Learning with Stitch Samplers: Exploring Stitch Samplers as Contextual Instructions for E-textile Tutorials

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Figure 1: (left) A modern stitch sampler designed by Dropcloth Samplers used for learning embroidery techniques; (right) the e-textile sampler designed for this study for learning stitches and circuit basics.

ABSTRACT

The field of textile fabrication has a strong pattern-making culture that enables individuals to reproduce items at home. Electronic textile (e-textile) researchers within HCI are increasingly exploring how computing can leverage these textile pattern-making practices, accessible fabrication tools, and do-it-yourself (DIY) maker cultures to enable individuals to make technologies for themselves with soft form factors that further blend computing into our everyday environments. In this paper we focus on the pattern-sharing artifact of stitch samplers, which are used for sharing, teaching, and learning stitching techniques, and explore how the design decisions around them should be adapted for practicing e-textile exercises. To do so, we conducted three studies: (1) preliminary interviews with five modern stitch sampler designers to understand what stitch samplers are used for, (2) a think-aloud user study of our initial e-textile sampler with ten beginners, and (3) interviews with five e-textile educators to reflect on applications and to better understand the opportunities and limitations of using samplers for distance learning. This paper contributes a better understanding of how HCI researchers can incorporate craft pattern practices for learning hybrid craft techniques.

CCS CONCEPTS

• **Human-centered computing → User interface toolkits**.

KEYWORDS

e-textiles, textiles, crafting, hybrid craft, education, tutorials

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1 INTRODUCTION

Tangible, graspable user interfaces embed computing in everyday objects, enabling users to interact with computers in ways that leverage our physical skills and aim to bridge the physical/ digital divide [21, 42]. As a result, researchers in human computer interaction (HCI) are increasingly exploring the role that materials play in interaction design. For example, beyond what objects are physically made of, researchers are investigating the 'material experience' and material culture of materials, which includes their properties, practices, and the people who use them, including their skills and values [25]. When working with hybrid crafts (which blend crafts with computing), individuals collaborate with their materials and each craft field has its own practices for navigating or working with the constraints of their materials [89].

Electronic textile (e-textile) practitioners combine textile crafting techniques with electronic making and computing, making e-textiles one of the strongest examples of hybrid craft practice [56, 72]. Yet combining two fields of practice is not trivial, as each field brings with it its own methods of sharing, learning, making, and documentation [10, 78]. This has resulted in e-textile specific microcontrollers [8, 9, 60], toolkits [79], tools and supplies [77, 78], and swatches and swatchbooks for documentation[26, 34, 64] to help blend the two practices while utilizing insights from each.

This blending of technology and textiles brings new values to computing such as increased personalization and new application contexts that help broaden participation [43]. However, an underrecognized area of difficulty that novices experience is the tacit nature of working with craft materials, specifically skills like learning to hand sew with e-textile threads containing metal [46, 48]. On top of learning how to build circuits, novices must learn the skill of stitching, and creating successful systems is dependent on both skills. For example, stitches that are too loose will result loose connections and non-functioning circuits.

In this paper we use the material culture artifact of stitch samplers to explore how this textile learning method could be used with e-textiles (see Figure 1). Before the invention of the printing press and printed patterns, stitch samplers or embroidery samplers were tangible references that were used for learning, practicing, and demonstrating stitching techniques [88, 99]. Stitch samplers were made by individuals who had mastered a technique to then be copied by students and then repeated for practice [88]. What makes samplers unique compared to other embroidered objects is that they were a practice space for performing and demonstrating many different techniques on a single piece of fabric. Individuals usually had several samplers for different techniques, such as one for alphabet and numbers, needlework designs, and mending or darning [88]. These samplers were then used to demonstrate mastery of needlework, and could be used to teach others the same stitching techniques [99].

Today, samplers continue to be used for teaching and practicing stitching techniques. Commercially, stitch samplers with printed guides and instructions on fabric are now available to help individuals learn embroidery techniques without an instructor. Samplers also help individuals learn the tangible and tacit skills that are often difficult to convey and are used to guide individuals through the process.

In this paper we discuss three studies that help us to understand what stitch samplers are, how they need to be adapted for e-textiles, and reflections from e-textile educators on constraints to consider for their use in workshops and courses. The first study consists of interviews with modern stitch sampler designers (n = 5) to better understand their motivations for designing samplers and how they are used. We then apply the design techniques from these modern stitch samplers to an e-textile sampler we designed, and evaluate it with novices (n = 10). We then interviewed expert e-textile educators to discuss their learning goals with e-textiles in the classroom, and the opportunities and limitations of samplers (n = 5).

Research question: Though previous work on samplers and swatches has focused on demonstration samplers to communicate, share, disseminate and record techniques [16, 26, 34, 64, 97, 98], this paper focuses instead on practice samplers and how novices can learn and practice techniques through samplers. Our overarching research question is the following: ***'How should we design practice samplers to help individuals practice the tacit skill of stitching while learning how to make e-textile patterns?'***

This study is timely, done one year into the COVID-19 pandemic, the interviews gave designers, novices, and educators the opportunity to reflect on tangible tutorials, and how textile and e-textile education has needed to adapt for online and distance learning. The unique challenges of this time gave us a window to further explore how tangible computing and hybrid crafts could be taught in distance learning settings, and how we can better prepare for them in the future.

There are several benefits to stitch samplers that make them ideal for use in workshops and courses:

(1) **Easy to produce:** With the large amount of print-on-demand fabric suppliers around the world it is accessible and locally-reproducible for educators to design and print off their own. Locations without print-on-demand fabric suppliers can also reproduce the samplers with DIY screen printing techniques.
(2) **Low cost:** Printed fabric samplers are relatively inexpensive at approximately $1 USD per sampler fabric square or "page".

With these benefits in mind, this paper contributes a customizable, reproducible, and scalable way to create e-textile tutorials with instructions in-place. This project demonstrates how HCI researchers can leverage craft and material cultures to develop new ways of creating hybrid craft tutorials.

2 RELATED WORK: LEARNING WITH SAMPLERS AND HYBRID CRAFTS

This project lies at the intersection of recent discussions in HCI on tangible tutorials and e-textile learning scaffolds. Scaffolds in the field of Tangible User Interfaces (TUIs) [42] are props and tools that help us think through problems [37, 40] and are helpful for novices in how they support and "scaffold" their learning. One of the benefits of TUIs [41, 42] is that they emulate how we interact with the physical world around us. For e-textiles specifically there are many different types of learning scaffolds including systems, toolkits, tools, and swatches and samplers, that enable novices to build e-textiles without e-textile expertise, as well as to support e-textile experts in learning new skills. These scaffolds help individuals ideate on possibilities, design and iterate concepts, build out e-textile prototypes, or learn new techniques.

2.1 E-textiles in Education

E-textiles combine the crafting cultures of physical computing and textiles [7, 10, 80], and expand the types of materials, tools, and patterns that individuals can use to make interactive devices. E-textiles change common perceptions of how technology is made, what it looks like, and how it feels. Notably a handcrafted approach to technology enables novices to customize their technology, leverages previous craft-based learning, and provides more transparency around how circuits work [75].

The first e-textile microcontroller and toolkit, the Lilypad Arduino, added sewable through-hole pins to a circular Arduino and made it easier to work with conductive textiles and materials [8], as well as to share e-textile tutorials around the same infrastructure [9, 60]. Since then these sewable designs have inspired a wide variety of educational e-textile toolkits that leverage common sewing patterns and supplies such as pins and snaps [79]. In a meta-synthesis of e-textile research over the past 10 years Jayathirtha et al. [43] found that the use of e-textiles in education broadens participation by challenging computing stereotypes (such as the skills and tools needed, and locations where computing devices get made), and helps to sustain student interest by expanding computing applications and disciplines.

2.2 Hybrid Crafts with Instructions in Place

There are many mediums for providing hybrid craft tutorials and guides such as books [11, 33], swatchbooks [34], websites [60, 75], applications [59], and projected in-situ guidance [81]. The benefit of projected in-situ guidance is that instructions are provided on the medium of the craft enabling a more direct and hands-on method of instruction [81]. For our project, we were inspired by modern samplers and paper circuit toolkits for how they scaffold craft-based learning. One excellent example of instructions in place is the Chibitronics paper circuit toolkits [85–87]. Chibitronics are circuit stickers that come with a booklet with guides and instructions for how to lay out the various circuits. Because paper is the medium of the platform, it is an ideal way to provide instructions in place and address potential issues. With the e-textile stitch samplers, we aim to provide the same type of support with the instructions being placed on the same medium as the toolkit – on the fabric.

2.3 Textile Patterns

The field of textile fabrication has a strong pattern-making culture that enables individuals to reproduce items at home. Pattern-sharing has existed within textile maker culture for centuries (such as knitting, crochet, and weaving patterns that could be manually marked down by hand and shared for others to recreate), but automation in pattern making enabled more widespread growth. For example, in the early 1800s, punch-card patterns for Jacquard looms automated and industrialized woven textiles, enabling faster reproduction of complex patterns [20]. On a more personal scale, the paper pattern industry in the early 1900s and the creation of affordable sewing machines led to a “democratization of fashion” [100] where individuals could recreate the latest fashions for themselves.

Within HCI, the ability to share patterns to be physically reproduced elsewhere is one of the key markers of the digital fabrication revolution [24, 66]. As a result, researchers have been exploring digitizing textile patterns such as the creation of AdaCAD software for digital looms [23] and Sketch&Stitch for digital embroidery [31]. The digitized patterns have also enabled new interactions possibilities such as embroidery games [1, 58], live participation and data inputs [2, 55, 83], incorporating found materials [3], and combining textile fabrication with other rapid prototyping pipelines such as 3D printing [14, 30]. Researchers have augmented digitized patterns with guided instructions and error correction such as Aesthetic Circuits where individuals can draw out an e-textile circuit and confirm their design before stitching [59], and Needle User Interface which is an augmented embroidery hoop for verifying stitch placement [69]. These projects demonstrate the value of not only sharing patterns but, especially for hand crafts, also providing instructions and guides in place.

2.4 Social Practices in Textile Making

Though pattern sharing has enabled individuals to recreate items at home, learning textile crafts is also a social practice. Historically for embroidery, individuals replicated and learned from the physical stitch samplers of a more experienced embroiderer, who both shared their samplers as well as taught techniques [88]. Though stitch samplers were once part of formal training and schooling, and became proof of one’s stitching skills for applying to household jobs [88], today textile handcrafts are often done for leisure within DIY communities [44, 94]. As a result, many textile craft groups gather for social interaction around a shared interest such as quilting bees [38], knitting circles [94], and textile craft guilds [93]. Makerspaces have also become sites for social craft activities, such as repair cafes where individuals bring their own items in need of repair and learn techniques from more experienced menders [17, 18, 71], or sewing cafes where individuals can learn more about textile tools and techniques[36]. Though these meetings might have teaching or workshop activities, participants also value them as opportunities to meet new people and socialize [45, 71].

Increasingly, textile crafting communities are incorporating technology and moving online [57, 96], a direction that has been further accelerated by the COVID-19 pandemic [12, 44]. For example, even before the pandemic, individuals could learn technical craft skills through online tutorials and video platforms [96]. Specific platforms aimed at maker communities such as Ravelry, Craftser and Instructables enable individuals to both learn techniques as well as share their own work, and DIY selling platforms such as Etsy enable makers to share patterns and crafted objects for profit [57]. Crafters are not only crafting but also “lifestreaming” their craft by documenting and publishing the process, while getting feedback and support along the way [4, 54, 62, 63, 73]. These logging practices further heighten the use of crafted objects as markers of time and memories associated with the making process [73, 90, 91].

During the COVID-19 pandemic makers made use of these digital platforms for community making initiatives such as DIY cloth masks [12]. Online and video tutorials also became the dominant form of running synchronous craft workshops as in-person workshops were no longer safe [44]. Textile craft instruction techniques shifted to favouring overhead cameras, and samplers which instructors had designed for in-person sharing (where samplers could be physically passed around) now needed additional instruction [44]. In this paper we further explore how samplers need to be adapted for distance learning when student and instructor are not co-located in the same space.

2.5 E-textile Samplers in HCI

Previous work has identified three types of samplers that textile educators use to teach stitching techniques [44]. These samplers make up the ecosystem of textile samplers and include:

- **Practice Samplers:** Activities that individuals do to learn and practice a technique,

- **Sampler Swatches:** Used for demonstrating a technique, and
- **Wearable Samplers:** Example garments using a technique so students could see it in-situ.

In the context of e-textiles, for **practice samplers**, a Kit-of-No-Parts [75] was one of the first to demonstrate how samplers could help teach novices how to build e-textile prototypes. A Kit-of-No-Parts [75] is an approach to teaching e-textiles that uses raw materials and combines them with craft techniques to increase personalization and help with skill transfer. The approach was presented through tutorials and samplers (crochet potentiometers, felted pompom pressure sensors, etc.) that helped individuals understand e-textile potentials, but unlike the previous projects which used these potentials just for ideation, with a Kit-of-No-Parts beginner workshop participants could then recreate the techniques presented in online tutorials while also customizing them to their own concepts. Similarly, in e-textile courses some instructors have used the creation of samplers and swatches as a method for students to apply the techniques learned throughout the course [84]. Other than A-Kit-of-No-Parts and individual course case studies, there is limited research on how practice samplers with activities can be used to support e-textile education and help individuals practice the tacit skills involved with e-textile creation.

Within e-textile research the focus has been on the second, **sampler swatches**, with e-textile examples used as demonstrations for cross-disciplinary collaboration and ideation [15, 26, 92, 101], for sharing techniques and materials among experienced practitioners [34, 77, 98], or for experiments and documentation of design process[28]. Previous work has used swatches and samplers to ideate a wide variety of textiles including touch-sensing textiles [74], colour-changing textiles [16], shape changing textiles [29, 68, 97], knitted controllers [61], non-wearable textiles [65], and textile physical affordances [64].

Wearable samplers, where a technique is shown on an example garment (in-situ), is common in usability studies for probing possibilities and getting feedback from potential users. Examples include wearable samplers to demonstrate sensors like touch sensing [52, 82], and actuators like soft speakers [67], colour changing textiles [22, 32, 39], and shape changing textiles [51]. Some e-textile toolkits, like Wearable Bits [47], can move between sampler swatches and wearable samplers by having swatches that can connect to make garments. Though wearable samplers are commonly used for usability studies, their use as educational tools is underexplored.

3 STUDY 1: UNDERSTANDING MODERN STITCH SAMPLERS

In recent years, stitch samplers have become popular again but now with added printed instructions and guides. We call this trend modern stitch samplers to differentiate them from their hand-stitched predecessors. These instructions and guides can be printed on fabric, iron-on fabric transfers, or water-soluble transfers. The benefit of modern stitch samplers is that they both provide the pattern as well as added guides and icons to further explain the steps.

3.1 Methodology: Expert Interviews with Designers

3.1.1 Research Question (Q1): What are the motivations behind the design of modern stitch samplers and how are these artifacts used, i.e., what are they used for?

3.1.2 Participants: To better understand the motivations behind modern stitch samplers and how they are used, we interviewed five stitch sampler designers (D1-5) who use different techniques to provide stitching instructions in place (including printing ink on fabric (n=3), printing chalk on fabric (n=1), and water-soluble transfers (n=1)). We recruited our designers through email and included individuals who have designed stitch samplers and sell them as kits online. Two sold samplers exclusively through Etsy, one only through their own website, and two through both Etsy and their own website.

3.1.3 Procedure: We conducted 30-minute semi-structured interviews through video calls (Zoom) where we asked participants a set of 9 questions that included: their background and motivations for designing samplers (how did they learn embroidery and stitching, how did they decide to produce samplers, how they use printed samplers), their design process (how they came up with their sampler design, the materials included with the sampler, materials they expect individuals to already have, and the populations they are designing them for), feedback they received from customers and purchasing trends, and their future plans for their sampler products. We obtained clearance from our institutions' research ethics board.

3.1.4 Analysis: We used orthographic verbatim transcription to transcribe 3 hours of video recording using Zoom transcription [13], and the first author reviewed and edited all transcripts. We then performed reflexive and inductive thematic analysis as described by Braun et al. [5, 6] that aims to generate analysis from the bottom up (in this case our interviews around what modern samplers are used for) rather than around existing theoretical frameworks. This approach emphasizes the active role of the researcher in meaning-making, where coding is an iterative process rather than made with a codebook [6]. This first involved familiarization and immersion in the data with reading and notetaking, and then an initial coding of the complete dataset with line-by-line data-derived semantic codes for each quote that aimed to mirror the language and concepts our participants discussed. These were coded in MAXQDA which enables easy iteration of codes [27]. With this initial list of codes, we then grouped them into central organizing concepts to create themes. These themes and subthemes were reviewed to create a thematic map. This thematic map was then used to develop the final themes on current uses of modern stitch samplers with codes and data extracts. We used this form of data analysis in all three studies.

3.2 Theme 1: Samplers Make Embroidery Less Intimidating

3.2.1 Samplers as embroidery introduction: All of our participants started off their careers leading embroidery workshops or making customized products or embroidery toolkits. After working on their initial embroidery products, they then developed samplers to help ease students into embroidery. D1: *"I was getting feedback from people that they were a little bit scared to just jump right in [. . .] because they didn't know how to stitch"*. Once completed the sampler then becomes a *"reference to go back to for future embroidery projects [. . .] when you are doing something else"* [D3]. This means that when users get to the step of embroidering an actual object or applied project they will have something to review and remember the steps of the stitch.

3.2.2 Helping with planning and preparation: Designers described samplers as *"instructional guides that [. . .] illustrate all of the stitches"* [D1] with the *"direction or the path"*[D4] to follow. In workshops before developing samplers, users often *"wrote down notes"*[D3] beside stitching exercises to remember how to do them later on, and samplers replaced this activity by already having pointers in place. D5: *"it cuts down on the time that it takes"*. Samplers are especially useful for novices who tend to skip the step of *"preparing for a project"* [D5], for example with textiles it is common to mark out a design with chalk before starting. These marks become a way of prototyping a design before stitching it in place. D4: *"that's one of the nice things about the samplers – they have the design worked out for you, so you don't have to think"* and can *"see the results right away"* [D5].

3.3 Theme 2: Modern Samplers as Reference Translation

All our participants discussed learning stitches from books, and then realizing that transferring the patterns onto fabric would make them easier to teach and disseminate. The development of modern stitch samplers is to a great extent an outcome of printing technologies. Half (n = 3) of our participants had backgrounds in printmaking and screen printing, and the others used computer printers to print their designs on fabric or fabric transfers. For example, D2 *"had already been selling digital download patterns of [their] designs and wanted to create printed fabric samplers because it's much easier than transferring the pattern"*. All participants used books as reference material (*"researching old textbooks"* [D3]) and saw printed fabric samplers as the next step to bring these stitching references to modern audiences to *"inspire people to use different textures and stitches that they wouldn't normally come across"* [D1].

Along with reference books, many participants learned how to teach the stitches from online videos. Three participants had received requests for video tutorials to go along with the samplers. D1: *"a piece of feedback I've gotten all along [is requests for] video tutorials"* and *"visual demonstrations"* [D4]. Though the samplers provided good guides and paths for where to stitch, users emphasized that videos helped *"explain things in another way"* [D3]. Other than supplementary video, the samplers did not require external tools only *"embroidery hoop, embroidery floss, and an embroidery needle"* [D2].

3.4 Theme 3: Samplers as a Continous Learning Platform

Many participants emphasized that though samplers are useful for novices, they can be used at any stage for learning new stitches and doing more advanced activities. All participants produced multiple different types of samplers, with three having monthly sampler clubs so that users can constantly expand their stitching skills. Novices will purchase more *"labeled samplers"* [D2] and as individuals get more experience the samplers can have more *"abstract designs"* [D3]. This continuous learning demonstrates how samplers can help individuals throughout their textile journey – *"anybody at any skill level can do it"* [D4].

3.5 Summary

Overall, our stitch sampler designers described stitch samplers as a way to take printed patterns from books and other materials and reproduce them in place. These stitch samplers supported novices because it gave them a pattern to start from, rather than having students chalk and mark one out beforehand. Because they are designed as practice projects, rather than final-end projects, they are a good introduction to stitching for those who have not stitched before, but can also be used for more advanced stitchers who want to learn new techniques. Finally, students would like samplers to be even more visual with added guides and videos.

4 STUDY 2: EVALUATING THE E-TEXTILE STITCH SAMPLER

Based on these initial interviews, we hypothesized that stitch samplers would be a useful way of guiding e-textile novices through initial exercises – to translate stitching references and instructions onto the fabric they would use for practice. Printing on fabric is an inexpensive way for educators to provide instructions and reference material for students.

4.1 Designing the E-textile Stitch Sampler

For our study, we used a commercial print-on-demand fabric supplier. We uploaded our file and then ordered several meters of sampler fabric that we then cut up into rectangles approximately 8.5"x11" (which then became less than $1 USD per sampler). We designed this initial sampler using the same techniques as the designers used in their modern stitch samplers (and which we describe below). In this study, we further explored how sampler designs might need to be altered to suit this hybrid context of learning the stitches, but also making a circuit. This exploration will also provide design guidelines for more augmented e-textile tutorials for future research.

To design our stitch sampler we made the following design decisions:

- We reproduced the following design decisions from the modern stitch samplers designed by the five designer participants: black guides on white fabric (with permanent ink so they could be used later as reference notes), introducing stitches before going into applications, large practice stitches before small ones, showing directionality with arrows and alphabetized steps, and notes in place.
- For this beginner e-textile sampler, the five activities on the sampler included: (1) how to use running stitch to make traces, (2) how to use satin stitch to secure printed circuit board (PCB) component through-holes, (3) the design of a simple circuit, (4) the design of a parallel circuit, and (5) the design of a simple circuit with switch.

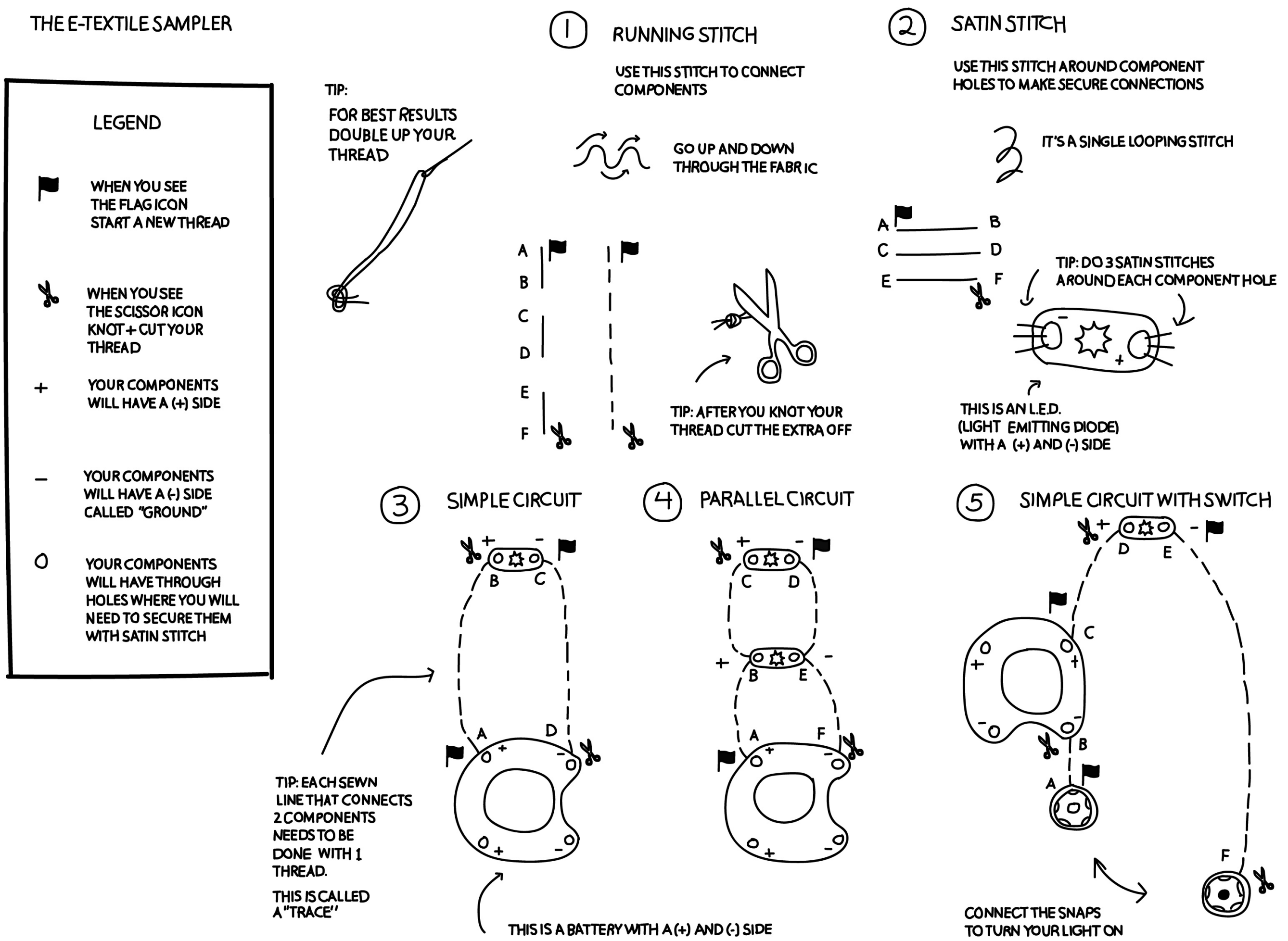

Figure 2: The E-textile sampler design file before being printed on fabric: The top row (Activity 1+2) teaches individuals how to make the stitches needed for making a robust e-textile circuit. The bottom row (Activity 3-5) covers how to make a simple circuit, a parallel circuit, and how to make a switch.

- The in-place instructions included: the polarity of components with power (+) and ground (-), that traces must be unbroken to make secure connections, to avoid shorts by cutting excess threads, and to avoid shorts by starting and stopping threads at specific times.

4.2 Methodology: Think-Aloud Protocol with E-textile Novices

4.2.1 Research Question (Q2): How should we design e-samplers and how do they need to differ from traditional samplers to support e-textile learning?

4.2.2 Participants: To understand the beginner experience of e-textile samplers, we conducted a study with 10 adult e-textile novices (P1-10), i.e., individuals who have never used e-textiles before. Our participants were recruited from a study participant mailing list for individuals interested in participating in studies. All the participants in the study were electronics novices but we also included those with sewing experience so they could provide feedback on other materials to include in the kit, as well as other instruction methods they might recommend.

4.2.3 Apparatus: To adhere to pandemic protocols, we did contactless drop-off deliveries which included the sampler (see Figure 2), 2 sewing needles, 2 snaps, 5 sewable LilyPad LEDS, 3 sewable LilyPad battery holders, 3 batteries, and a bobbin of conductive thread (see Figure 3).

4.2.4 Procedure: We then conducted 90-minute videos calls (on Zoom) with participants where we used a think-aloud protocol to get their feedback while they worked through the exercises. This protocol involves asking participants to verbalize their thoughts

Figure 3: The supplies sent to the participants with the sampler: 3 battery holders, 3 batteries, conductive thread, 2 snaps, 5 LEDs, 2 sewing needles.

throughout the session. We gave participants a safety tutorial at the beginning (e.g. batteries should not be ingested and thread should not be licked) but otherwise we did not give any verbal instructions or guides other than the fabric sampler. During the think-aloud activity if a participant forgot to think-aloud, or presented a change in facial expression, the first author probed them to verbalize their thoughts with questions such as "What are you doing/thinking?". If a participant asked the researcher a question about the sampler, the first author responded with "What do you think your next step should be?" After they completed the sampler we asked them clarifying questions about the features of the design they had discussed during the think-aloud activity, as well as whether there was anything missing from the sampler that they would like to see added.

4.2.5 Analysis: We used orthographic verbatim transcription to transcribe 15 hours of video recording. We then performed inductive thematic analysis as described by Braun et al. [5] with the same method for all three studies (see 3.1) that included notetaking and familiarization, an initial line-by-line data-derived codes for each quote, an initial list of codes and themes to develop a thematic map, and then a list of final themes on the beginner experience with e-samplers. Our analysis focused on semantic codes that mirrored the language of our participants as they went through the exercises.

4.3 Theme 1: Samplers as Communication Tool and Reference

4.3.1 Alphabetized Steps. Even though the researchers could not see participant's samplers while they were doing the activity, we were always able to tell where participants were and what aspects of the sampler they were talking about. This happened because all participants immediately used the markers and terminology present on the sampler when discussing the process even though they were not asked to do so. Our results suggest that samplers would aid in virtual video call debugging between student and teacher. The alphabetized steps on the sampler helped participants communicate where they were stitching and how they were building their circuit. All students used the alphabetized steps to communicate the step they were at. For example, when P10 described sewing one side of the parallel circuit (see Figure 4): *"start with satin stitch at A, running stitch to point B, then satin stitch [at B], then running stitch to C with one continuous thread"*. During this distanced activity the alphabetized steps gave participants a reference point for discussing each micro-step within each activity.

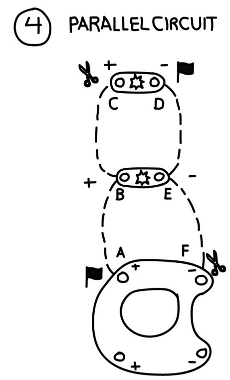

Figure 4: Illustration of parallel circuit activity.

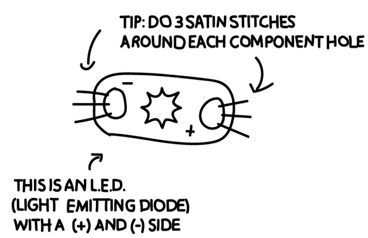

Figure 5: Terminology: "This is an L.E.D."

4.3.2 Terminology. Once a component or stitch was introduced to participants in the sampler, they then used that terminology to describe the component or stitch throughout the rest of the activity. For example, once a battery holder or L.E.D was introduced, participants then referred to the component as that term. This was noticeably absent before they reached that step. For example, before P7 reached the first simple circuit where the battery holder was introduced, they called the battery holder *"the purple thing"*, and P10 also used the term "lights" before L.E.D.s were introduced (see Figure 5). The most common piece of feedback on the sampler was that components need to *"be introduced at the beginning"* [P4] and have a *"legend for the components"* [P5]. This demonstrates that while embroidery samplers can introduce stitches throughout, with e-samplers components need to be introduced at the beginning.

4.3.3 Polarity. All participants discussed the polarity of components and referenced the polarity icons on the sampler (see Figure 6). For example, when sewing a component down P8 said they were *"just about to attach the positive side of the L.E.D"*. The icons also helped participants to troubleshoot when their lights were not turning on. When P7 had a circuit that was not lighting up they were able to discover the error on their own by looking at the icons on the sampler: *"I see your thing here [the icon] - I have them reversed"*.

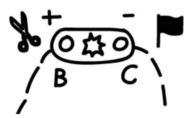

Figure 6: Showing component polarity icons for power (+) and ground (-).

4.4 Theme 2: Samplers and Practice

The tacit aspects of the sampler activity were the most difficult and most frequent comment from participants.

4.4.1 Thread Difficulties. Every participant mentioned how difficult the conductive thread was to work with and how it would be *"a real point of frustration for beginners"* [P1]. The thread *"snags"* [P2], *"gets twisted"* [P6], and *"gets super tangled"* [P3] into *"little knots"*[P5]. Through practicing the activities participants learned that they *"have to be very, very careful with it"* [P4] until they got a *"feel for the thread and how tight you can pull it"* [P9]. *"If you do enough of these it gets easier. You learn to avoid getting tangled. [. . .] This is very messy right now"* [P9]. Individuals who had sewing experience also had difficulties with the e-textile threads. This emphasizes the unique aspects of working with e-textile materials, and the tacit skills involved in learning how to use them.

To help with these thread difficulties, and tangibly manage the weight of the components and having to *"hold components in place"* [P5], participants recommended that sampler toolkits should include *"something to stabilize it"* [P4] like an embroidery hoop. Four participants also suggested needle threaders to keep participants from licking the thread to get it through the eye of the needle.

4.4.2 Trace Length. Another common difficulty was how each trace (the conductive track that connects two components) needed to be completed with one continuous thread and *"gauging how much you need"* [P2] to complete that trace (see Figure 7). Every participant discussed guessing how long their thread would need to be for each trace and questioning whether they would have enough to reach the next component. Several participants had to make shorter traces and adjust the pattern to make it work as evidence in the following quotes. *"I don't really have enough to make a decent knot anymore"* [P1], *"It's going to be very close"* [P5], *"I didn't leave enough"* [P6], *"I'm going to run out"* [P7], and *"definitely not enough"* [P10] Five participants explicitly asked for future versions to *"suggest a length of string"* [P5] that lists *"the minimum length for the thread"* [P2]. Trace length, and having to use one continuous thread is unique to e-textile making, since with regular sewing when one runs out of thread, they can just start again with another and it won't impact their work. As a result, gauging how much one needs is uniquely important to the functionality of e-textile circuits.

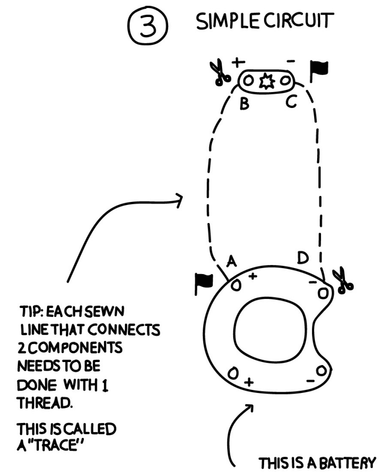

Figure 7: Trace length: Connecting components with a single thread.

4.4.3 Practice and Progression. Participants emphasized the importance of practice in their understanding of the concepts: *"I kind of understood it in an abstract way before I did it, but I understood it in a practical way as a I was doing it"* [P5]. All participants also discussed the progression of the steps as helping them "prep" for the next one. P8: *"It made sense to do the stitches first and to give that a try to get used to the thread, and like figure out what you're doing and then start with your simple and your parallel [circuit] and then the switch. I think that's a really good progression of stuff to go through"*. P9: *"It's really clear that they're building on each other"*.

4.5 Theme 3: Follow the Line?

Though the samplers helped participants make correct circuits, or quickly fix mistakes, participants questioned whether they had to follow the guides exactly. This was due to the stitching guide lines. All participants understood guides but most took the guides literally, and often asked if they could make their own stitch size. As P1 states: *"I'm going to have to make little teeny tiny stitches if I follow those black lines, does it matter if they're equal?"*, P4: *"I don't have to worry about hitting the exact spot that you've marked down right?"*, P7: *"can I make it [the stitches] bigger?"*. Others understood them as guidelines right away: *"the instructions show me how those stitches are to run and how they'll connect"* [P6], and *"It doesn't matter where just so long as I'm beside it and I go down and up"* [P1]. E-sampler designers should be aware that participants *"will likely be inclined to follow them"* [P9] and to include in the instructions that participants can decide their own stitch size.

4.6 Theme 4: Guides for What Not to Do

As part of our research ethics protocol, we informed participants about a few safety guidelines (battery and e-textile threads safety) before starting the activity. Many of our participants mentioned that this safety information was valuable and needed to be included on the sampler. For example, for avoiding licking threads, for sewers it is often *"a reflex"* [P2] and half of our participants referenced wanting to lick the threads. P5: *"It's good you said that. If you weren't here the first instinct is to stick it in your mouth"*. Another safety issue that arose throughout the activity was that half of our participants lost place of their needle. P1 suggested having a place to *"park my needle"* on the sampler to help novices get in the habit of handling a needle safely. Safety guidelines was a unique need for e-samplers that was not present in any of the embroidery samplers in our sampler designer study.

The current sampler had tips on what to do, but did not include tips on what not to do. Half of our participants also requested troubleshooting tips as well as tips on what to avoid such as *"nothing on the back crossing over"* [P8]. Participants requested a list, for example, *"if you think it's not working check this, this, this"* [P9].

4.7 Theme 5: Each Activity Needs a Sampler

Compared to the embroidery samplers that had many activities on one fabric sheet, our participants wanted each e-textile activity to have its own sampler with *"more room to breathe"* [P9]. The combination of stitching guides and instructions was *"overwhelming"* [P5] at first glance with multiple activities on one sheet. P3: *"A little bit more spaces in between [activities], because when I first look I'm like oh my God what's going on, but then I'm like oh no it's simpler than it looks."* P4: *"With all the instructions I started definitely getting into information overload – can you separate it out a bit more?"*. Our participants suggested having the practice stitches area have its own sampler, then each activity on its own sampler as well *"which might give more space for the tips"* [P9]. This suggests that participants could benefit from a series of samplers on their own fabric pages, instead of a single sampler with many activities. Historically stitch samplers also tended to have a theme to each sampler, such as one for mending, one for letters, etc. Participants also suggested providing more room for descriptions on each activity. P10: *"It would be nice if the instructions said like a line about 'let's practice the activity' before we get into it, like something that's telling me what I was going to do"*.

4.8 Summary

This study demonstrates how craft techniques and tutorials, such as stitch samplers, cannot be translated as-is to hybrid crafts, and need to be adjusted to the specific needs of the hybrid craft. E-textile materials are unique, and even participants with sewing experience had to practice and get used to working with the conductive threads and e-textile components.

4.8.1 Designs that worked: Our participants said that the sampler was useful for gradually learning the techniques and progressing from practice stitches to then applying them to making circuits. The numbered activities and alphabetized steps not only helped to guide individuals through those steps but also helped with communication between the researcher and participant, which would be especially useful for distance learning settings. The polarity icons helped individuals create their circuits and self-correct polarity errors.

4.8.2 Designs that need to be changed: Overall, the sampler concept needed to be explained, i.e. that stitch lines are guides. Whereas modern stitch samplers introduced new stitches throughout the sampler, with e-samplers the components and terminology need to be introduced at the beginning. Also, while stitch samplers might include many stitching techniques and activities on one sampler, our participants recommended that more space was needed for e-samplers and that each activity needed its own sampler "page". To help with stitching, our participants wanted a recommended thread length so that they would not run out of thread while creating one continuous thread for each trace, as well as an embroidery hoop to make it easier to stitch with the weight of the components. Participants also recommended including safety information and recommendations for how to troubleshoot and fix mistakes.

5 STUDY 3: REFLECTIONS ON SAMPLERS IN E-TEXTILE EDUCATION

After testing the samplers out with novices, we wanted to interview educators to better understand how they teach e-textiles and the opportunities and limitations of samplers within their courses. The pandemic has given e-textile educators a unique time to reflect on e-textiles and how to teach them in a distance learning setting where teacher and student are not co-located in the same place.

5.1 Methodology: Expert Interviews with Educators

5.1.1 Research Question (Q3): What are the opportunities and limitations of e-samplers in relation to the goals e-textile educators have for their workshops and courses?

5.1.2 Participants: To better understand how educators could use e-textile samplers we interviewed five expert e-textile educators who teach at the university level (E1-5). All participants are active researchers in the field and have published research papers on e-textiles. One participant taught within a computer science department, three in multimedia departments, and one in a design department. Two participants taught in North America, and three taught in Europe. We recruited participants through email.

5.1.3 Procedure: We conducted 30-45-minute semi-structured interviews through video calls (Zoom). The interviews began with questions about how they use e-textiles in their courses, what are the first exercises they go through with novices, what materials are required for the lesson, and the difficulties students come across. With those learning goals in mind, in the second half of the interview the researchers introduced the e-textile sampler (educators looked at photos of it on an online whiteboard software) for feedback and discussions on opportunities and limitations of the approach.

5.1.4 Analysis: We used orthographic verbatim transcription to transcribe 3 hours of video recording. We then performed inductive thematic analysis as described by Braun et al. [5] with the same method for all three studies (see 3.1) that included notetaking and familiarization, an initial line-by-line data-derived codes for each quote, an initial list of codes and themes to develop a thematic map, and then a list of final themes on the learning goals that educators have when using e-textiles in the classroom and the potential benefits and drawbacks of using stitch samplers as educational tools.

5.2 Theme 1: Meeting Students Where They Are

Our educators discussed how e-textiles is a hybrid craft taught in a variety of course programs such as industrial design, fashion design, interior design, multimedia design, and computer science. For example, E2 taught e-textiles within two different programs: *"One is students who are already computer oriented [. . .] and the other is in the fashion department"*. Educators chose different initial activities depending on the program that the e-textile course was taught within and emphasized that this was to make physical computing and electronics less intimidating to that population.

All of our educators used turning on LEDs as their first activity, but how they presented this activity varied depending on the department the students were in. For computer science students *"who were extremely reluctant to make circuits that didn't involve an Arduino"* [E3] it was important to scaffold their learning with coding activities, and as a result e-textile activities focused on building textile sensors for the Arduino rather than circuit basics. For textile design students, material exploration with a *"garden of textiles workshop"* [E1] was important and coding to a lesser extent so instructors used a pre-programmed capacitive touch board that lit up with conductive materials and capacitive touch. For multimedia students, classes focused on the basics of electronics starting with a *"simple LED and coin cell battery"* [E2,E4] and then stitching a simple circuit *"with a break in the circuit to make a switch"* [E4] that can turn into a *"tester tool"* [E5] for exploring materials in their environment. For students without textile backgrounds another element was making sewing less intimidating by allowing practice and first drafts to be messy so *"they see the result, and then they can clean it up after [. . .] whereas with fashion students they for sure know how to sew"* [E2]. This variety demonstrated how toolkits for e-textile novices need to be flexible to these different learning goals, and specifically with the sampler the importance of enabling instructors to easily customize their own to suit their course needs.

5.3 Theme 2: E-textile Learning is Strengthened by Trial and Error

The three educators who taught in multimedia design programs emphasized how students learned e-textiles best through trial and error. They might be taught the concept in the lecture, such as component polarity, but it was when they made the mistake that they really understood it. E5: *"When you're thinking of which part connects to which part this is when you understand how it works. I always worry that if people have too many instructions, then they're just going along without really thinking. [..] I think there's no learning without mistakes."* When these mistakes happened, our educators liked that the sampler could be used as a reference to troubleshoot and fix errors, and highlighted that these samplers could be built up into a variety exercises, becoming the lecture notes. E2: *"I like the idea that it is a reference. I think it would be really cool if it was expanded"*. E5 had students make swatchbooks throughout their class with samples and notes: *"that would be a nice crossover to have several [fabric] sheets and then you make a book out of it [. . .] a form of documentation"*.

5.4 Theme 3: Difficulties Debugging at a Distance

Our educators found *"the most difficult part [of distance learning] was debugging online"* [E5]. In class they could *"actually have a look at what's wrong [and] what they are doing"* [E3] and online follow-along live demos were *"a little difficult"* [E4]. To solve for this most of our educators (4) posted online overhead video tutorials that students could watch at their own pace. E4: *"What's good about it is that they can go back and re-watch the things they don't understand. Where they need to, they can go more slowly."* Yet debugging issues with students afterwards through video calls remained a problem. E5: *"It was just things you have to ask like 'Did you check this?' [. . .] and if we tried everything I'd suggest they make a video. It was difficult"*. Whereas online video tutorials at their own pace were better than the in-class experience, debugging common issues was more difficult online.

5.5 Theme 4: Material Constraints in E-textile Education

One educator moved their ubiquitous computing class to e-textiles specifically because of pandemic constraints: *"I was teaching a course called interactive systems and during the pandemic we decided to switch from breadboard activities to e-textiles because we hoped that students could use household items"* [E3]. Yet e-textiles for distance learning also had their own constraints. Our educators had students who were dispersed throughout the world during the pandemic and had to include *"a few different part numbers and to crowdsource part numbers"* [E4]. This resulted in educators having to adapt to students using a variety of different toolkits. Even for in-person classes pre-pandemic, our educators chose different toolkits in order to lower the costs of e-textiles, with the Lilypad components we used in the samplers being *"expensive"* [E2,E4,E5] compared to other sewable component suppliers. For this reason, our educators emphasized the importance of being toolkit agnostic in the sampler illustrations. E2: *"I know a bunch of [e-textile educators] just have different ones, and this specific footprint [of the Lilypad] is like really distinctive"*. They suggested having illustrations that could apply to any kit, for example, *"maybe LED as a kind of tiny star"* [E3].

Keeping costs down is especially important for e-textiles since most students keep the components rather than borrowing them and returning them to the school. Compared to Arduino toolkits with re-usable components, only one educator had experience with re-usable e-textile kits and said they were *"horrible to maintain"* [E3] and would always need to be re-stocked. Due to the students keeping the parts *"cost and access"*[E2] are always top of mind. E5: *"I never actually used ready-made kits [. . .] like normally it's like keep it as cheap as possible"*. These limitations emphasized the importance of any supplementary materials and supplies not adding to the cost of the activities, as well as the trend of e-textile materials being something that students keep after the course.

5.6 Summary

Our interviews with e-textile educators uncover some of the potential benefits as well as limitations of e-textile samplers. The benefits include debugging at a distance where the sampler could help with communication and troubleshooting for specific activities. The ability to illustrate one's own samplers, or easily customize our files, enables educators to design samplers that scaffold the specific needs of their students depending on how they are approaching e-textiles (i.e. from computing, multimedia, or textiles and fashion). They saw applications for the sampler as a practice tool as well as for referencing what students had learned. Samplers that students could keep also fit with the general trend of students keeping e-textile components since they are difficult to undo.

There were also some limitations of the sampler format. Our educators used a wide variety of e-textile toolkits to keep costs down and recommended that component design illustrations needed to be toolkit agnostic so that they could work with any toolkit. They also discussed how customizing circuits and personalization is one of the benefits of e-textile education, so while e-textile samplers might help with practice, it is also important that students map out and create their own circuit designs. When students make their own designs, and create errors, that is when they really learn how to apply what they have learned. E-samplers are a good first step for practice and reference, but it is also important for students to have their own customized applications afterwards.

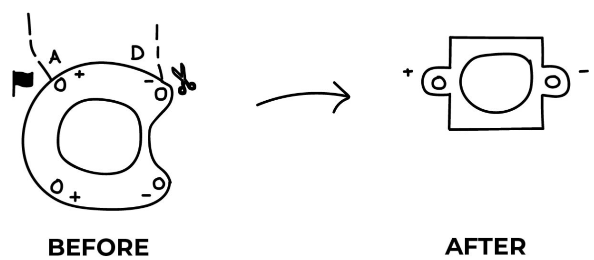

Figure 8: Example of e-sampler changes: In original sampler, components (such as the battery holder shown here) had branded footprint of the Lilypad and were introduced in place. In our study participants recommended toolkit agnostic components introduced before activities.

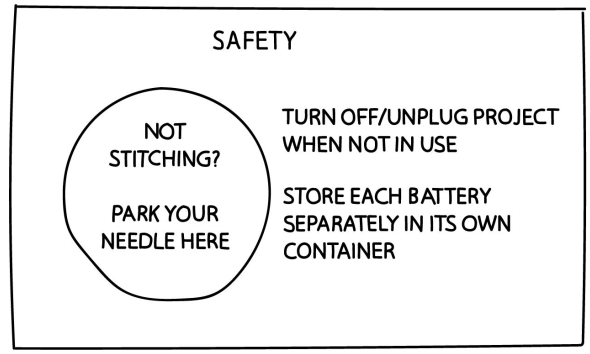

Figure 9: Our participants recommended adding additional information to the sampler such as safety information and what not to do.

6 DESIGN RECOMMENDATIONS FOR E-SAMPLERS

Based on our three studies we have several recommendations for individuals who want to design their own e-samplers for courses and workshops:

- **R1: Include practice space.** Participants needed practice to learn how to use the thread and the tacit aspects of making e-textiles. As a result, we recommend including practice space for individuals to practice the stitches before interactive or electronic activities. These exercises will help participants learn how to gauge how much thread to use for each trace, and educators can also include measurements to help scaffold this learning. This followed the insights from Study 1 that samplers help to make embroidery less intimidating (by providing practice space) rather than jumping into a full project (Study 1, Study 2 and Study 3).
- **R2: One activity per sampler.** Unlike embroidery stitch samplers that have many activities in one sampler, e-samplers designed in a similar manner appear overwhelming. Having one activity per sampler provides more room for introductions to each activity, and a greater ability to focus on one activity at a time. Our participants recommended separating each activity out onto a separate sheet. For example, having the practice stitches and the simple circuit on one sampler, and then the parallel circuit on the next (Study 2).
- **R3: Treat the sampler as reference notes and describe each activity.** One of the greatest strengths of the e-sampler is as a reference for discussion with educators and for future projects, and several educators described them as augmented swatchbook pages. These references can also include information like safety and troubleshooting tips (Study 1, Study 2, and Study 3).
- **R4: Introduce components all at once.** Whereas embroidery stitch samplers only provide instructions and recommendations in place, our novices wanted e-textile components to be clearly identified rather than scattered throughout the sampler (Study 2).
- **R5: Use toolkit agnostic symbols when possible.** Due to the financial cost of e-textiles and the variety of toolkits that are available around the world, our educators recommended that samplers be toolkit agnostic when possible, and especially for common components like LEDs and battery holders (Study 3).
- **R6: Include numerical and alphabetized steps and terminology.** The combination of alphabetized steps and terminology enabled novices to discuss the step they were at so educators can easily locate an area of their circuit, and the stitching technique the student is using (Study 2 and Study 3). This design choice from the modern stitch samplers translated well for the e-samplers.

7 DISCUSSION

Our three studies extend current discussions on e-textile education, cost and accessibility, material references, and troubleshooting aids.

7.1 E-textiles are Taught in Diverse Contexts

Though e-textile education has been studied at the elementary school level [43, 49, 50, 95], more research is needed on adult and university learning. An important difference, and one highlighted by our educators, is that e-textiles are taught at the university level in a diverse set of programs including art, design, and computer science, and e-textile scaffolds must support and be flexible to learners with diverse backgrounds. This includes leveraging skills they already have to make e-textiles less intimidating, such as E3 introducing computer science students to e-textiles with Arduino and coding exercises before building circuits, and E1 introducing fashion design students to e-textiles with material exploration and pre-programmed microcontrollers. Most research to date has aimed to bridge gaps between collaborators from different fields such as the textile interface swatchbooks [26, 101], samples [16, 97], and residencies [15] but an area for future research is to further explore the unique learning needs of these diverse groups and what activities need scaffolding and supports. For samplers, our studies suggest that educators would find design files and the ability to customize their own activities more valuable than a set of standard samplers (these design assets are included in our supplementary material). This would give them the flexibility to quickly design and print their own based on their course learning goals.

7.2 Cost and Accessibility

The greatest strength, as well as limitation, of e-textiles is that once sewn in place they are difficult to undo. The strength of e-textiles is that individuals can build prototypes that can exist in the wild and circuits will stay securely in place. At the same time, the limitation of this feature is that e-textiles are not easy to re-use which creates unique challenges for their use in educational settings. Research into tools like the ThreadBoard [35] and Punch-Sketching E-textiles [48] aim to make e-textile thread re-usable for prototyping, and re-usable e-textile and wearable toolkits like i*Catch[70], Wearable Bits[47] and MakerWear [53], could help in the future for enabling students to prototype concepts and then return the materials once the activity is complete. Yet our educators expressed that currently they must plan for students to keep e-textiles supplies or have students purchase their own. As a result, considerations for cost must factor into incorporating any new tool or material into e-textile courses. This includes both for the material as well as the toolkit presented on it. Our educators emphasized the importance of toolkit agnostic samplers that could be used with less expensive components. Fabric samplers, which when ordered through print-on-demand fabric suppliers cost less than $1 USD per sampler (and with print-on-demand fabric widely available locally around the world or through DIY screen-printing), could provide a low-cost and easily accessible opportunity to support e-textile learners while also providing a reference for them to refer to when prototyping future projects.

7.3 Sampler Swatchbooks

Based on the feedback from designers, novices, and educators, the strongest benefit of samplers is their use as references for future projects. Our modern sampler designers referred to samplers as tangible references to help translate techniques from textbooks and other traditional teaching materials. Our beginner users demonstrated their understanding of the e-textile terms, concepts, and techniques in how they described their process during the sampler activity.

To improve upon our current iteration, users suggested that e-samplers need to be divided into 1 activity per sampler, and educators suggested they could augment the swatchbooks already used as course documentation. As a result, we think the next step is to use samplers as sampler swatchbooks where the activities are the practice notes students reference when they want to return to a topic. Similar activity books already exist with the hybrid paper craft kit Chibitronics [85–87]. These e-sampler swatchbooks could then be used in a similar manner as current swatchbooks for probing possibilities and teaching others techniques [26, 34, 76], and helping novices to transition into educators themselves [44]. These research directions put instructions on the material that students are working on (paper for paper circuits and fabric for e-textile ones), using materials that are easy for educators to replicate in their own course contexts.

7.4 Use Samplers as Troubleshooting Aids

Expanding on the value of e-samplers as a reference, our studies suggest that for virtual learning samplers are also useful for debugging and discussing issues. Our beginner participants were able to reference the alphabetized steps and activities, as well as the type of stitches they were using, to describe what they did in the sampler and the specific location they were discussing. Our educators also discussed how debugging was the hardest part of distance learning due to limitations of video calls and recordings. Having common reference points for discussion could help with these debugging conversations. Notably, our novices who did make errors, such as sewing on LEDs backwards, were able to correct their errors by reviewing the sampler icons and recognizing what they had missed. To further expand the e-sampler as a troubleshooting aid, our novices recommended including a list of items to check at the end of activity, as well as including not just what to do but also what not to do.

How we design practice samplers is especially important for distance learning, when students will not be co-located with an instructor's sampler swatches and wearable samplers for tangible references. Our e-textile educators discussed this as one of the limitations of online learning where it was more difficult for students to explore materials before purchasing them for projects. At the same time, it is clear that practice samplers would benefit from coinciding video tutorials with overhead demonstrations of the process. Our modern sampler designers discussed this as their most frequent item of feedback from customers, and our educators discussed this as one of the benefits of online learning. Previous work has also found that overhead video tutorials were even more effective than in-person classes because students could see up close what the instructor is doing, with many educators saying they will continue to use the technique even if classes return in person [44].

7.5 Tensions in E-Sampler Recommendations

Together these three studies provide design recommendations for how the tutorial medium of stitch samplers needs to be adapted for e-textile education, but also reveals some of the tensions between specific learning goals.

Clear guides vs application of knowledge: Educators want students to be able to figure out how to do the activities (i.e. supports for troubleshooting, error correction, and debugging at a distance), but they also highlighted that errors are an important part of learning, and customization is one of the benefits of using e-textiles to teach physical computing. Samplers can help with learning the tacit skills of stitching alongside initial circuit exercises, but it is also important for students to design and make their own circuit designs and to apply what they have learned. One way to address this could be to design samplers with specific challenges for students to address. For example, the first sampler could have stitch lines, whereas the second activity could have only components and students need to figure out where the stitch lines should go. Consecutive samplers could incrementally remove guides and supports as students begin applying what they have learned. Educators could also consider what aspects of the sampler they want as "guides" vs "rules". For example, educators could use different colours, or a lighter gray, to demonstrate what parts of the sampler can be customized (such as stitch lines), and what parts need to be followed (such as component polarity).

Practice vs reference materials: Traditionally, educators develop samplers for practice and samplers for demonstration (termed practice samplers and sampler swatches in previous work [44]). With the e-samplers, designers and educators saw them as both practice activities and reference material (Study 1, Study 3). The benefit of the sampler format, compared to application activities, is that it gives novices a low-stakes activity specifically meant for practicing stitches. As our designers in Study 1 discussed, stitch samplers help to make stitching activities less intimidating. For our educators, they saw value in having the samplers as a type of activity book, replacing notes and textbooks, where individual pages could provide both practice as well as reference material to refer to when students are applying their knowledge. Using samplers as reference material makes them a higher-stakes item, since a circuit done incorrectly is not a useful reference. To correct this, we recommend that educators focus on the editable nature of textiles [44], that stitching can be cut out and redone. Valuing the sampler as reference material means that students will have to undo errors rather than just practice the techniques – they will have to practice getting them right.

On top of error correction, valuing the sampler as practice or reference material will result in different types of instructions. For example, needle parking is a good habit to get into while learning how to stitch, so will be more useful in samplers for novices. As they begin to learn and practice the techniques, the consecutive activity samplers might not need that instruction anymore. Our sampler recommendations are for the first samplers that individuals have to do, but recommendations can be gradually removed as students become familiar with specific tacit skills, safety information, and circuit concepts.

7.6 Tutorial Mediums in HCI and Hybrid Crafts

Though novices have learned crafts through distance learning methods since the invention of the internet (and through methods such as books beforehand), how we teach physical skills at a distance has become an especially important issue during the pandemic [19]. For physical crafts where the hands are busy during the activity, traditional tutorial formats like books, videos, and online step-by-step tutorials, which require practitioners to stop the activity to navigate instructions, tend to interrupt the making process [19]. This is one area where we can learn from the tutorial formats of crafts, and instruction methods such as stitch samplers, where the tutorial is embedded in the material. But augmented instructions are not just limited to the materials, we can also embed them in the tools. For example, the e-textile tester tools developed by Irene Posch provide a way for novices to verify their circuits using the tools of the craft [77, 78]. Using both augmented tools and in-place tutorials means that novices do not need to look at other instructions, their focus can remain on the project they are making.

The benefit of print-on-demand fabric technologies and suppliers is that it becomes easier for not only educators, but also students, to create their own sampler files and share them with others. Just as individuals upload their maker tutorials online, the sharing of illustration files for fabric printing mirrors other digital fabrication pipelines [24, 66]. This digital sharing of files could emulate the tangible in-person sharing of samplers that were historically used to teach stitching techniques, where an individuals practice sampler was then used to teach others. Even those without local print-on-demand fabric suppliers can use traditional paper printers to create iron-on transfers. As a result, e-samplers are a reproducible and customizable method of sharing e-textile tutorials in-place.

8 CONCLUSION

E-textiles is a hybrid craft that blends cultures, materials, techniques, and forms of documentation from two fields. Swatches have previously been explored for their use as documentation and demonstration tools, but in this paper we contextualize their use within the sampler ecosystem and focus on a new type of sampler - practice samplers - and particularly how we can design them to support e-textile novices and educators in activities that include learning through doing with instructions printed in place.

In this paper we discussed three qualitative studies: (1) interviews with modern stitch sampler designers, (2) novice studies with an e-sampler with instructions printed on fabric, and (3) interviews with e-textile educators on how they use e-textile in their courses and potential opportunities and limitations of samplers. We found that e-samplers were valuable for communication for virtual debugging challenges as well as for references and notes. We then used these studies to create recommendations for how educators can design their own e-samplers for their courses. In our supplementary material we include the design asset file for educators to easy develop their own samplers with updates from our recommendations and study results. Overall, this paper contributes a greater understanding of the variety of samplers that can be used in e-textile education and how beginners can practice and learn with e-samplers.

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