Hand Spinning E-textile Yarns: Understanding the Craft Practices of Hand Spinners and Workshop Explorations with E-textile Fibers and Materials

Lee Jones
lee.jones@queensu.ca
Queen's University
Kingston, Ontario, Canada

Ahmed Awad
a.awad@queensu.ca
Queen's University
Kingston, Ontario, Canada

Marion Koelle
marion.koelle@offis.de
OFFIS - Institute for Information Technology
Oldenburg, Germany

Sara Nabil
sara.nabil@queensu.ca
Queen's University
Kingston, Ontario, Canada

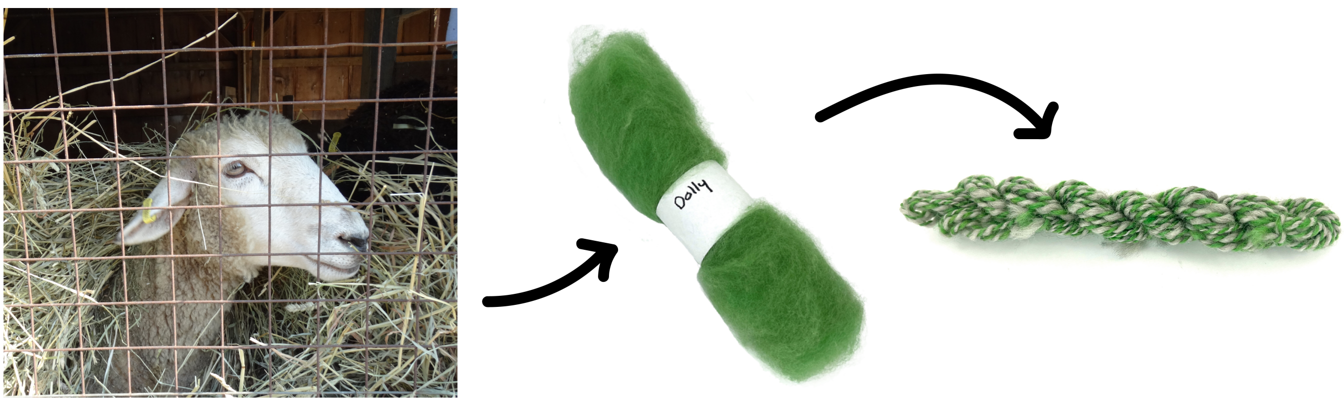

Figure 1: Wool fleece from a local sheep named Dolly was dyed, hand spun, and plied with conductive fibers to make a hank of conductive yarn. Participants described how hand spinning included design decisions that go all the way back to fiber sourcing.

ABSTRACT

The 'material turn' in Human Computer Interaction (HCI) is increasingly drawing attention to the computational affordances of materials and how we can craft with them. In this paper, we explore opportunities for combining the maker cultures of hand spinning with e-textile crafting. In our first study, we interviewed 32 hand spinners on their practices to better understand their motivations for spinning their own yarns and the techniques they use to do so. In our second study, we conducted workshops with 6 spinners at a local spinning guild, where participants worked with the conductive fibers and spun e-textile yarns. After the workshops, we conducted follow-up interviews with each participant to understand the opportunities and tensions of hand spinning e-textile yarns. Our findings show how spinners can blend local materials with conductive ones to develop their own custom interactive textiles, and the mismatch between how these fibers are sold and what information spinners require to inform their design decisions. Through these results, we hope to empower makers and inspire the design community to develop tools to support these DIY practices.

CCS CONCEPTS

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

KEYWORDS

e-textiles, hybrid craft, yarn, thread, spinning, hand spinning, smart textiles, maker culture, DIY, material turn

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1 INTRODUCTION

Hybrid crafts have expanded the materials that can be used in creating Tangible User Interfaces (TUIs) and how individuals can craft with technology [36]. Hybrid crafts leverage specialized microcontrollers to combine crafting skillsets with materials that have computational affordances [25]. For example, microcontrollers like LilyPad [13, 14], Chibitronics [89], and Makey Makey [18], are combined with conductive materials like metal threads, tapes, and paints to craft interactive devices. This combination is enabling researchers in Human Computer Interaction (HCI) to create novel devices using techniques used in crafts such as ceramics [114, 115], stained glass [29], silversmithing [105], and embroidery [49].

Within HCI, the field of electronic textiles (or e-textiles) demonstrates what computing can learn from craft practitioners, and the benefits of combining computational and craft practices. E-textiles reimagine what "computers" look like, and transform them into something customizable and soft [78]. E-textiles enable makers to leverage textile skillsets and expand the backgrounds that are valuable in an HCI context, such as technical textile expertise [20, 103].

1.1 Why hand spinning?

In contrast to commercial yarn, hand spinning is the process of developing yarns by hand. Though spinning can involve machines (such as spinning wheels[1] or e-spinners), the crafter's hands are used to feed the fibers into the machine (a process called "drafting"). Overall, "hand spinning" encompasses practices with many different (but easily accessible) tools that rely on the crafter's hands and their tacit skills of how to hold and guide the fibers for twisting to create a structurally stable yarn.

From an HCI and personal fabrication perspective, spinning enables individuals to customize their own yarns at home [5, 28, 71]. Instead of buying commercial e-textile yarns (which tend to be gray or other metallic shades), spinners have the ability to blend yarns. They could, for example, add texture, different materials, colour, or different levels of conductivity, or spin other smart materials into or with their yarns. In doing so, spinning provides the potential to have e-textile yarns that blend into projects and can be customized to a maker's creative vision. Spinning e-textile yarns extends the customization opportunities that e-textiles provide, while also encouraging individuals to be makers of e-textile materials, rather than consumers. Finally, spinning is an accessible hobby for individuals to learn, and though finely crafted tools can be expensive, spinning tools start at a low cost.

1.2 Contribution

Our first study involved interviews with hand spinners to understand their craft practices. These interviews were used to design a workshop for spinners with an understanding of the material culture of their craft. Our second study was a series of workshops, with follow up interviews, where spinners created their own e-textile yarns and used block coding to create touch interactions. Together, these studies provide the following contributions:

(1) ***Introducing HCI researchers to the maker culture of hand spinning***: We present insights from interviews with 32 hand spinners on their spinning practices and motivations. Participants discussed how DIY self sufficiency motivated them to spin, as well as their ability to control the design process and outcome. They discussed enjoying the tangible and tactile process of spinning. From these insights, we map out the main tools, processes, and design decisions that spinners integrate while fabricating yarns.

(2) ***Providing insights from e-textile workshops***: We present insights from workshops and follow-up interviews with 6 members of a spinning guild on their experience of spinning with e-textile materials. In follow-up interviews, participants discussed how exploring new materials is part of spinning practices for intermediate spinners, how fibers need to match, how e-fibers create wear and residue, and how e-textiles would fit within the planning and application areas of their practice. They discussed how the information provided with e-fibers doesn't match with the information spinners need to integrate e-textiles into spinning practices.

These contributions support the vision of blending hand crafts with interactive technologies, and enabling textile makers to craft technologies that "disappear" into their environment [108].

2 RELATED WORK

2.1 E-textiles

E-textiles leverage aspects of both physical computing and textiles [27, 60]. The metal conductive threads that make the field possible have been used in craft practices for over 1000 years for their aesthetic characteristics [49], but in HCI these materials also have electrical [81] and computational [86, 87] affordances. Since the first prototypes were made [86, 87], the maker culture of e-textiles has expanded to include custom microcontrollers [13, 14], toolkits [84], tools [38, 80, 82, 83], creativity support programs [65], forms of documentation [31, 32, 37], and tangible tutorial formats [45, 47, 83]. Researchers have explored soft and flexible materials that can be used to make interactive devices, and expanded the palette of materials available for physical computing [36, 75, 113]. Finally, researchers have expanded the fabrication methods with the wide variety of textile processes available.

E-textiles, by leveraging textile culture, provide novel benefits to physical computing [15]. E-textiles enable makers to use more portable and accessible tools, expanding the locations where making can happen [51, 82, 90]. Textiles bring new values to computing such as customization and personalization [42, 78]. E-textiles is a multidisciplinary field with many ways in, expanding the skillsets that are considered valuable [20, 103]. For example, researchers in HCI are increasingly reaching out to textile communities to learn from their technical expertise [44, 46, 47, 61, 68], as well as valuing craft-based labour and its place in computing history [92].

Though there are synergies and coproductions [23] in the meeting of the diverse fields that make up e-textiles, there are also moments where their cultures diverge and frictions arise. For example, fields can have different jargon, end goals, and applications [15, 70]. In this work, we conduct an in-depth study with spinners to understand their practices and initial impressions of combining them with

[1]Throughout this paper we have underlined hand-spinning terms that are further defined in Appendix A

e-textiles. In doing so, we aim to understand the opportunities and tensions that arise to create more cross-disciplinary understanding.

2.2 Yarns in HCI

The first explorations into e-textiles re-purposed metal threads for their conductive affordances [81, 86, 87]. Though e-textile threads and yarns have resulted in a wide variety of novel interfaces since that time, few researchers have explored how makers can create their own interactive yarns [85, 96]. Instead, researchers in HCI have focused on applications for consumer e-textile yarns, or have used manufacturing processes not available to the average maker. For example, many processes such as braiding machines, chemical coating, and extruding filaments rely on expensive or custom equipment. Here we discuss the yarn fabrication processes that have been used in an HCI context.

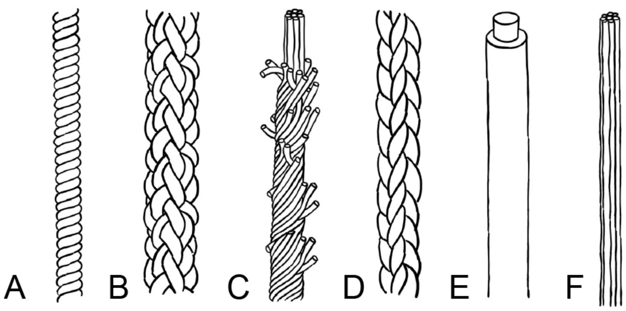

Figure 2: Researchers in HCI have used the following yarn fabrication techniques to create e-textile yarns: (A) plying, (B) braiding, (C) core spun, (D) knit cord, (E) coating, (F) filament, as well as combinations of the above.

2.2.1 Plying. Plying (Figure 2A), where yarns are spun together, has been used for spinning a conductive thread with smart materials, such as thermochromic dyes [21]. By combining one heating wire with yarn that has thermochromic dye, it is possible to create colour-changing yarn that doesn't require the use of heating pads. Researchers have also used conductive fibers to create their own conductive yarns by spinning and then plying the yarns [85, 96].

2.2.2 Braiding. Braiding (Figure 2B), where three or more yarns are interlaced, has been used like in I/O Braid [76] to create matrices of sensing and actuation within a single cord. Researchers have created attachable hair braids, interlacing extensions with SMA wire and thermochromic dyes, that can actuate as wearables [24]. Braiding can also happen around a core, such as Cord UIs [97], where conductive thread was braided into cord sleeve to detect touch and pressure. Project Jacquard [88] involved the development of an insulated copper core of thin wire braided with silk and surrounded by a second layer of spun (Figure 2C) or braided fiber that could be dyed after spinning.

2.2.3 Knit cord. Tubular knit cord (Figure 2D), also known as french knitting or i-cord, is a type of circular knitting used to create stretch-sensing [88, 95, 102] and touch-sensing [98] cords.

2.2.4 Coating. Coating (Figure 2E) is when a layer is applied around a material. Resistive coatings have created stretch and pressure sensing yarns. For example, RESi [77] is a conductive thread that is dip coated with resistive material for force sensing. Similarly, Polysense [41] used polymerization to create resistive yarns. This coating process has been applied for interactive artworks [11], wearables [12], and hair interfaces [72]. Researchers have also coated Project Jacquard yarns with thermochromic fabric paint to develop colour changing yarns for weaving and crochet [21, 22]. Nabil et al. [73] similarly used thermochromic pigments on sewing machine bobbins to embed colour-changing yarns with sewing.

2.2.5 Filament. Filaments (Figure 2F) are a single strand of material, and the most common method for creating e-textile yarns [66]. For example, ThreadSense [59] created a thread by extruding conductive material (carbon filament) from a 3D printer. Within HCI, researchers have re-purposed thin filament materials as threads, such as optical fibers [7, 17]. Thin wires, such as Shape Memory Alloys (SMA), which remember their shape, can create shape changing fabrics [55, 58, 73, 104]. Similarly, air tubes create pneumatic actuation in textiles such as knits that can "crawl" [54] and expand [67]. OmniFiber [53] similarly uses fluid tubes to make threads that move. ModiFiber is a composite of techniques [26] to create reversible twisting and shrinking actuation.

Though these works present huge innovations for e-textile research, innovating what computers are capable of and the soft form factors they can provide, they mostly explore the user as a consumer, rather than the user as a maker who could craft their own e-textile yarns. Among these fabrication methods, we explore the method of hand spinning, due to its accessibility to makers. In doing so, we further explore within the "plying" area of fabrication. Our research focus is on the ***culture*** of hand spinning, focusing on the customization and design opportunities that spinners currently use in their practices, as well as the opportunities and frictions when these meet e-textile fibers.

3 STUDY 1: INTERVIEWS WITH SPINNERS

We conducted interviews with spinners to understand their craft.

3.1 Method

We pursued three research questions:

- ***Q1***: What motivates individuals to spin yarns?
- ***Q2***: What is the material culture of spinning including tools, materials, and techniques?
- ***Q3***: How do spinners evaluate their yarns?

3.1.1 Participants. We recruited 32 participants (P1-P32) by sending out a recruitment poster to spinning guilds across Canada. Before joining the study, we asked participants what tools they use, and their experience with spinning (see Table 1 in our Appendix). All participants had significant experience with spinning.

3.1.2 Procedure. We conducted semi-structured interviews through Zoom [19]. Major topics included: motivations for spinning, what they enjoy about spinning, their process, what they do with the results, and for instructors we asked for teaching recommendations.

3.1.3 Data analysis. We anonymized transcripts from 29 hours of interviews and edited and verified them using video recordings. We analyzed the data with Braun and Clarke's reflective thematic analysis, and inductive coding [8–10]. This involved note taking while reading the transcripts, and then coding quotes at the sentence level. These codes were iteratively grouped with connecting codes to create narrative subthemes, and themes, with a focus on spinners' values. We include participant quotes with conversational filler words ("like" or "um") removed for clarity.

3.2 Theme 1: Do-it-yourself and self-sufficiency

3.2.1 Turning raw materials into something useful. Participants described hand spinning as the process of turning *"raw fiber"* (P23), usually *"derived from animals, but it could be derived from plants"* (P12) into something useful. Spinners take materials that are *"not strong enough to stand on [their] own"* (P25) and that in *"their original state are pretty useless"* (P19) and give them strength through the process of spinning them. As P20 summarized: *"you impart it with a certain amount of twist so that it holds, and then it can become something useful"*. This strength is at the microscopic scale where fibers are *"covered in little scales. The reason spinning works so well is that when you have a couple of hairs you combine with each other, they call it a twist lock. The scales are forced to interlock with each other and amazingly get really strong, [and difficult] to pull apart"* (P17). Twist gives yarn *"great linear strength"* (P30). If twisted in a stable and consistent way the fibers will *"all stay together"* (P6).

3.2.2 Use what you have. Spinners can use readily available materials - such as working with plants, fleeces, and fur in their environment. For example, *"different kinds of goats and rabbits, and from almost every animal you can get fiber"* (P30) or pet fur from dog breeds such as Saint Bernard (P16), Samoyed (P29), huskies (P11), and poodle (P1). Participants described that you don't need spinning equipment to get started, and throughout history *"people used what they had around"* (P2). Drop spindles can be made with household items with a *"weight and a stick"* (P2). Any collection of materials can be used as long as there's a *"balanced weight at the bottom"* (P11). As P5 described: *"it's is literally the same idea [that] the Vikings used – a stick and a rock and then a notch"*. Drop spindles were the most frequently mentioned DIY item, since they are often used for beginners, but participants also discussed items like *"dog brushes"* (P6) to prepare fiber, *"spinning wheels [made] out of bicycles"* (P13), and niddy-noddy made of *"plastic plumbing pipe"* (P18).

Along with everyday items, several participants discussed the benefits of rapid prototyping tools and digital fabrication to make *"3D printed spindles"* (P22). P5 discussed how individuals could also 3D print the spindle weight and attach them to sticks. This reduces the price and enables individuals to give away the spindles during workshops, such as at schools: *"3D printing satisfies something deep within me about going back to the Vikings. It's the same process [...] fun, interesting, easier to manufacture."* Digital fabrication can also help fix tools. Participants described inheriting or finding *"antique wheels"* (P32), and needing to refurbish them in order to get them to work again. As P7 summarized the issue: *"A lot of old wheels have some parts damaged or missing, and so for a lot of people that's a challenge"*. Participants frequently described the benefit of 3D printed bobbins. Finding the correct size of bobbins can be difficult, and when ordering unique supplies there can be huge delays. Custom wood bobbins were described as expensive: *"I've seen a lot of 3D printed bobbins, because the manufacturer wants 5 times as much as what someone has whipped up on a 3D printer"* (P17). Especially for old wheels, bobbins aren't available anymore: *"If you have an antique spinning wheel that you love, but it only has one bobbin, that's very limiting. A lot of us use that existing original bobbin as a prototype, and make themselves six 3D printed bobbins to match it [...] printing allows us to make things in perfectly measured and tailored shapes"* (P11). These new technologies enable crafters to potentially *"revive a wheel that would otherwise be very expensive to revive"* (P7).

Figure 3: Drop spindles can be hand carved and participants expressed valuing this DIY self-sufficiency. Photo courtesy of Paul Sparling.

3.2.3 Supporting small industries. Participants who worked with raw fleece could often get their materials from local farmers or hobby farmers, and described wanting to support local micro-industries. As P7 described: *"You can obviously get things online. I personally like to support local farmers"*. Participants leveraged their guild networks for finding fleeces, as well as informal sellers from sources like Facebook marketplace. *"We have local farmers who sell fleeces. I'm in touch with a couple of shearers who tell me where to find fleeces that they like because they've shorn them"* (P30). These fleeces are a renewable resource, as farmers need to continually shear their sheep. As P26 described, *"It actually costs money to shear the sheep [for farmers], but they have to do it for welfare reasons. So, if I can put some more money in a farmer's pocket [...] I like to do that. I always like to support farmers"*. Some spinners would team up with a farmer, for example, P16 discussed how as a spinner *"you can do kind of a deal. [Find] someone who sends you the fleece, and you do the cleaning, and prep, and spinning, and then you send them half back. I've done that before."*

Several participants described spinning after purchasing a farm, or purchasing a farm based on their interest in spinning (Figure 4). P9 described how their hobby farm led to spinning: *"We thought, maybe, we'll get a couple of sheep. So we went, brought them home in the back of our SUV, and once it was time for them to be shorn, I*

Figure 4: The Angora goats that motivated one participant to learn to spin. Several participants were motivated to spin after purchasing a farm or the other way around. Photo courtesy of Devon Stringer, Two Cozy Chicks Woolens & Wares.

said, 'Well, I guess I'll have to learn how to spin', and I just jumped in with both feet." In contrast, P14's spinning journey started by buying an old farmhouse and finding flax preparation and spinning tools inside, to then deciding to grow a field of flax for spinning in their back field. As they describe: *"We kept on finding things, and we realized that whoever had been living in this house had been spinning and weaving flax into linen, and then weaving because we found parts of looms and parts of spinning wheels. Then we planted a field of flax, and then it just went from there. It started because of finding equipment."* Participants, through these farms and hobby farms, expressed a desire to support local industries. As P22 described: *"My hope is that industry will follow, and we will start doing these products more in our own country"*. Some have also seen how online sales can support these industries. P20 described someone who owned 2 cashmere goats expanding to 40 goats due to online demand: *"I've been watching over the last 10 years. A lot of producers are more willing to get harder to maintain animals, because now there's a market for the fiber."* Guilds have also promoted "breed studies" for members to try out and learn the characteristics of each breed to expand demand. P11 expressed the benefits of breed studies: *"I love it. By the end of the year, I'll have spun 12 different kinds of fiber, from 12 breeds of sheep, most of them grown in Canada."*

3.3 Theme 2: Control over process and result

3.3.1 From start to finish. Participants described a sense of pride in working with the *"raw materials"* (P6, P22) and making an item *"from scratch"* (P32). Processing fleece adds to the backstory of the final object. As P17 described: *"When you have the finished product that you use, there's a bit of pride in kind of bragging that I made this from scratch"*. There's a sense of achievement in transforming the raw fiber into something of value: *"There's creativity, I think, because you could take a pretty disgusting pile of fluff, and then you can launder [it], dye it, and spin it, and you can end up with gorgeous sweaters, or shawls, or blankets, or any number of things"* (P31). Going through the process helped participants understand the effort that goes into textile objects. As P29 stated: *"If you've gone through the whole process, you have a greater appreciation for that piece."*

Participants involved in the full process described the steps of preparing the fiber for spinning, often with animal fleeces. As P23 described: *"It's quite an intense process"*. After the animal was sheared, participants would "skirt" the fleece, which involved cleaning it of the things animals come up against while living outside – such as dirt, vegetable matter, and feces. For animals bred for spinning, some participants discussed how a coat could protect the fleece and reduce the amount of cleaning needed. As P19 described: *"I put coats on my sheep so that the hay doesn't get into the fleeces"*. At this stage individuals sort through the fleece (*"scoring it"* (P17) or *"grading it"* (P7)), to pick parts of the fleece they want to use. As P18 described the process: *"I like to analyze different sections of the fleece for length of the fiber (so staple length of the locks), whether it's coarse or fine, depending on what type of breed it was."* Afterwards, they wash the fleece to remove lanolin, *"a waxy, greasy kind of substance"* (P17) that sheep naturally produce to protect their fleece, or sometimes spinners preserve lanolin for its water-resistance properties.

Based on the grading of the fleece, fibers can be prepared in different ways. As P30 described: *"For short staple lengths you would use carding, and for longer staple lengths you would use combing"*. The fibers can be organized in different ways for spinning – depending on if the spinner wants to spin worsted (organized and long fibers) or woolen (fluffy and airy, and generally with shorter fibers). Worsted spinners use top, where long fibers are combed into alignment. In contrast, woolen spinning prep aims to add air and space to increase softness and warmth. Woolen spinning can be done in several ways with carders. These carders, which look like dog brushes, or drum carders (gear-like circular drums covered in bristles) are used to blend fibers together (Figure 9). The carded fiber can then be prepared into several forms including: roving where it's prepared in long cords, a rolag where it's rolled into a *"fluffy cylinder of fiber"* (P11) from a batt (a flat sheet of fiber pulled from a drum carder).

The term "sheep to shawl" described how makers can participate in the entire process. *"Sheep to shawl competitions"* (P5) involve groups of shearers, spinners, and weavers that bring a sheep fleece to a final garment within a set time. For some spinners, they were motivated to spin by the larger process. This perspective was exemplified by P26: *"I will wash it myself, card it myself, spin it myself, and knit it into mittens. I enjoy the process, [the] whole thing, from meeting the shepherds, to washing it, to carding it, to seeing the evolution of the yarn as it builds up on the spindle, to determining how I am going to apply it. The building blocks that you can see happening, and the connection to a different way of life. Genuinely to get a sense of being able to do something for yourself."*

3.3.2 Picking the parts you enjoy. Though participants often had experience with sheep-to-shawl processes, they highlighted how spinners can choose the steps they want to engage in. As P11 described how the craft has flourished and expanded: *"When I first learned to spin, you had to get wool straight from a shepherd* *and process it yourself. Now you could get stuff that is processed for the individual home spinner. The world of spinning has opened up, which is really kind of exciting and fun."* As P6 summarized: *"That's a benefit of spinning, you can pick and choose whatever parts of the process you enjoy."* Online markets have changed the way spinners can engage in their craft: *"Now the world is your oyster. You can order anything online, and they'll deliver anywhere"* (P22). As a result, spinners can *"find their spot"* (P14). As P31 discussed: *"You'll find the part of this process that is for you [. . .] whether it be combing, carding, spinning, weaving, or knitting. There's some part of that process that will be more enjoyable for you than the other parts, and then that's where you end up focusing your attention."* For example, individuals can buy prepared fiber where *"you can just sit down and spin it"* (P12). As a result, individuals who don't like the preparation stages can skip them. As P25 discussed this shift in their practice: *"I started spinning originally with a fleece [. . .] and I realized that was not the beginning point for me."*

Among fiber types, participants described finding their "spot" of fibers they preferred. As P1 summarized their material exploration: *"I do the things that I enjoy, and I try everything to find out whether I enjoy it."* Their personal preferences highlight the tactile and embodied experience of spinning – where both the feeling of the fiber and the "muscle memory" of spinning are important parts of the practice. Even participants who worked towards their Master Spinner Certificate[2], and had practiced and mastered how to spin with a wide variety of fibers, usually had fibers they preferred. For example, P4 described their preference for purchasing yarn when they wanted to make a project with cotton: *"I hate spinning cotton. I've done it. I can do it. I hate it."* Similarly, P6 described purchasing yarn for a project with silk: *"I find it kind of grippy, and I find it hard to draft, and so it's just something I don't enjoy spinning."* Some participants also discussed purchasing yarns for specific characteristics, such as washability for children's garments, or when needing a large amount of yarn.

3.3.3 Customization and personalization. One of the motivators for spinning is customizing the design process. As P1 described: *"I like being in control. I like being able to make exactly what I want."* Similarly, P28 discussed how the process of spinning goes all the way back to the fleece: *"I like to start from the fleece myself because it gives me control of the whole process"*. This ability to customize yarn was described as empowering. For example, P5 described it as *"one of the most powerful things I had ever done. It feels like I have power over the entire manufacturing process"*.

The most obvious example is the visual aspects of the yarn, such as the *"endless creativity of all the colour combinations"* (P27). On top of the ability to purchase and blend pre-dyed fibers to create custom blends of colour, half of participants (N=18) described the value of hand-dyeing. These participants enjoyed creating custom dyes, and either dyeing the fibers before spinning (to have a more variation and "depth" (P5) in the colour), or dyeing after spinning (for consistency or for clearer colour demarcation with techniques such as tie-dye), or dyeing during spinning (such as dying singles before plying them together). As P7 summarized the options: *"[You can] dye it when it's teased, or you can dye it when it's carded, or you can dye it when you spin it."* Dyeing practices varied from intuitive to more controlled with "spreadsheets" (P1) for dye formulas. Playing with colours and colour-combinations was described as a way of making yarns their own. As P21 described: *"That's a huge part of the appeal [of spinning] for me is that that aspect of manipulating colour."*

Spinners described the affordances of different fibers, and variations between breeds of wool: *"We look at the different breeds, because each breed of sheep produces a different kind of a wool."* (P7). These differences at the fiber level had an impact on the final result. As P32 summarized: *"Understanding how a fiber behaves is crucial to your garments"*. For example, the length of the fiber could influence what it can be spun with, and more curly fibers could be well-suited for decorative art yarns. As P17 summarized: *"There's massive variety in different sheep in terms of how long the fibers are (what we call staple length), how much crimp they have, [and] how they pull apart"*. Based on these differences, spinners adjust their practice. As P28 described, *"With every different breed I have to adjust my peddling and my drafting [. . .] so that I can produce a consistent yarn"* (P28). Fibers also feel different based on the thickness of the fiber (wide and coarse, or fine and soft) which varies depending on the breed of sheep and the body area the fiber was sheared from. *"Something coarse is going to be an outer sweater that's not going to be touching your skin or your face. If it's something you want to have close to your body, then you're definitely going to want a much softer, finer fiber"* (P29). Spinners look at the fiber diameter, i.e., microns of the fiber (μM), with lower microns resulting in a finer, softer result. As P20 summarized: *"Certain producers will actually send samples away to have the microns tested on it, and that definitely influences my decision to buy or not to buy [the fiber]"*.

3.3.4 Spinning for replicability. Participants had different ways of spinning depending on their outcome goals. For example, art yarns could be spun more intuitively, whereas yarns for specific purposes or large projects required planning and measurements for replicability. We had nine participants who had partially completed, or completed, the six-year Master Spinner certificate, where a large portion of their training was understanding how to work with different fibers and how to document the results for replicability.

When planning out projects, participants made sample yarns to determine the type of yarn they wanted to spin. Notes could be easily added to the sample by attaching cards (*"little tags"* (P2)) and writing reference notes. These notes ensure that a spinner can repeat their work. As P18 summarized: *"If I'm going to make something again, or if I haven't made enough for that project, I need to know the details."* Spinners recorded measurements to gauge the consistency of their yarns including preparation information such as the type of fiber used (for example, breed, staple length, μM, dye information), as well as wheel set up, and how it was spun. Wheel set up included the type of wheel used to spin the yarn (for spinners that have multiple wheels), and optionally wheel ratio, which can be increased or decreased depending on the whorl used on the machine. This ratio and whorl used determines how quickly the wheel spins the yarn. While spinning, spinners could measure their yarn by Angle of Twist (AoT), Wraps Per Inch (WPI),

[2] There are two main programs in Canada that offer the Master Spinner Certificate including Olds College in Olds, Alberta and the Ontario Handspinning Seminar offered through the Haliburton School of Art and Design in Haliburton, Ontario. Each program is approximately 6 years long.

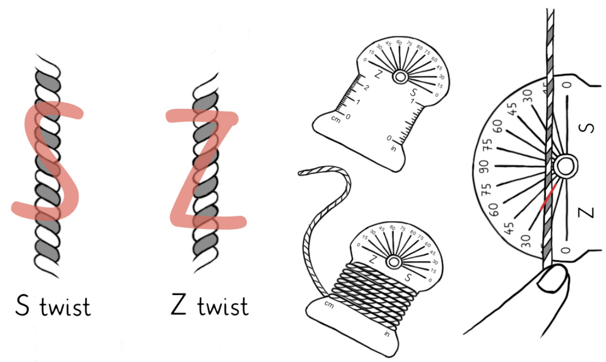

Figure 5: Spinners have yarn gauges for quality control. They allow spinners to assess Wraps Per Inch (WPI, here: 8) and Angle of Twist (AoT, here: a 30 degree Z twist) to ensure the replicability and consistency of yarns.

and Yards Per Pound (YPP) (see definitions in appendix A). Angle of Twist, measured with a protractor, ensures that yarn is spun at a consistent angle. Wraps Per Inch measures the thickness or diameter of the yarn. By wrapping yarn around an inch of a measuring tape, you can then count how many times it can be wrapped to ensure a consistent diameter. Yards Per Pound, also known as grist, measures the density of the yarn (i.e. how much fiber or weight is packed into 1 yard).

Many spinners have Angle of Twist and Wraps Per Inch on a little measuring tool (*"a spinner's control card"* (P23)) to keep track of these measurements while spinning. As P21 summarized, *"[It is] essentially a quality control card, so that as you are spinning you can check to see if it matches"*. This enables a spinner to spin consistently over several sessions: *"I can pretty well pick up where I left off and not change the diameter or the degree of twist"*(P12). It also helps individuals if they want to repeat a yarn they have spun before: *"I was trying to recreate a blend [...] the tool card was super important for me, because I needed to match the yarn that I had made a year ago"* (P23). Overall, though many spinners have an intuitive aspect to their practice, there are also ways to measure their hand spun yarn for replicability and consistency.

3.4 Theme 3: An embodied practice

3.4.1 Tactile and meditative spinning. Though spinners could spin for control and replicability, such as when working towards a specific outcome, most participants (N=23) had an improvisational aspect of their practice that involved spinning just because they *"enjoy spinning"* (P31). As P16 described the difference: *"Sometimes I do have a project in mind, but often I don't have a particular project in mind. It's more about the process for me."* These participants enjoyed spinning for the sake of spinning. Improvisation could involve picking fibers to spin based on mood, such as P15, *"My favorite is to go up to the [spinning wheel] room and think, 'Okay, what do I feel like today?', and start pulling the colours."* Participants also improvised by "listening to" or responding to the fiber. As P27 described their approach: *"The fiber will tell you what it wants. When you're spinning the fiber, it wants to be spun bulky or it wants to be spun fine, and I let it do what it wants to do"*.

Along with spinning to spin, almost all participants (N=29) discussed the meditative and tactile enjoyment of spinning. They highlighted that *"there's the tactile part of it"* (P24) and that is an important reason why they engaged in the craft. Spinners described spinning as meditative and how it made them focus on their tactile experience. As P3 described: *"I love the feel of the fiber in my hands [...]. I just spin away and I'm in this la la land!"* Spinning required just enough focus: *"Spinning focuses my brain on what I'm doing with my hands, and I can calm down and relax and just enjoy what I'm doing"* (P23). Most participants spun using a spinning wheel, where hand drafting was combined with the foot movement of treadling. Experienced spinners get into a repetitive *"rhythm"* (P21), which improved the consistency of their yarn. Overall, spinning was described as *"meditation with movement"* (P19).

Spinners identified as *"people who like to touch things"* (P14). For example, the most common criteria for evaluating a successful yarn was whether it felt nice, *"How does it feel?"* (P22). When meeting with other spinners to share materials or yarns, participants described that it was common to physically feel the materials being shared. As P20 described a successful yarn: *"I'm looking for something that, almost unconsciously, makes you want to reach out and touch it"*. Participants described spinning as *"satisfying" (P14)* due to how it combines this meditative tactility with a tangible end result – *"it is meaningful and tangible"* (P5). As P16 described, spinning is enjoyable because *"you have something to show for it at the end."* Participants were motivated to spin by this combination of relaxation and productivity, as P21 described: *"There's something really satisfying about doing something for the meditative benefits and then getting something at the end of it."*

3.4.2 Breaking down the embodied movements. Along with the meditative aspects, almost half of participants (N=15) discussed coordination as the hardest part of learning how to spin on a wheel – *"getting the coordination between your feet, which are moving and rotating the wheel [treadling], and the hands, which are drafting"* (P30). As P13 summarized: *"The most difficult thing is to get the tension and rhythm"*. This embodied skill, like *"riding a bike"* (P14), was required lots of practice and then suddenly *"it just clicks"* (P1). As P7 described: *"When you're starting to learn it's very frustrating, and then suddenly you've got it"*. To make it easier for beginners, most participants (N=17) recommended breaking down the steps by learning how to draft with the hands first , and then learning how to treadle with the feet. This *"splitting of the learning process"* (P6) enables individuals to focus on drafting , rather than coordination between drafting and treadling. As a result, most beginners start with a drop spindle rather than a spinning wheel. As P32 described: *"People prefer to teach on a drop spindle, because then you are just doing the drafting process without the foot engagement"*. E-spinners, which spin using a motor, were described as easier for the same reason – *"learning on an electric wheel I think is the easiest way to start because you don't even have to worry about your feet"* (P20). As P12 summarized, this also has accessibility benefits: *"You don't have to have your feet on the treadles. For people who have motor issues, it's a great thing because it allows them to continue to spin"*.

4 STUDY 2: E-TEXTILE YARN WORKSHOPS

We elaborated on study 1 with a workshop that encouraged spinners to create e-textile yarns.

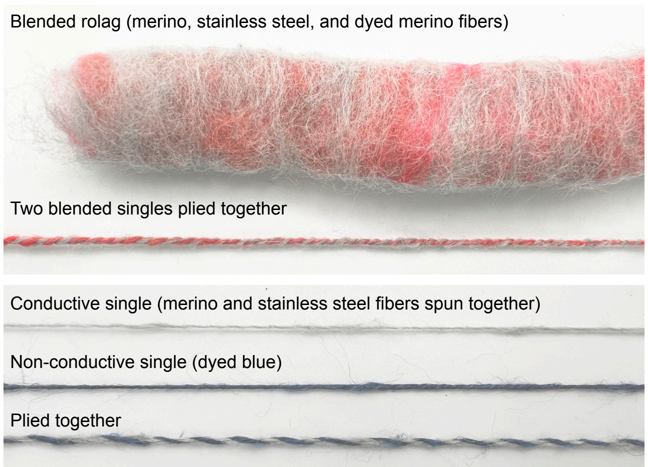

Figure 6: Hand-spun, conductive yarn can be created by blending fibers together (top) or by plying conductive and non-conductive singles together (bottom).

Figure 7: Materials available during the workshop included (left to right) Merinox from Bart & Francis, conductive stainless steel filament from Adafruit, and stainless steel conductive thread from Sparkfun.

Figure 8: Participants experimented with (1) spinning the e-fibers, (2) measuring conductivity with a multimeter, and then (3) using the Adafruit Circuit Playground Express and block coding to program capacitive touch interactions.

4.1 Preparing the workshops

In preparation, we created samples (Figures 6) to demonstrate how conductive materials could be blended, hand spun, and plied; how to measure the conductivity of the yarn with a multimeter; and how to work with capacitive touch and yarns on the Adafruit Circuit Playground Express. We also mapped the practices discussed in Study 1 by providing three different commercially available conductive fibers (Figure 7 and 9).

4.2 Method

We pursued two research questions:

- ***Q4***: How do spinners feel about the tangible materiality of working with e-textile fibers?
- ***Q5***: If, or how might, spinners imagine e-textiles being incorporated into spinning practices?

4.2.1 Participants. We advertised through a local spinning guild during a month-long festival where members could sign up for workshops and learn new skills. On signup, participants indicated what tools they use, and their experience with spinning (see Appendix, Table 2). All 6 participants (W1-W6) were experienced spinners.

4.2.2 Procedure. We conducted in-person workshops followed by individual interviews.

Part 1 - workshop: Workshops introduced e-textiles with an overview of the history of this research field. Participants then experimented with spinning e-textiles using their tools, materials, and e-textile materials. We brought local wool and three types of conductive materials (Figures 7 and 9) that are commercially available for spinners including:

(1) MerinoX wool steel fibers mix (80% Wool 20% Extra fine steel fibers) from Bart & Francis [6]
(2) Stainless steel filament fibers from Adafruit [2].
(3) Conductive Thread 60g (Stainless Steel) from Sparkfun [101].

Participants spun a sample. Then, we demonstrated measuring conductivity with a multimeter. Subsequently, participants then moved back and forth between spinning and testing samples. After a few samples, we demonstrated capacitive touch with the Adafruit Circuit Playground Express microcontroller [1] and showed block coding in Microsoft Makecode [69]. Finally, participants created interactive systems with their yarns: they combined capacitive touch interactions with their custom yarns that could, for example, trigger lights or sounds from the microcontroller when touched.

Part 2 - interview: Afterwards, we interviewed each participant 1-on-1 about their workshop experience. Questions included what it was like to work with conductive fibers, their learning curve, how easy or difficult they found the activities, and ideas for future research directions.

4.2.3 Data analysis. We analyzed 5 hours of transcripts using the same method as Study 1 (Section 3.1.3).

4.3 Theme 1: Familiarity with adapting to fibers

Participants described how trying new fibers, and getting used to spinning with them, was part of their spinning practice. After the basics, i.e., *"getting their feet coordinated with their hands"* (W5),

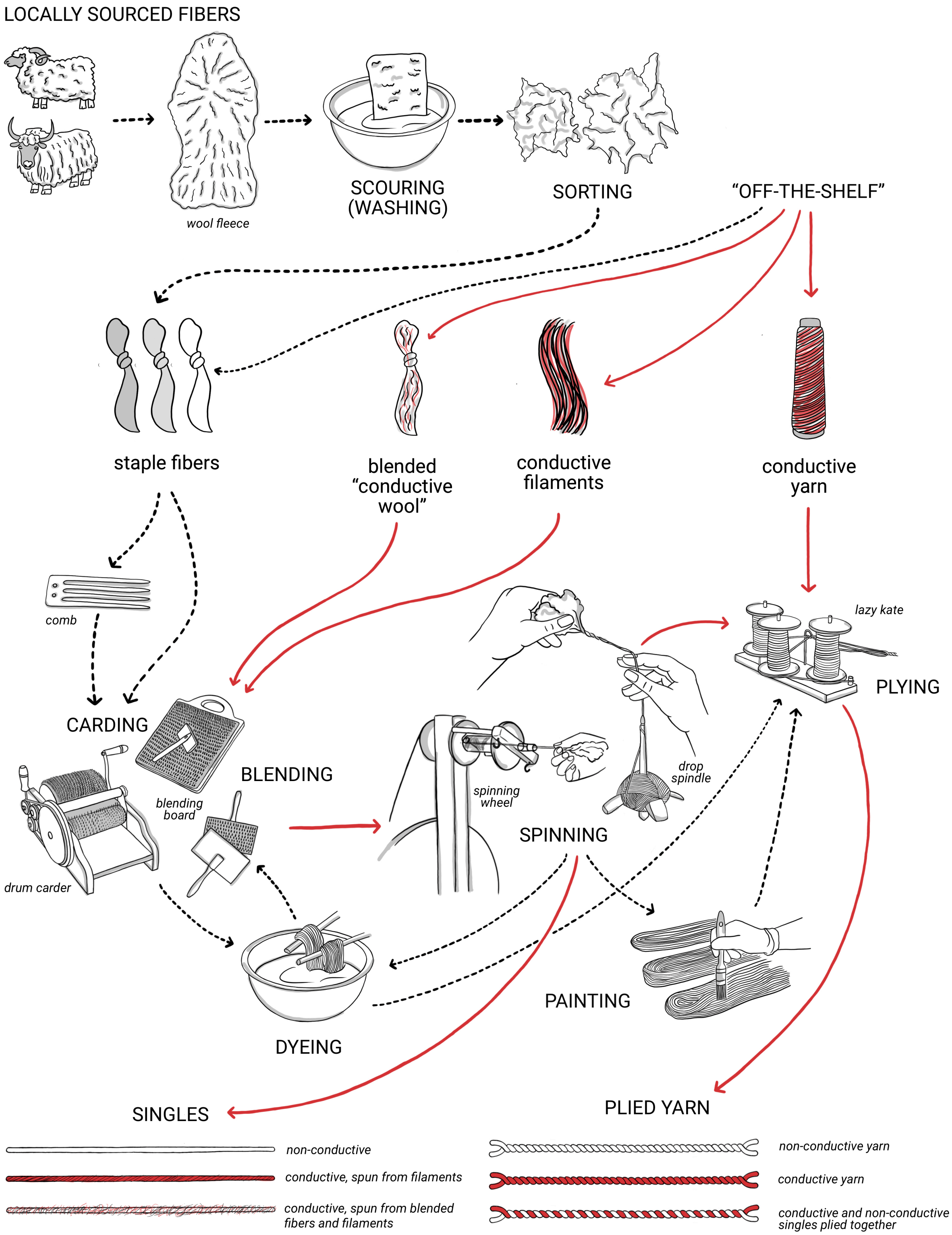

Figure 9: Hand spinning process with conductive fibers. Areas with red solid lines were explored in the workshops in Study 2, the dotted lines show the expanded space discussed in the interviews in Study 1. This overview provides opportunities for e-textile researchers to leverage spinning techniques and design variables to customize their yarns.

Figure 10: Participants created e-textile yarns that were conductive and could "blend" into textile projects.

spinners next gain expertise on how to atune their spinning practice to fibers with different characteristics. Thus, while e-textile spinning might not be a good starting point for novice spinners, sampling and adjusting to new fibers is common practice amongst intermediate spinners. Participants reported that spinners *"all have a tendency to branch out, and everybody has their thing that they work on"* (W2). They named the ability to share fibers and expertise, and try out different samples, as a benefit of guild membership. W5 elaborated on the e-textile fibers: *"That's the kind of thing that would actually be fun in a guild setting [...] you just go out and say, 'Hey, would you like to try this out?'"* When acquiring a new fiber, participants spin samples and gauge *"How do you adjust your spinning style to accommodate that fiber?"* (W1). W4 described adjusting to the e-textile fibers: *"I did that first little sample and was like, 'Oh, yeah, less twist', and then it was fine."* Experimentation with novel materials was a motivator for participants, who described trying new things as part of the fun of spinning. This motivated W2 to sign up for our workshop: *"It was a big step out of my comfort zone, which is the biggest reason why I did it."*

Comparing e-textiles to fibers they had spun before, participants noted: *"Some of them felt similar to what I'm used to spinning, but it was nice to see the reaction that it was conductive"* (W6). They compared it to "rustic" materials like rough wool - *"they don't necessarily draft super easily. You have to work at it a little bit, or you prep it in a certain way, so that it will draft more easily [...] it wasn't completely different that way"* (W1). Compared to fibers like wool, participants described the e-textile fibers as less stretchy: *"there was no give to it"* (W6). W5 summarized: *"When I'm spinning with wool or alpaca, or silk, or stuff like that, it's easier to attenuate, to stretch out, whereas the [e-textile fiber] strands that I was using weren't. [...] You couldn't pull it out and stretch it."*

4.4 Theme 2: Fibers need to match

4.4.1 Filament affords customization. Due to the e-textile's lack of stretch, blending gained importance during the design process. E-textile fibers were blended with fibers that matched. While blending, participants asked themselves: *"Does it match the fiber that I'm putting it with?* (W5). W1 explained how the lack of stretch caused the materials to not *"draft very easily, but it wasn't totally offensive. I knew it was different and [then worked on] trying to blend it together with something else"*. This desire for matching fibers led participants to appreciate the stainless-steel filaments because they could be cut to custom staple lengths and customized to match the fiber they wanted to blend. The resulting blend was also easier to spin and softer. W4 explained how this transformed the metal fibers, which initially felt harsh, into a material that was nice to spin: *"It's counter-intuitive to be spinning with metal, we're so used to soft fiber. We cut the long one into pieces and blended it in, and I like that because we had a lot of control over how much would be used, which made it feel softer. [...] You want to have something that feels kind of soft on the hand. I think part of the reason some of us spin is the tactile thing, how it feels. [...] We cut it to the length the same length as the wool fiber, and then started to raise the proportion of wool versus to the proportion of metal, which made it softer and easier to spin. But we did check conductivity to make sure we'd included enough of it."* Creating custom staple lengths allowed them to create a final blended yarn with almost no distinction between regular and e-textile fibers as captured in W2's experience: *"I was surprised that I liked how it felt afterwards. I was not completely turned off by it. It just sort of blended in really well. It didn't sit there and scream 'I'm man-made'. There wasn't this division of fiber in the end"*.

4.4.2 Making the match. Spinners needed certain details to "match up" materials. If a seller didn't provide details, for example when buying material from a local farmer or *"buying fibers that are off the beaten track"* (W2), participants discussed how the name of the breed or name of the plant was enough to look up the characteristics online. For example, looking up a specific breed will provide approximate measurements. W3 described how breed was the first thing they would look up: *"I think I'd like to know what breed of sheep, because that makes a difference to the length of the fibers"*. When buying prepared or blended materials they similarly would *"look for staple length"* (W1) as well as measurements such as *"the diameter of the fiber"* (W4) and *"the thickness of it"* (W6). This information would give spinners the ability to *"compare to other things they've already worked with"* (W4). In this way the e-textile materials created a friction. They were too novel a material for individuals to look up the content through traditional methods, instead relying on the supplier information. As a result, when suppliers don't provide this information it creates a blocker.

4.5 Theme 3: E-fibers create wear and residue

4.5.1 Wear and residue on tools. Spinners like to use their own tools, as W2 described, *"spinners tend to be very personal about what they like to use"*, and especially when trying new fibers like to use familiar tools. At the same time, the use of their tools brought up concerns about wear and residue from the e-fibers. Some wear was described as natural, and during the workshops participants showed areas where materials would rub their tools and create grooves – *"[wheels] will get grooves over time it's just the nature of the beast"* (W2). As W5 described: *"Where it [i.e. the fiber] feeds into the wheel it comes across the wood. Even just using normal fiber, I've got a groove that's been worn over the years into the wheel"*. Participants were concerned that doing a lot of e-textile spinning would accelerate this wear. As W4 described: *"The wood kind of gets eaten away, naturally, with any yarn, and this one [i.e. the stainless steel] probably would speed that up"*. Participants suggested providing "guards" for the e-fibers. As W4 summarized the group discussion: *"We thought about maybe a little guard over that section that could be inserted. It would be easy enough to make something that clipped in"*; or as W5 described: *"a tough little gizmo that you'll overlay somehow"*.

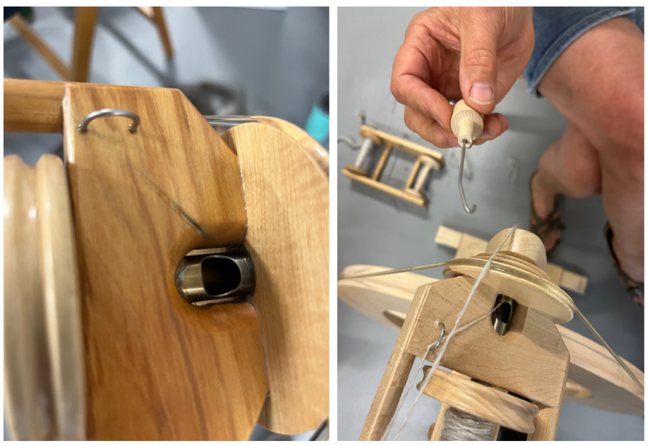

Figure 11: Participants showed us areas of the wheel that naturally get worn down from the friction between materials and the wood (left). Participants discussed wanting to have a tool to measure yarn while spinning. One group discussed creating a wheel orifice hook that could do so and having yarn measurements available "on wheel" (right).

Similarly, preparation tools, such as hand carders, were areas of concern. As W6 described: *"I would worry about the hand carders [. . .] Some of the hand carders and the drum carders they're expensive little tools [..] I don't know how long you could play with the steel before [they] would be wrecked."* W2 recommended having another set for working with the e-textiles: *"Would I use my good hand cards on it? Probably not. If I was going to do it on a regular basis I would probably have 2 sets of carders."*

Participants with experience in sheep to shawl competitions, i.e. where they would spin raw fleece (coated in lanolin), compared the e-fibers as creating a similar residue. As W1 described: *"It's a little bit like when we do sheep to shawl, and we're spinning in the grease, spinning the raw fleece that's not been washed. After that my wheel is covered in lanolin, and I always have to wash it all down. So same sort of thing. I would want to wipe it down."* W2 described how e-fibers would create a similar maintenance task: *"If you spin dirty fiber [. . .] you have to clean it regularly. A lot of people don't do that. So that would be my only issue with the wheels. Just make sure that it's wiped down and oiled regularly while you're spinning it. I would say after every bobbin."* This combination of wear and residue was a concern due to the preciousness of the tools. As W2 described, spinners with a full set of equipment would really value those tools: *"Anybody with spinning equipment that does it a lot will spend a ton of money on those things. Spinning equipment is expensive"*.

4.5.2 Spinning safely. Alongside equipment, participants brought up how spinning a lot would create concerns about continuously rubbing materials against your skin. Part of this was due to the material's lack of flexibility and stretch while drafting. As W5 discussed, sometimes spinners will go fast on the wheel and materials can get caught - *"is it going to slice into my fingers?"*. A more common reflection was noticing residue on their hands after the workshop: *"We washed our hands afterwards [and] you don't realize how much is on your hands until you washed and you could see it."* (W1). W2 recommended including wipes in workshop settings to emphasize these safety aspects: *"For some people the visuals [are] what makes them learn, so the visual of 'This is what you just wiped off your hands'. So, this is why you don't touch your mouth. You don't eat while you're doing this, you don't touch your eyes, and [you] wipe your hands off regularly."* Not eating or touching your face while spinning, and hand washing afterwards, are common spinning practices due to working with animal and plant fibers, but the increased residue with the e-fibers made this practice more important.

Participants also discussed protective equipment. Spinning with gloves is not viable, due to the tactile nature of spinning. Instead, W5 discussed lap protectors for spinners, especially when working with messy fibers: *"I would have brought my lap thing. Not everybody has one of those, but a lot of us do. It's just a piece of leather, or pleather, or vinyl, or something like that. Something to protect you."* W4 discussed working with messy fibers, and how bits of fluff can get in the air while spinning: *"I did wonder about this idea about inhaling metal. Because when we do a lot of work with flax or linen, [. . .] it always comes off as you're weaving or spinning, and some people are quite sensitive to it. So, I'm not sure about how the metal is that way, whether we need to be worried about that."*

4.5.3 Only for small amounts. The concerns brought up by participants on residue and wear were extrapolating on doing a lot of e-textile spinning (for example, production spinners who produce skeins at scale). In contrast, participants discussed how e-textile spinning was more suitable to small amounts and one-off projects. For example, if you were making an interactive garment, only a portion of it would use conductive yarn. W1 expressed feeling conflicted about e-textiles at first, but then warming up to the idea of using only a small amount in a project. W1 noted: *"It felt strange as somebody who really promotes natural and local fibers [...] how does that [i.e. e-textiles] fit with my belief? There [are] lots of fibers that are available that I won't use because of the way they're processed, but then I realized we weren't spinning a bunch of it. To put it in a project you would only use it in a particular area or a small amount."* W2 similarly described a change to a more positive attitude when they realized an interactive project could still be mostly natural fibers: *"The whole combining technology with fibers [...] I really was struggling with [it]. 'Am I gonna like this? Is this just gonna be more than my psyche can deal with?' [...] I came out with a very different impression than I went in with. It really changed* *how I look at pairing technology with natural fibers".* These shifts in attitude demonstrates the importance of small amounts when hand spinning e-textile where large volumes feel incompatible with hand spinning practice, both due to residue and wear but also due to preferring natural fibers.

4.5.4 How will it react? Participants voiced the need to understand how a material will respond to activities, such as washing or dyeing. They discussed how dyeing, and its affordances for customizing fibers or spun yarns, was a core part of their spinning practice. As W6 asked: *"What would happen if I took that yarn and dyed it?"* As materials tend to respond differently to different dyes, participants would adapt their dyeing recipe, or when they dye in the spinning process. W5 explained their dyeing decisions: *"Sometimes I might be trying to dye something, and I might be using a vinegar as a mordant, or I might be using a different kind of mordant. Is that going to react with the steel? Should I change the color that I'm trying to [spin with] this stuff [i.e. the e-fibers], or should I dye it first, and then spin it?"* Not being able to dye the e-fibers could be adapted to, and in workshops we said not to dye them due to a lack of information from suppliers. To adapt to this constraint, participants said they could dye the materials before blending with the e-fibers, or ply a custom e-textile yarn with another yarn they had dyed. Overall, if fiber suppliers provide this type of information in the future, it would open up the design space possibilities for spinners.

Another concern was washability. We said not to wash them due to a lack of information from suppliers, as well as one supplier warning of the impact of detergents. Overall, participants discussed how spinners expect information on *"fiber care"* (W4), and critiqued how e-textiles fibers were not being sold for fiber audiences. W2 discussed the tension: *"This fiber was not developed by a spinning company for spinners [...] so spinners have to adjust to what it was developed for, because it was not developed for them".* With a lot of experience teaching spinning workshops, W2 would include this specific information when introducing a fiber to spinners: *"If I was teaching [a new fiber], there would be a discussion about care, wearability, all these things that are part of garment construction. Because, basically, unless you're doing a wall hanging, most people are spinning and working for garment construction, you know, sweater, socks [etc.]"* (W2). W3 got stuck on washability: *"The washability is something that bothers me, because if you can't wash it then how can you use it? Because anything that you make with a fiber you need to be able to wash it."* Delicate washing methods were acceptable for spinners. Thus, inability to machine wash the materials was not a deterrent. W5 described: *"Most of the stuff that I make I would hand wash, usually in cold water".* It is rather the lack of details on washability that created a blocker. Including this type of information would help spinners understand the constraints of the material and how to use it. W1 summarized: *"If it's really delicate, you would have to think about a different application."*

4.6 Theme 4: Application-focused spinning

4.6.1 Focus on function. Participants observed that e-textiles fit the planning parts of their practice better than intuitive or art-yarn practices. Rather than "spinning to spin", they would use e-fibers only within a planned project. All participants described planning their project and application as their next step. W1 elaborated: *"So we've explored the spinning of it. Now it's [time to] think of an application".* Leveraging the planning side of spinning involves moving backwards, with the end goal in mind. W2 noted: *"What's the end result? And what do I have to do to get there?".* Participants would then customize all the spinning design parameters (such as preparation and fiber blend; yarn spinning measurements like angle of twist, diameter, density; and aesthetic characteristics like dye colour) to suit the specific application.

4.6.2 Testing while spinning. During the workshops, participants moved back and forth between creating and testing - spinning samples and then testing them with a multimeter. Yet, they expressed interest in testing ***while*** spinning. Similar to other spinning tools used to measure yarn (such as cards for measuring angle of twist and diameter), participants strove to be able to test the conductivity of their yarn while spinning it. W1 summarized their need for *"an easy way to test for conductivity as you're doing it. [...] Something right at the wheel, so that you can check while you're doing it."* Participants discussed opportunities for leveraging spinning wheel accessories, such as the spinning wheel orifice hook, also known as a threading hook, which is used to guide yarn into the spinning wheel. W4 described the group's concept of *"a hook that is also a tester. It, first of all, would be fairly easy to make, and it would serve two purposes which I do like as well."* Overall, participants highlighted the value of technology and tools being able to provide information on yarn composition, saying things like *"I'd like to know the proportions of the mix"* (W3) and *"the percentage of stainless steel to wool"* (W4). For example, W5 imagined a project where the material could tell someone what it was: *"You could make it so the fiber itself can tell them what it is in some way".*

5 DISCUSSION

Our results highlight opportunities and frictions when hand spinning culture meets e-textile materials. We discuss the information spinners need to inform their design decisions, suggestions for future work on embedding assistance and guidance on wheel, and the role of hand spinning within the maker movement.

5.1 "This fiber was not developed by a spinning company for spinners"

This sentiment by W2 was echoed throughout post-workshop interviews. We only used commercial products, yet participants expressed that the information we could gather from available product descriptions left out key details or was not consistently available across products. Participants expressed the need for the following information to inform their design decisions: (1) fiber measurements (such as staple length and diameter in μM), (2) fiber care information (such as washing, drying, bleaching, ironing), and (3) fabrication information (dye compatibility and spinning safety). They were also interested in knowing the origin of fibers, such as the location and breed information for prepared blends. They expect this information to be provided by producers because they couldn't reference traditional resources. In contrast, e-textile researchers are typically looking for other types of information when making material decisions, such as resistance in Ohms per centimeter (Ω/cm), and how much voltage (V) can be safety applied to a yarn. By interviewing spinners on their information needs, our aim is that fiber producers could expand their market to fiber crafters and hand spinning practitioners. This would further enable deeper material exploration [78], which is currently left out of most e-textile toolkits [84].

5.2 The "Planner-Improviser Spectrum"

Even though e-textiles often fit within application-focused practices, participants expressed a desire to have information available "on wheel" in real-time. This relates to what Jelen et al. [44] note on fiber practitioners existing along a "Planner-Improviser Spectrum" - with some practices requiring structure and pre-planning and others enabling improvisation. Due to their tactile enjoyment of the practice, most of our participants incorporate both sides into their practice. Requesting information "on wheel" links to research on improvisational guidance in textile fabrication, such as recent work on operational guidance on knitting machines [110] and braiding devices [112], improvisational peddals [110] and patterns [3] for digital looms, or supporting improvisational quilt pattern design [63, 64]. Participants had tools for measuring yarns ***while*** spinning, such as the spinner control card for gauging Angle of Twist and diameter in Wraps Per Inch. Similar tools exist for stitching e-textiles, such as Posch's e-textile tester tools for measuring a stitched trace [80, 82, 83]. These tools enable makers to make corrections while crafting rather than fixing mistakes afterwards [80, 82, 83]. Other tools enable easier "undo" actions [38], or leverage reversible processes [16, 52, 56, 111]. E-textile toolkits aim to make parts that can be combined to create prototypes, and then taken apart and iterated upon to fix mistakes [43, 50, 84, 99].

Providing yarn conductivity information "on wheel" would let spinners enjoy the tacit and meditative aspects of spinning, rather than interrupting their spinning process to test for conductivity. By interviewing spinners on what they need from the practice, our work encourages future innovations that are usable to craft practitioners, building off of hybrid craft innovations such as sewable microcontrollers [13] and tangible methods of information sharing [32, 37, 47, 79]. By more deeply understanding the barriers to participation [68, 70], as well as potential opportunities [15, 20, 23, 103], we aim to enable future work in making e-textile crafting more usable to groups of interested practitioners.

5.3 Hand spinning and the maker movement

The digital fabrication revolution enables individuals to share digital patterns and re-create objects locally [30] in ways that also intersect with the textile industry. Today, makers can recreate textile machines with digital files at any makerspace. For example, researchers have developed digital files for Jacquard Looms [4], and knitting machines [33–35, 93, 94, 107], and this enables others to build, and remix these innovations [48]. Spinning is part of this revolution as well. Drop spindle designs are widely available for 3D printing and laser cutting. E-spinners (electric spinning wheels) enable spinners to hand spin and draft into a motorized wheel, rather than peddling with their feet, and have also seen a growth among spinning communities. For example, Dreaming Robots [91] and Studio Hilo [39, 40] have released e-spinners with files for reproducing them yourself. The benefit of this approach is making the files available to spinning communities for feedback and continuous iteration and design improvements. For maker communities, digital fabrication provides the opportunity to reproduce patterns using local materials.

Spinners are similarly value driven [100, 106, 109]. Participants described valuing DIY approaches to spinning, such as making drop spindles out of everyday materials, and working with local communities of farmers to source their fibers. Spinning involved not just the act of hand-spinning but all the design decisions along the way. For participants who worked in a "sheep to shawl" process, they valued the ability to create something "from scratch". At times the use of "man-made" fibers with e-textiles created frictions, but participants described feeling positively towards using small amounts and blending them with natural fibers. This also provides an opportunity for future research to explore making conductive yarns that further blend into these natural fibers, and expanding on initial research in HCI on biodegradable interactive materials [57, 62, 74, 116]. Participants highlighted how their communities could benefit from digital fabrication, such as the ability to fix tools, make custom spools, and how tools (e.g., e-spinners) have made spinning "on wheel" more portable and accessible.

6 CONCLUSION

Hand spinning provides the opportunity to customize e-textile computing to match a maker's creative vision, and create projects that blend into their environment. For example, spinners can customize the fiber characteristics used, the colour of the yarn, the texture of the yarn, and leverage local sourcing (Q1). There are different ways that spinning tools can be accessible (or made in a DIY manner), can be used on-the-go, and the way that spinners have measurement tools to ensure the replicability of their yarns (Q2). Participants in our studies discussed their tactile enjoyment of spinning, and how next to pre-planned and replicable projects for specific outcomes, they enjoyed the intuitive or improvisational part of their craft practice, valuing the "feel" of spinning (Q3).

Based on the processes participants described in Study 1, we then mapped out the spinning processes and e-textile materials we could leverage in workshops with spinners. We then conducted Study 2, workshops with local spinners at a spinning guild with the e-textile fibers, to better understand the constraints and opportunities for spinning e-textiles. Participants discussed how the e-textile materials create residue and wear, and as a result should only be used for small batches (Q4). They also discussed how trying new fibers is a part of the practice for intermediate spinners, how e-textile fibers and non-conductive fibers need to "match", and how e-textiles would fit with the application and project-focused part of spinning practices (Q5). Overall, the main constraint that arose was how commercially available e-fibers were presented in a way that impeded spinners from designing with them, and we map out their needs for working with a new fiber and incorporating it into their practice. Our goal is to further the interdisciplinary understanding of hand spinning by discussing both the processes that HCI researchers can leverage in future work, as well as providing a better understanding of how spinners approach e-textile fabrication, and the constraints they experience along the way.

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A DEFINITIONS

- Angle of Twist: When fiber is spun it is twisted. Different fibers will require more or less twist to hold together. As a result, spinners measure the angle of their twist to ensure a consistent yarn.
- Batt: When fibers are prepared with hand carders or drum carders to create a sheet of fiber. This sheet of fiber is called a batt.
- Blend: The blend is the mix of fibers to be spun. When mixing fibers, spinners will often see this as a percentage of each material.
- Bobbin: On a spinning wheel, the bobbin is the part that collects the yarn that has been spun. It is a removable piece that can be taken off.
- Carder: Also known as hand carder (see hand carder).
- Drafting: Drafting is the attenuation by hand of prepared fibres while spinning.
- Drop Spindle: A drop spindle is a balanced weight that an individual spins by hand to wind on, and spin their yarn.
- Drum Carder : A crank machine that turns two cylinders with wire spikes. Fibers placed in the middle will go through the carder and this prepares them (into a batt) for spinning.
- Electric Spinning Wheel (or e-spinner): A device that uses a motor to increase the speed at which a yarn can be spun.
- Fleece: Fleece is the fiber that protects certain mammals, such as sheep, from the elements. Sheep need to be sheared of their fleece because they do not naturally shed.
- Grading: Organizing the fleece tufts by quality and other characteristics such as length. Used because different aspects of the fleece can be exposed to wear (such as near the legs or underbelly), and the fleece also has slightly different characteristics depending on where it is on the body.
- Hand Carder: These brushes are used in pairs to open up fibers and prepare them for spinning. By brushing the fibers between them, it pulls the fibers into alignment.
- Hank: A coil of yarn for dyeing or storage.
- Lazy Kate: A tool that holds yarn bobbins to be plied together.
- Niddy-Noddy: An object with two cross pieces that is used for winding yarn after it has been spun. The distance between the crosses is made to a specific length so that spinners know how much yarn they have by how many rotations they are able to wind on.
- Ply: Means that a yarn is made of more than one single that have been twisted together.
- Rolag: After creating a batt by carding, a rolag is made by wrapping the batt around a stick or other tool to create a cylinder of fiber. This fiber is then ready to spin.
- Roving: When fiber is carded or combed into a long strand in preparation for spinning. It is most commonly used to create worsted yarn.
- Spinning Wheel: Any machine that increases the speed of spinning. Many are foot operated.
- Staple Length: The length of a tuft or lock of fleece.
- Tease: Opening up the fibers by pulling them apart.

- Top: When fibers are commercially prepared into long rope-like strip.
- Treadling: The foot movements involved in activating a spinning wheel. Spinners must coordinate their treading speed with how quickly they can hand draft their fiber.
- Whorl: The whorl is a circular pulley that drives the spinning wheel motion. Depending on the size of the whorl the spinning wheel will spin faster or slower. Whorls can often be swapped out so that spinners can change how fast they would like to spin a specific fiber.
- Woolen: A blend of short fibers that are carded to create an "airy" fluffy yarn.
- Worsted: A blend of long fibers that are aligned.
- Wraps Per Inch: A measurement used to evaluate the consistency of the diameter of a spun yarn.
- Yards Per Pound: A measurement used to evaluate the density of a spun yarn.

B PARTICIPANT DEMOGRAPHICS

Table 1: List of study one participant demographics including: years of experience with spinning, tools used for spinning, and spinning activities they engaged in. Participant age ranges included: 2 aged 20-39, 9 aged 40-59, 20 aged 60-79, and 1 aged 80-100. Participant pronouns included she/her (22), he/him (2), they/them (1), and 7 chose not to disclose.

ID	Experience	Spinning Tools	Spinning Activities
P1	32 Years	Spinning wheel, Drop spindle	Spinning, selling, teaching
P2	15 Years	Spinning wheel, Drop spindle, Charkha	Spinning, selling, teaching
P3	47 Years	Spinning wheel	Spinning, teaching
P4	17 Years	Spinning wheel, Drop spindle	Spinning
P5	8 Years	Drop spindle	Spinning
P6	10 Years	Spinning wheel, Drop spindle, Supported spindle, E-spinner	Spinning
P7	12 Years	Spinning wheel, Drop spindle	Spinning, selling, teaching
P8	12 Years	Spinning wheel, Drop spindle, E-spinner	Spinning, teaching
P9	34 Years	Spinning wheel	Spinning, selling, teaching
P10	52 Years	Spinning wheel	Spinning, selling, teaching
P11	47 Years	Spinning wheel, Drop spindle, E-spinner	Spinning
P12	48 Years	Spinning wheel, E-spinner	Spinning, selling, teaching
P13	30 Years	Spinning wheel	Spinning, teaching
P14	6 Years	Spinning wheel, Drop spindle, Walking wheel/great wheel	Spinning
P15	13 Years	Spinning wheel, Drop spindle, Supported spindle	Spinning, selling
P16	10 Years	Spinning wheel	Spinning, teaching
P17	3 Years	Spinning wheel, Drop spindle	Spinning, teaching
P18	11 Years	Spinning wheel, Drop spindle, Charkha	Spinning, teaching
P19	57 Years	Spinning wheel, Drop spindle	Spinning, selling, teaching
P20	14 Years	Spinning wheel, Drop spindle, E-spinner	Spinning, selling, teaching
P21	2 Years	Spinning wheel, Drop spindle, Supported spindle, E-spinner	Spinning, teaching
P22	2 Years	Spinning wheel, Drop spindle	Spinning
P23	5 Years	Spinning wheel, Drop spindle	Spinning, teaching
P24	20 Years	Spinning wheel, Drop spindle	Spinning, selling
P25	5 Years	Spinning wheel	Spinning, selling, teaching
P26	30 Years	Spinning wheel	Spinning, selling, teaching
P27	50 Years	Spinning wheel, Drop spindle, Supported spindle, E-spinner	Spinning, teaching
P28	45 Years	Spinning wheel, Drop spindle	Spinning, selling, teaching
P29	50 Years	Spinning wheel	Spinning, selling, teaching
P30	11 Years	Spinning wheel, Drop spindle	Spinning, teaching
P31	40 Years	Spinning wheel, Drop spindle	Spinning, selling, teaching
P32	16 Years	Spinning wheel, Drop spindle, E-spinner	Spinning, selling, teaching

Table 2: List of study two participant demographics including: years of experience with spinning, tools used for spinning, and spinning activities they engaged in. Participant age ranges included: 1 aged 40-59 and 5 aged 60-79. Participants pronouns included she/her (4), and 2 chose not to disclose.

ID	Experience	Spinning Tools	Spinning Activities
W1	9 Years	Spinning wheel, Drop spindle, E-spinner	Spinning, selling, teaching
W2	30 Years	Spinning wheel, Drop spindle	Spinning, selling, teaching
W3	10 Years	Spinning wheel, Drop spindle	Spinning, selling, teaching
W4	12 Years	Spinning wheel, Drop spindle	Spinning, selling
W5	20 Years	Spinning wheel, Drop spindle	Spinning, selling
W6	35 Years	Spinning wheel	Spinning, selling, teaching