also considered a learning activity. Participants also described material exploration and an interest in exploring what other materials they could make lace with, which provides opportunities for incorporating other novel materials into bobbin lace practices, such as e-textile material exploration.

There are also constraints or tensions with bobbin lace. For example, participants described how bobbin lace was difficult to "undo", which could create added frictions when combining these practices with e-textiles as it could make learning exercise more frustrating (i.e. having to start from the beginning or undo stitches). Compared to e-textile kits for hand-stitching, it is also harder to improvise with bobbin lace, and most lacers we interviewed described following patterns, which limits the customization opportunities that e-textile activities can provide. At the same time, this gap also provides a research opportunity for future creativity support tools to facilitate improvisation in bobbin lace. Our next step was to further explore these opportunities and tensions by developing e-textile bobbin lace samples.

5 Part 3: Interactive Samples

In e-textile research, sampling is a way of learning and practicing techniques [71, 73–75, 105], externalizing and communicating insights [49, 50, 57, 98], and getting feedback from others [126]. Rather than the creation of fully-functional devices, design researchers sample a portion (such as a specific actuator or sensor) to scale down and narrow in on specific design questions. For this portion of the research we used sampling to encourage discussion and gather feedback from lacemakers.

5.1 Method

We engaged in a Research-through-Design process that involved making interactive bobbin lace samples, and gathering feedback and recommendations for improvement from lacemakers. For this portion, we further engaged the same group of bobbin lace makers **(see Appendix Table 1)**, due to how bobbin lace guilds are designed for continuing education and feedback, and hold a wealth of specialized expertise on the craft. Rather than creating full prototypes, we focused on creating samples (N>200) to spark discussion with tangible examples to talk through.

Our research question for this portion of the study was how to combine e-textile and bobbin lace practices. This included focusing on (1) pattern readability (making patterns that were readable by bobbin lace audiences), (2) making e-textile samples that looked like traditional bobbin lace, and (3) designing e-textile components (i.e. printed circuit board [PCB] components) for bobbin lace.

5.1.1 Procedure. This study took 12 weeks and involved three phases that included 2 guild meetings dedicated to e-textile ideation and feedback, with RtD sampling by the reasearch team in between.

Guild Meeting 1: Initial Impressions (1.5 hours): During the group discussion with the guild, the first author spent 45 minutes introducing the group to e-textiles. Afterwards the group spent 45 minutes discussing tensions and opportunities for e-textile bobbin lace. The goal of this group discussion was to get first impressions on what parts might be difficult (i.e. tensions) and what parts might be well-suited (i.e. opportunities) when combining these two crafts together, and to inform our RtD sampling process. The data gathered from this session was the meeting transcripts.

RtD Journals (10 Weeks of Sampling): The research team spent 10 weeks creating interactive bobbin lace samples (see Figure 10) for guild feedback. Each member of the research team individually created bobbin lace samples and documented each sample with a weekly written Research-through-Design journal [103] that included the following headings: (1) what they tried that week with the bobbin lace resources they referenced, (2) process steps of what they made with documentation photos, (3) descriptions of what went well and what didn't, and (4) next steps. The research team then met weekly to share their RtD journals and insights. As a final step we developed interactive samples that aimed to explore how different soft sensors patterns from A-Kit-of-No-Parts [105] (including stretch sensors, push buttons, potentiometers, fold switches, and swipe switches) could be translated into bobbin lace patterns (see Figure 10). The data gathered from this process was 50 written RtD journals and associated experimentation samples.

Guild Meeting 2: Sample Feedback (1.5 hours): The research team conducted a group discussion with guild members where we presented interactive samples for feedback. For each sample we showed: (1) the draft bobbin lace pricking pattern, (2) stitching diagrams, (3) images and videos of the making process, (4) videos of the sample in action plugged into a microcontroller (for example, increasing lights with increased stretch), see Figure 11. The data gathered from this session was the meeting transcripts.

5.1.2 Data Analysis. Our data analysis included the anonymized transcripts from both workshops and 50 written RtD journals. For the transcripts, we first compared and verified the transcripts with their corresponding video recordings. We then conducted inductive thematic analysis in the same manner as Part 2, but with a focus on the insights from the sampling process and improvements and recommendations participants provided during the group discussion sessions. Recommendations were first grouped by similarity to create subthemes, and then into themes based on core principles of how bobbin lace is created and coproductions with e-textiles [41]. We structure the findings as the challenges that arose when combining e-textiles and bobbin lace together. By analyzing the results in this way, we aim to surface initial recommendations for individuals wanting to combine these practices. We include quotes from participants (P) and research team journals (R) to demonstrate our findings.

5.2 Challenge 1: Contact and connection

5.2.1 Designing for hard-soft connections. A common design challenge in e-textiles is creating hard-soft connections where "soft" textile materials (such as conductive threads or fabrics) need to attach to "hard" components (such as printed circuit boards (PCBs)). Participants described the ways that current e-textile toolkits (designed with buttonholes for sewing stitches) would need to be re-designed for the types of stitches involved in creating bobbin lace. Primarily, rather than sewing components on a textile surface, bobbin lace would involve braiding in components as beads (see Figure 12).

As a result, the diameter of the bead's centre through hole would matter, with a smaller center diameter resulting in closer and stronger connections with the inserted conductive thread. P9 described how the components needed to match the material being

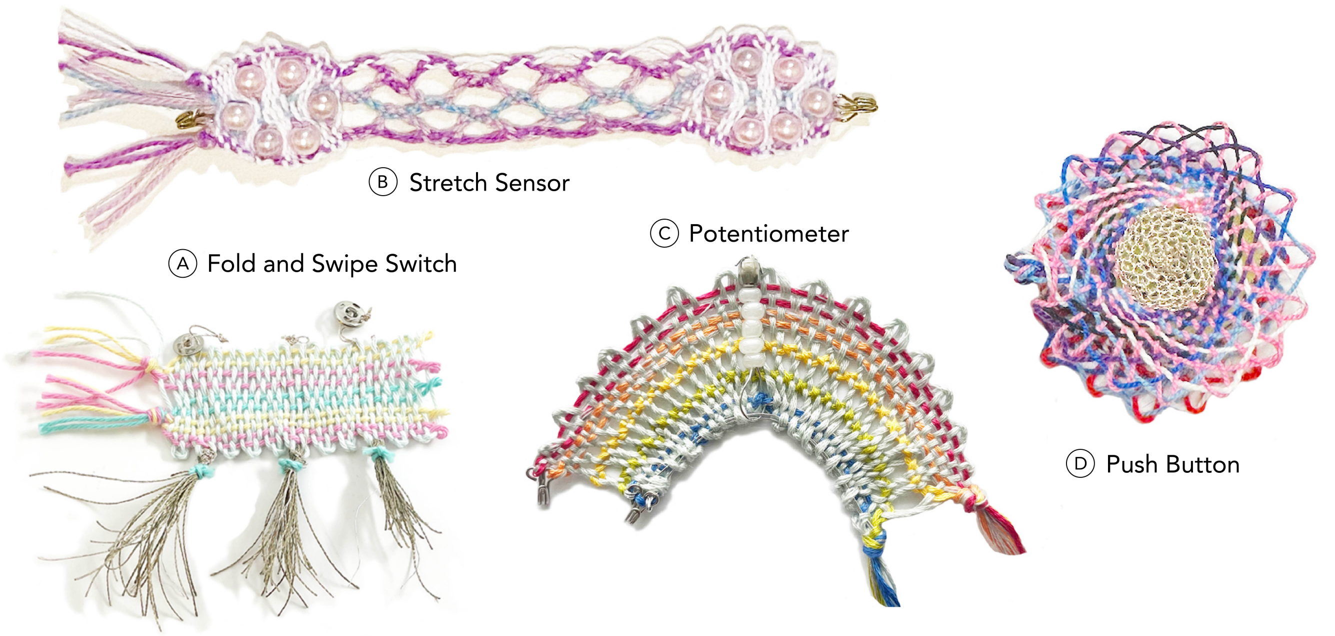

Figure 10: Some interactive e-textile patterns from A-Kit-of-No-Parts [105] that we transformed into bobbin lace patterns for guild feedback including (a) fold and swipe switch, (b) stretch sensor, (c) potentiometer, and (d) push button. Along with lace stitches, we also used other parts such as the conductive tassels for the swipe switch, beads in the stretch sensor, a long string of beads for the wiper in the potentiometer and wire to hold the structure, and sponge between two layers for the push button.

Figure 11: For each sample, we provided the following items for guild feedback: (a) bobbin lace patterns, (b) images with steps of the creation process, (c) photos of the final stitched sample, and (d) videos of the sample in action with an explanation of how it worked. This series shows the pattern, creation, and interaction of a bobbin lace stretch sensor with variable resistance thread.

used: *"You want the hole to be the right size for the fiber that you're using. [. . .] If the fiber is too thick for the hole, obviously you'll have problems getting it through. If it's way too thin compared to the hole size, your component is going to flop around."* To adjust for this, the research team explored different sizes of beads, and found that the strongest contact connections were made with smaller beads (to match the thread) and stitching the threads both before and after the bead to hold it tightly in place. As R3 discussed in their design journal: *"I discovered it is best to use smaller beads. When adding the bead, I did cross, twist, added the bead onto the right thread between the middle 2 threads, passed the left thread through the right side of the loop [see Figure 13], then did one last cross and continued on with the pattern."*

Figure 12: To transform LEDs into "beads" that could be laced, we curled up the LED's two "legs" into circular bead shapes. The smaller the circular hole, the better it held in place. Lacemakers recommended making the hole the same diameter as the thread or material you are using.

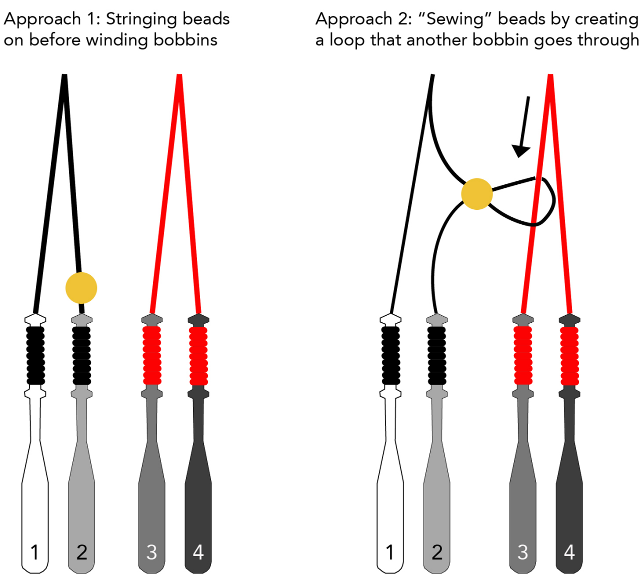

Figure 13: Beads can be integrated into bobbin lace in two ways. The first approach is before winding them. The second approach (recommended by lacemakers) creates more secure connections, and involves putting one thread through a bead to create a loop and then placing another bobbin through the loop. Lacers often use a small crochet hook to help with this task.

5.2.2 Stitches to hold. There are two different stitching methods for incorporating beads in bobbin lace. The first is to string them onto the threads before winding your bobbins, and then bring the bead into the lace pattern at the desired time (*"pop it up where I want it"* (P2)). The second is where a thread is put through the bead to create a loop, and then another bobbin is put through that loop. This second technique is called "sewing" in bobbin lace. As R2 described the issues with the first approach: *"When adding the beads, I planned how many I wanted and stringed them onto the threads before starting. They didn't sit very nicely or exactly where I wanted them to"*. The second "sewing" approach resulted in components that wouldn't flop around. As P8 summarized the differences in their own experience with beads: *"When you do a sewing on a bead, it's stable in place, whereas [when stringing beads on beforehand] those beads have the potential to move"*. The sewing approach required another tool, *"a crochet hook to loop the thread through the bead"* (R1), but made stronger connections.

5.3 Challenge 2: Predicting threads

5.3.1 Similarities to colourwork. Participants described the challenge of controlling conductive threads as similar to the challenge of "colourwork" in bobbin lace, where you want to know where each specific thread will end up to control the colour of the lace rather than the thread geometry. As P9 described the similarity: *"If you want to direct a conductive thread to a certain place, isn't it the same as if you were just trying to send a coloured thread to that place?"* When doing lace with colourwork, participants discussed how the pattern would include set up steps explicitly stating which colour of thread to place on which pin. As P12 described: *"When we are using different colours, the instructor generally tells us to hang [specific] pairs on the pins. You've got them marked up at the top [of the pattern]. For example, she would say, 'Hang 2 of colour A on the leftmost pin', and then so on all the way down the row. She tells us the setup for the colours right at the beginning."* Similarly, P2 (a lace instructor) described how she has students learn where the threads go by sampling due to the complexity of bobbin lace patterns: *"I make people do a colour study to see where [they] want each colour to go"*.

Figure 14: Predicting where threads will go can be difficult with bobbin lace. As a first step, we leveraged more predictable stitch types such as passive threads in CTC stitch and parallel zigzags with CTCT.

The challenges with colourwork highlight the difficulty of predicting where an individual thread will end up. As P18 described, it's more difficult to improvise with bobbin lace: *"I would want it mapped out exactly for every stitch. [You would] have to put it into your design and into your working diagram. Otherwise, you could have short circuits, and it wouldn't work. It could be done, but it also would get very complex depending on how fancy we're making your lace. You'd have to map those circuits, so they never touched in the wrong place, and they were always continuous to where you wanted them to go and what you wanted them to do"*. To address this, our initial sample exploration leveraged stitches that were more predictable and kept threads in a parallel formation. For example, the passives in cloth stitch (CTC) that would hang vertically. As R5 described this benefit: *"Since there are [multiple] passive threads in the cloth stitch that never touch, this presented an opportunity to have two conductive [parallel] threads in one piece of lace"*. Similarly, we used whole stitch (CTCT) to create vertical zigzag lines that remained parallel to each other (see Figure 14). Overall, the similar challenges between controlling material and controlling colour provide an opportunity to map out and sample potential e-textile bobbin lace patterns with colourful threads, and using colour to better understand where conductive threads might go in an e-textile pattern.

5.3.2 Leveraging "gimp" threads. Another solution that lacers suggested was to leverage the use of "gimp" threads in bobbin lace that would help with *"integrating"* (P23) conductive threads into the design of the lace. Gimp threads (also known as cordonnet) are typically a thicker thread that is used to provide an outline or more definition to a bobbin lace design. P2 described the way interactive gimp threads could add to the design: *"You could just have one wire going through to embellish the design itself. [For example], use that fairy light [string] as a gimp to outline a motif, and it becomes a lot easier to manipulate at that point."* Similarly, P10 recommended gimp threads for more control: *"You want to keep certain threads away from each other, and sort of guide threads along certain paths, and so one thing would be to look at gimps, which [are] something where we always control where the threads are going"*. Gimps are free to move separately from main lace geometry, so though they are held securely within the lace design, the lacer can control their direction and move them left or right as desired. So overall, though it can be difficult to predict where individual threads will travel with bobbin lace stitches, especially with more complicated patterns, gimp threads can travel in any direction and therefore provide greater freedom to improvise.

5.4 Challenge 3: Annotating patterns

5.4.1 Pattern representations. Though a pricking (the pattern placed on the pillow) is used to work and pin the bobbins, lacers described how it's not uncommon to work with more than one pattern representation when creating a piece of lace, and how e-textiles could leverage these different diagrams. So, a lacer might work with multiple representations of a pattern all printed on different pieces of paper. For example, along with the pricking, a lacer could have a "stitching diagram" that will have what stitches to make (such as CT, CTC, CTCT), and a "thread diagram" to illustrate where the threads go, which is especially helpful for more complicated patterns to verify what the lace will look like. As P6 described: *"Sometimes you'll get two diagrams together, one that you would actually make the lace on [the pricking], and the second one is basically your instructions."* P10 further described the differences between the different diagram types: *"A lot of the working diagrams, they're based on [the concept that] a line represents two threads. So, a line represents a pair of threads, and the international colour code, for example, is colouring 2 threads at a time, not one. [For] your conductive thread, they don't always have to stay together as a pair. You might need to go to the level of a thread diagram, where every individual thread path is there."* The thread diagram could provide more notation for conductive threads and components, whereas the pricking could be more about where to pin and what stitches to use.

5.4.2 Managing colour conventions. One area of tension between bobbin lace patterns and circuit diagrams (especially when designing for novice makers) is the differing use of colour coding conventions in both. For example, in bobbin lace, colour is used to demonstrate the type of stitch to use. As P12 discussed, pattern designers will often use *"a colour diagram that's internationally understood."* For developing bobbin lace patterns, lacers recommended using the lace colours, and representing physical computing patterns in a different way, similar to the symbols and icons on simplified circuit diagrams. As a result, the research team began using symbols to represent materials, such as a lightning bolt to show which bobbin pairs should use conductive thread.

5.5 Challenge 4: Maintaining lace structure

5.5.1 Maintaining negative space and structure. Adapting and scaling patterns to match materials is an important part of lacing practices that came up a lot with the e-textile material exploration. For example, if a pattern is not scaled correctly to the material, the stitches can become quite dense and more like a fabric rather than a lace, which is often defined by its negative space or the "holes" in the fabric. As P2 discussed during the feedback session: *"One thing I'm seeing here in terms of observation is the thickness of the thread relative to the pricking. So, the way you're doing that stitch. It is so dense that you cannot see it is lace"*. The research team came across this constraint while working with the e-textile materials, which were often a different thickness and stiffness when compared to the cotton threads we laced them with. As R5 wrote in their design journal: *"I learned the size of a pattern is very important, since if it is printed too small, the details of the lace get cluttered, while if it is too large, the design can be loose and stretched out."* When we wanted holes to be large, participants provided feedback that we could add more structure on the edges with denser stitches or adding extra twists to the pattern. As P12 described: *"Put in extra twists on the outer edge stitch."* Lacers also discussed the practice of "starching" their lace after completing it to keep structural integrity. As P23 described: *"We often lightly starch lace to hold the shape."* When requiring denser areas, such as conductive patches for push buttons, lacers recommended using lace motif structures of "tallies". As P2 described: *"This is basically the daisy and tally where there's a really tight weave in here."*

One of the benefits of using materials like wire is that it helped to strengthen and further maintain the lace structure along with providing conductivity. As R4 described how they incorporated wire into their pattern: *"I decided to use it almost as [the] boning or ribbing of my design [. . .] to create defined edges or support throughout a design and to add touch input "*. Wire could be worked into the lace or incorporated afterwards. As R1 described the finishing addition of wire: *"I weaved in a metal wire after the lace was finished to keep the shape"*.

5.5.2 Lacing with new materials. Beyond scaling and structure, the types of stitches you can use changes with each material. For example, when working with wire R2 noted how some bobbin lace stitches required too much bending and so patterns had to be

Figure 15: Bobbins designed by Richard Pikul for wire and gimp thread. The hole in the neck secures the wire for winding and the head holds and tensions it.

adapted to match: *"Stiffer materials proved to be more challenging to manipulate and twist around the pins. The shape of the crosses and twists didn't naturally form like how it did with the thread"*. R1 noted that wire would require different tensioning: *"The wire was much more difficult to work with, as it is not as relaxed as thread or embroidery floss as a material. It was not as forgiving, especially when trying to create tension in the stitches. It was also much more difficult to make the knots to finish off the sample in the end"*. As a result, lacers recommended using specific bobbins that are designed for use with wire (Figure 15) where hitch knots are not required to keep the material on the bobbin and to help with tensioning. Wire is a specialty within lace practices and lacers have unique movements for them that avoid excess bending. As P2 described: *"Manipulating the wire [. . .] for certain stitches I found I manipulate them differently than if it were a thread. The movement is sometimes a bit different, and one of the characteristics of wire is that once it's folded in place it's hard to change that compared to if you're working with fiber."*

5.6 Summary and next steps

Participants described how e-textile PCB components would need to be re-designed as beads to fit the stitches involved in bobbin lace. An important opportunity is that the requirements they described also match up with the PCB requirements of another type of common lacing technique - tatting. Previous research at TEI has explored how to design LEDs and other components as beads for tatting [107]. Due to the similarities in the requirements for these parts (including the orientation of the through holes, and designing through holes as "beads"), there is an opportunity to design a general "lacing" or "lacemakers" e-textile toolkit, rather than separate ones for these different types of lace.

Other important coproductions include the common pattern design choice of using "gimp" threads, which can move throughout a piece of bobbin lace more freely than the ground pattern, and as a result could be used when you want to control where a specific conductive thread will go. This expands upon previous e-textile bobbin lace samples developed for the E-textile Swatchbook Exchange [57, 80, 81], which leveraged conductive thread as gimp threads. Participants also described using wire (a metal and conductive material) in bobbin lace, and the tools already available for working specifically with wire (such as unique bobbin designs). These overlaps in current practices make it an exciting craft for e-textile integration.

6 Discussion: Opportunities for HCI

6.1 Collaborating with craftspeople

Initial explorations into e-textile hand crafts mainly explored what e-textiles could add to K-12 ***computing*** education to encourage more diverse engagement with computing and to teach computing concepts [68]. As e-textiles as a field advances, it becomes increasingly important to explore how the tools, materials, and patterns from the practice can be integrated into different textile crafting practices, rather than just using them as a tool to teach computing. K-12 education also focuses on a specific age group (from children to teenagers), whereas textiles are enjoyed by a wider range of the population, including adults and seniors [69, 74]. There is a lot that we can learn in HCI from looking to craft practitioners as experts and by valuing their technical expertise [38, 39]. Rather than reinventing the wheel, working with textile practitioners can help us get to innovations that integrate the practices of computing and textiles together [109, 110]. To reach these individuals, outreach with textile guilds is an excellent and underexplored resource for research collaborations, and these groups hold a wealth of expertise and knowledge. As discussed in previous work with quilting guilds, the culture of guilds provide a lot of benefits when it comes to feelings of inclusion and belonging while learning new things [96], which can support both the sharing of e-textile knowledge by HCI researchers and the technical expertise of craft practitioners. By engaging with textile guilds (both through individual interviews with members and group discussions at guild meetings) we learned more about what lacemakers enjoy about making lace and the intricacies of how to incorporate e-textile materials into bobbin lace patterns, while also sharing e-textiles with a group of interested practitioners. This research extends upon our previous collaborations in HCI with textile guilds. For example, one of our previous projects on hand-spinning e-textiles [72] aimed to understand what information spinners would need on e-textile materials to integrate these materials into their spinning practices, and further extend the customization opportunities that e-textiles provide. Overall, as e-textiles as a field advances into the particulars of each textile craft, guilds are an excellent way of understanding the intricacies and the aspects of a craft that practitioners value.

6.2 Tangible tools for bobbin lace

Though participants enjoyed the challenge of bobbin lace, and figuring out where threads go, they also described how difficult it was to get started with bobbin lace. One of the unique opportunities of bobbin lace is that there are many tools and accessories that could be augmented to support novices while learning to work the bobbins to create lace patterns. Similar supporting tools exist for other interlacing techniques in HCI. For example, the project BraidFlow [136] involved the creation of an augmented braiding disk that would guide users with colourful lights on how to construct braiding patterns, with a button to move to the next step (i.e. next stitch position). Augmented tools could include supports like highlighting which four bobbins to work with or the order of how to work a specific pattern. For example, the project Needle

User Interface [100] involved an augmented surface that would recognize when and where a needle went through it to support practicing embroidery stitches. Similar interactive surfaces could be created to recognize pin placement on the pillows used in bobbin lace, and to provide feedback on the next step in the pattern. Previous work examining the embodied effort and steps involved in bobbin lace [44] provides a starting point for researchers in the area of tangible user interfaces to further explore how tangible devices could help support these tasks.

6.3 Creativity support tools

Currently, bobbin lacemakers have creativity support tools for creating lace grounds [106] and Inkscape extensions for editing lace tesselations [63]. Here we highlight gaps for future design research, such as opportunities to support colourwork, scaling patterns to match material, and improvisational pattern design.

6.3.1 Simulating the path of specific threads in a pattern. Lacemakers described the challenge of understanding where a conductive thread would go in an e-textile pattern as similar to the challenges they currently experience with colourwork, where lacers want to control where a specific colour or material of thread will end up. This is an area that could use the computational support similar to that of tools that already exist for other textile fabrication techniques such as knitting [130] and weaving patterns [42, 45], where a user can visualize how a specific colour of yarn will show up in their pattern.

6.3.2 Scaling patterns to material diameter. A challenge that lacers experience when engaging in material exploration is the ability to scale a pattern to the material they are using, and this challenge also extends to material explorations with wire and e-textile threads. Similar tools exist for other textile crafts such as punch needle [37], a craft where the thickness of the thread (and resulting needle diameter) needs to match the density of the backing fabric. For example, PunchPrint [37] parametrically adjusts the pattern file for a 3D printed backing fabric to match the needle diameter that a user wants to use, and this expands the types of yarns and materials that can be used with punch needle crafts while still creating a structurally stable textile. The ability to similarly scale bobbin lace patterns would further support material exploration and experimentation in the craft, which is already an area that lacers are excited about.

6.3.3 Supporting improvisational practices in pattern design. In our interviews with lacers, participants expressed wanting to design their own patterns but also how this required a high level of expertise due to the complexity of bobbin lace. One opportunity here is the vast amount of work already done on developing mathematical models for bobbin lace [61, 62, 66], while also evaluating patterns to see which ones can be tangibily laced [23, 64, 65, 67]. Participants who created their own patterns described a collage approach, where they could take patterns from GroundForge [106] and the Inkscape extension Tesselace [63] and combine them together in vector software. Other tools support this collage type approach such as recent work on creativity support tools for improvisational quilting [86–88]. Node-based software for pattern designs like AdaCAD [42, 45] and Dynamic Toolchains [129] could also help support these goals by, for example, being able to grab a type of lace ground and place it onto a specific portion of one's design.

Another aspect of lace pattern design is that many types of lace have motifs. A current gap is helping individuals design their own patterns with customized motifs or images. For example, similar tools exist for machine knitting, where individuals can take photos from their environment and use these patterns for machine knitting [20]. Similarly AdaCAD allows individuals to upload images and drag and drop patterns (weave structures) onto specific areas [42, 45]. Other tools support sketching approaches to pattern design with the added benefit of verifying whether the sketched circuit will function [54, 92, 115]. Helping individuals customize their bobbin lace patterns would support creativity goals of personalization and self-expression, while also supporting further e-textile experimentation and integration.

7 Conclusion

Bobbin lace is a unique form of weaving that has the potential to extend how smart materials can be interlaced into textiles. In this paper, we provide an introduction into the opportunities and challenges that occur when bobbin lace practices meet e-textile practices. We first look at the history of how metal threads have been used in bobbin lace for design precedents we can leverage in e-textile hybrid crafting. In particular, the locations where metal-thread bobbin lace was used (as strips and bands) and the affordances of bobbin lace compared to other techniques (such as reusability and transferability). We then interviewed 17 bobbin lacemakers to understand what motivates them to lace and the challenges they experience. With a better understanding of bobbin lace crafting culture, we engaged in a Research-through-Design process of creating interactive bobbin lace samples alongside feedback sessions with members of a national bobbin lace guild. From our design journals and the feedback transcripts we discuss four main challenges that arise when trying to lace e-textiles, and how lacers recommended addressing them. Together, these three contributions (metal thread history, interviews with lacemakers, and e-textile sample exploration) aim to provide an initial overview of the opportunities and tensions that come from integrating e-textile hybrid crafting with bobbin lace practices and next steps for creativity support tools.

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A Participants

Table 1: Study participants, their bobbin lace experience in years, and the parts of the research project they participated in. Part two of the project involved individual interviews, part three of the project involved guild meetings for feedback.

ID	Experience	Participation
P1	7 Years	Interview, Guild Meeting 1
P2	30 Years	Interview, Guild Meeting 1, Guild Meeting 2
P3	20 Years	Interview, Guild Meeting 1
P4	29 Years	Interview
P5	6 Years	Interview, Guild Meeting 1
P6	15 Years	Interview, Guild Meeting 1, Guild Meeting 2
P7	25 Years	Interview, Guild Meeting 1
P8	26 Years	Interview, Guild Meeting 1, Guild Meeting 2
P9	3 Years	Interview, Guild Meeting 1, Guild Meeting 2
P10	30 Years	Interview, Guild Meeting 1
P11	7 Years	Interview, Guild Meeting 1
P12	10 Years	Guild Meeting 1, Guild Meeting 2
P13	20 Years	Guild Meeting 1
P14	30 Years	Guild Meeting 1
P15	35 Years	Guild Meeting 1, Guild Meeting 2
P16	15 Years	Interview, Guild Meeting 1
P17	28 Years	Interview, Guild Meeting 1, Guild Meeting 2
P18	20 Years	Interview, Guild Meeting 1, Guild Meeting 2
P19	11 Years	Interview
P20	30 Years	Interview
P21	3 Years	Interview
P22	3 Years	Guild Meeting 2
P23	7 Years	Guild Meeting 2