Stitching Together the Experiences of Disabled Knitters

Taylor Gotfrid
University of Washington
Seattle, WA, USA
gotfrid7@cs.washington.edu

Kelly Mack
University of Washington
Seattle, USA
kmack3@cs.washington.edu

Kathryn Lum
University of Washington
Seattle, USA
lumk3@cs.washington.edu

Evelyn Yang
University of Washington
Seattle, WA, USA
evyang@cs.washington.edu

Jessica Hodgins
Carnegie Mellon University
Pittsburgh, PA, USA
jkh@cs.cmu.edu

Scott E. Hudson
Carnegie Mellon University
Pittsburgh, PA, USA
scott.hudson@cs.cmu.edu

Jennifer Mankoff
University of Washington
Seattle, USA
jmankoff@cs.washington.edu

ABSTRACT

Knitting is a popular craft that can be used to create customized fabric objects such as household items, clothing and toys. Additionally, many knitters find knitting to be a relaxing and calming exercise. Little is known about how disabled knitters use and benefit from knitting, and what accessibility solutions and challenges they create and encounter. We conducted interviews with 16 experienced, disabled knitters and analyzed 20 threads from six forums that discussed accessible knitting to identify how and why disabled knitters knit, and what accessibility concerns remain. We additionally conducted an iterative design case study developing knitting tools for a knitter who found existing solutions insufficient. Our innovations improved the range of stitches she could produce. We conclude by arguing for the importance of improving tools for both pattern generation and modification as well as adaptations or modifications to existing tools such as looms to make it easier to track progress

CCS CONCEPTS

• **Human-centered computing** → **Accessibility systems and tools**; **Empirical studies in accessibility**.

KEYWORDS

Accessibility, knitting, craft

ACM Reference Format:
Taylor Gotfrid, Kelly Mack, Kathryn Lum, Evelyn Yang, Jessica Hodgins, Scott E. Hudson, and Jennifer Mankoff. 2021. Stitching Together the Experiences of Disabled Knitters. In *CHI Conference on Human Factors in Computing Systems (CHI '21), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3411764.3445521

CHI '21, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8096-6/21/05…$15.00
https://doi.org/10.1145/3411764.3445521

1 INTRODUCTION

Knitting is a craft that people have used for hundreds of years as a means of making clothing, producing for income, making heartfelt gifts, self expression, creativity, art, and joint exercise or physical therapy. Further, many people find that knitting aids in relaxation and meditation [13]. Knitting is also unique in being the only fabrication domain that is used all over the world and has a very long history of including people with disabilities [1]. Knitting has been studied in the context of ageing [23], and outside of accessibility (*e.g.,* [13, 17, 22, 33]). However, the intersection of accessibility and knitting is an important domain for inquiry. Books, classes and websites about knitting rarely foreground user-developed assistive knitting solutions (be they physical, process alterations, mental strategies, *etc.*). By studying and documenting existing solutions, we hope to improve knowledge about what is currently available and to identify spaces where further innovation is needed to include a wider variety of knitters with disabilities.

We present a two-part investigation into the knitting processes of disabled knitters. First, we investigate how knitters with disabilities knit today. We explore this through interviews with 16 expert knitters with a variety of disabilities in which we asked about how they knit, how they use patterns, how they design knitting patterns, and what tools they use to accomplish their goals. We also analyze six accessibility-related knitting forums on a popular social-media and pattern sharing platform for knitters. Our analysis focuses on accessibility in the context of motivations for knitting, the knitting process including tools used and error recovery, pattern selection, how participants modify or customize knitted objects to satisfy their specific needs, and experiences of bias within the knitting community. Our findings relate to topics of general interest in the domain of fabrication including customization [8], pattern accessibility [19], process modifications [29], material and representation changes [9], and error recovery [12].

Based on these findings, we used a case study method to conduct iterative design of novel knitting accessibility technologies with one interviewee with multiple disabilities. We used a combination of semi-structured interviews and think aloud testing to understand how the participant knits today, the issues she faces, and her

knitting goals. We developed and tested several prototypes with her, including a modified loom and a one-handed knitting needle solution. Our contributions are as follows:

- We contribute the first investigation into the knitting experiences of proficient knitters with disabilities
- We identify accessibility barriers affecting the knitting process and pattern accessibility. We also highlight some of the ways in which knitting can benefit accessibility (increasing number of accessible patterns, accessibility of tools, *etc.*).
- We present lessons learned from a series of prototypes to explore gaps in existing tools, including tools for advancing through patterns, purling on a loom, and one-handed knitting

We conclude by highlighting opportunities for innovation in the domains of automatic sensing of the knitting process and intelligent support for modifying patterns. This adds to the growing body of crafting & making research in the disability space (*e.g.,* [12, 16, 23, 25, 29]).

2 BACKGROUND AND RELATED WORK

In this section we begin by first giving a brief overview of some contexts in which accessibility and crafting have been researched. We then introduce terminology specific to the craft of knitting and discuss some of the mental and physical benefits of knitting. We also discuss existing digital, physical, and knitting pattern generating tools and research in the space of hand and machine knitting. Digital tools have allowed for knitters to augment the physical crafting experience embedding different layers of information into their knitting project, imbuing their creative process with new meaning. Physical tools are used at numerous points throughout the knitting process that aid with certain knitting techniques, tracking progress in the knitting pattern, or to aid knitters with impairments. Fabrication and pattern generating tools have lowered the ceiling, making it possible for novices to create customized knitted objects.

2.1 Accessible Making

Recent work has explored ways of increasing the accessibility of making crafts more accessible for people with disabilities. Work has been conducted designing accessible STEM curricula and workshops teaching disabled makers electronics or other making skills. Race *et al.* (2020) developed non-visual curricula for teaching circuit design and conducted workshops teaching blind and visually impaired makers how to solder [29]. In Meissner *et al.* (2017) participants are introduced to a variety of technologies (e.g. circuits, Arduino, and 3D printing) then tasked with designing and developing their own maker project [25]. Finally, Giles *et al.* (2018) conducted co-design workshops for blind and visually impaired participants to learn about e-textiles and e-textile development [12]. In all three of these studies, the workshop were modified so the format in which the material was taught as well as the materials used in the crafting process were accessible. For instance, in [29] blind and visually impaired participants were taught how to solder by a blind instructor. These works show that through participating in the making process, disabled makers gain a sense of confidence working with the materials or technology and a sense of empowerment [12, 25, 29]. Engaging disabled makers throughout the making process helps identify key areas where the accessibility of the teaching materials, technologies, or crafting materials themselves can be made more accessible. It also helps improve access to wider communities who may not have had exposure to these crafts before. Our work extends this research specifically focusing on knitting and the knitting process.

2.2 Why Knit?

Knitting is a fiber-arts craft that has been practiced for hundreds of years [1, 30]. Besides the functional value of knitting, the love that hand-knitted gifts convey, and the fact that it is relatively easy to customize a knitted object to fit a specific body size or shape, knitting is an enjoyable and relaxing craft that is easy to do while reading, talking, watching a show, or while hanging out with a group of friends who also knit. Researchers have also documented real mental and physical benefits of knitting. In a survey of 3,514 knitters, many used knitting as a method for stress-relief or as a coping strategy to help with anxiety, pain, or depression. Participants also said that knitting helped their thinking, problem solving skills, and concentration [31]. In another study exploring how crafting has supported older adults as they aged, two out of three participants used knitting as a way to increase the level of mobility in their hands and reduce the pain caused by arthritis; whereas the third participant used knitting as a outlet for her mental health providing her with both a sense of community through her participation in a knitting group and as a way to help her cope with stressful events in her life. Participants also mentioned that they had to change the materials they would use or their making habits to accommodate for their changing abilities [22].

However, the intersection of knitting and disability is understudied. The literature does not document which tools and technologies are accessible to which users and whether advances in technology (such as knitting apps) may have introduced new accessibility challenges.

2.3 The Craft of Knitting

Traditionally, knitting is performed with two long, thin pointed sticks called *needles*, which a knitter uses to pull a series of loops of yarn through other loops, creating fabric in a grid-like structure in rows, one stitch at a time. Loops stabilize each other so that the whole knitted structure does not unravel [17]. There are several other types of knitting needles such as *circular needles*, shown in Figure 1(c), which are two short knitting needles connected with a cord, and *double-pointed needles* (DPNs) which are short and have points on both ends. Knitters can also execute the same types of stitches by using a *knitting hook* to manipulate yarn around the pegs of a *loom* (see Figure 1(a)) instead of needles. Regular knitting needles are typically used to create objects made of sheets of knitted fabric, such as a washcloth or scarves whereas circular needles and double-pointed needles are used to create tubular objects such as hats and sweaters. When an object is knit using circular needles it is often referred to as knitting *"in the round"*. Looms also come in a variety of sizes and shapes and can be used to create both tubes and sheets.

Knitted objects are composed of units called *stitches*. Stitches vary in type and difficulty. Different stitch types can be used to

Figure 1: Examples of knitting craft and techniques from our interviews. (a) Knitting a hat on a loom [2] (P2-V); (b) a cardigan with intricate colorwork (P14-M); (c) a hat being knit in the round illustrating the use of stitch markers and needle caps (P15-M); (d) a completed hat textured using a grid pattern of knit (highlighted in the callout with a circle) and purl (highlighted with a rectangle) stitches (P6-V).

accomplish different functional purposes and produce unique appearances [17, 24]; two common types of stitches are the *knit stitch* and *purl stitch*, both of which are integral to many knitting patterns. For example, in in Figure 1(d), the callout shows a 4x4 rectangle of knit stitches (one is highlighted) to the left of a 4x4 rectangle of purl stitches (one is highlighted). A wide range of stitch types can be used to form more complex patterns and allow for unique texturing and shaping of the knitted object. Different colored yarns can further add to the visual interest, as shown in Figure 1(b).

A *knitting pattern* details how to make a specific knitted object in a specific size. Patterns typically specify the stitch type and order for each row in a pseudo-english format called KnitSpeak [17] or in a visual format called a chart (see Figures 2 and 3 for an example of each). *Knitting charts* are visual representations of patterns which use symbols arranged in a grid to show stitch type and location. Since needle diameter (called *size*), yarn diameter (called *yarn weight*, and each individual knitter's tension (how tight their stitches are) are all related and can impact size, patterns often specify them. To calculate the expected size of an object, it is necessary to convert stitches into inches, a conversion that is done using *gauge*, the number of stitches *per* inch. Most knitters will knit a *test swatch*, a small rectangle that can be measured to count the horizontal and vertical stitches per inch, prior to starting a knitting project to calculate gauge.

The ability to work with a certain tool (needle, circular needles, DPNs, or loom) of a certain size or peg spacing, or to make specific types of stitches, may affect the types of objects that the knitter can create. If the knitter is using materials other than the ones specified in the original pattern, the knitter may need to modify the pattern so the resulting knitted object still measures as expected. In addition, patterns may need to be adjusted to fit a specific body size.

2.4 Knitting Support Tools

Knitters may use various non-essential physical and digital tools (beyond yarn and needles) to support their knitting. Such tools are used widely by knitters, and are intended to lower the barrier to entry for novices, simply to make knitting easier, or to increase the accessibility of knitting.

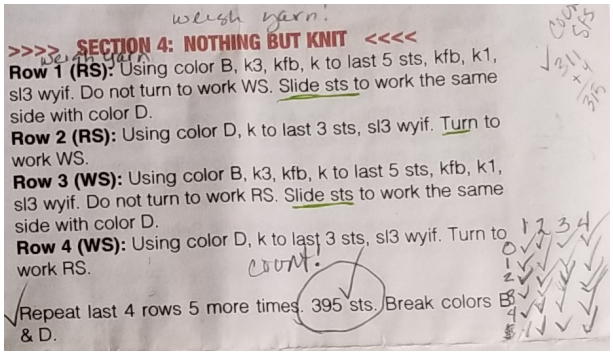


Figure 2: A portion of P16's written pattern

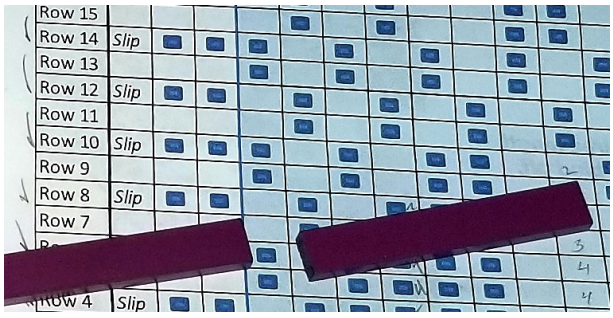


Figure 3: A portion of P13's knitting chart

2.4.1 Physical Tools for Knitting. Although physical tools, sometimes called *knitting notions*, are not essential to the knitting process, they are frequently used. Tools may aid in error prevention. For example, a stitch marker may be placed on a needle to keep track of where the stitch type should change in a row. A row counter may be placed on a needle, or worn as a ring, and displays the current row number. A dial or switch can update the row number each time the knitter starts a new row, making it easier to find one's place in the pattern. A tool can also make certain stitches easier to produce. For example, a *cable stitch* requires taking one or more stitches off one needle, knitting the next few stitches, and

placing them back on the needle they came off of, and then knitting them. This is hard to do since knitting already takes two hands, and the stitches might unravel if there is nothing to hold them. A small double-pointed needle with a special shape can help make this much easier. A temporary stitch holder or needle cap can help ensure stitches do not unravel when the knitter is working on a different project or a different part of the current project. Many variations of these knitting tools exist, and they can be expensive. It is no surprise, then, that the Maker community has started to develop (do it yourself) DIY versions. On sites like Thingiverse [36], many creators have shared CAD files of various 3D-printed knitting tools such as looms, stitch markers, row counters, and knitting needles.

There are also knitting products specifically geared to increase knitting accessibility. These primarily focus on knitting itself rather than the accessories. For instance, devices such as the Knitting Aid [7] and Knitting Belt [5] keep one needle stationary so the knitter only needs to maneuver one knitting needle instead of two. Existing items such as the Knitting Aid, Knifty Knitter looms [4], and the Norwegian knitting thimble [3] are examples of assistive technology primarily for those with motor impairments. Knitting while blind requires no special tools, as described by bloggers Ana and Crystal (fingeringyarn.com), although screen-reader accessible patterns are important.

2.4.2 Digital Tools. The most well known digital knitting tool is ravelry.com, a knitter's social media site that has become intertwined with the material practices of knitting. Through social media, knitters have access to forums to discuss, exchange, meet, and appreciate a shared pleasure in a craft with others, as well as extending the creative practices of knitting through representations of projects online in digital project archives, blogs, *etc.* [28]. Knitters also incorporate digital tools to make online searches alongside knitting for reference, keep a digital record of images to help manage collections of yarn, store information about current knitting projects in progress, track alterations made to a pattern they are knitting, and help form a sense of membership in knitting groups [13].

Researchers have also used explorative design to directly incorporate digital tools into the crafting process [33]. For example, *Spyn* is a digital record keeping log (audio/visual, media, text, and geographic data) that connects points of data with specific locations on the physical knitted object. Roesner and Ryokai investigated themes such as how digital augmentation impacted the knitted object's creation process and the recipient of the knitted object's interpretation of the data collected [33].

Other digital tools such as the app KnitCompanion links to a users' Ravelry account, allowing a user to access their pattern pdfs, access abbreviation legends while viewing the written or charted pattern, and allows for custom highlighting so users can annotate the digital pattern and keep track of where they left off [6]. Digital knitting support tools have grown rapidly in number in recent years, particularly on mobile phone platforms.

A final category of digital tools help novices create patterns even with little knowledge of the mechanics of the craft. There is a wide range of knitting pattern generating tools for machine and hand knitting. One category focuses on chart making: From fonts for excel that support chart making (*e.g.,* stitchmastery.com/knitting-font-collection) to freely available custom tools (*e.g.,* stitch-maps.com), knitters have a variety of options to choose from. Other categories convert pictures to charts (for example to add a picture to the front of a sweater) or allow a knitter to customize a design or create specific types of objects (one tool focuses entirely on machine knit sweaters for example–seedlingsoftware's *SweaterMaker*). In recent years, research advances have also focused on pattern design. Narayanan *et al.* (2018) designed a visual programming interface that allows users to create 3D machine knitted objects. Their system could generate augmented stitch meshes from 3D models and their interface allowed users to edit the stitch mesh while preserving the object's knittability [27]. Additionally, Igarashi *et al.* (2008) developed Knitty, a tool for novice knitters that creates hand-knitting patterns for stuffed animals based off of a 3D surface model [20]. Following the development of Knitty a user study was conducted with novices to assess ease of use. In this study children (ages 10-14) used the sketching function of Knitty to sketch their 3D surfaces, and then Knitty produced a knitting pattern for the participant to follow along stitch by stitch. All participants were successfully able to knit their customized plushie with the instructions provided by Knitty [18]. Additionally, Kasper *et al.* (2019) developed a web interface in which users could customize the shaping and stitch pattern of knitting templates of everyday garments in a single workflow for machine knitting which they tested with users with no prior knitting experience [23]. As another example, Hoffman *et al.* (2019) developed the KnitPick pipeline to interpret or modify hand-knitting patterns to create textured knitted objects, and is capable of generating knitting pattern instructions for both hand-knitting and machine-knitting [17].

3 STUDY METHOD

The goal of our study was to explore how disability and knitting interact. Our overarching goal was to understand how knitters with disabilities engage in their craft at all stages of the process, from pattern design and modification to the physical process of knitting itself, including what tools are used and pattern accessibility. To this end, we conducted semi-structured interviews with experienced knitters who self-identified as disabled. We chose to focus on experienced knitters because novice knitters with and without disabilities face many challenges and often engage with parts of the craft (for example, they might not use all types of stitches, or might knit patterns but not modify them). We also collected forum data from online discussion groups talking about knitting and disability.

3.1 Interview Method

We conducted semi-structured interviews with 16 knitters with disabilities. Eleven participants were visually impaired, seven participants had a mobility impairment, and two participants had a cognitive impairment (see Table 1). Participant numbers indicate these impairments, for example P1-MVC has a **M**otor, **V**isual and **C**ognitive impairments. One participant requested that her parents attend the interview. Participants were recruited through posts on social media sites such as Facebook or Ravelry, ads posted in an email newsletter sent through a crafters group for the visually

impaired or blind, phone calls recruiting through virtual crafting groups, and through word of mouth.

3.1.1 Interview Participants. All of our interviewees identified as female, which is not surprising given the typical demographics of knitters (one self-selected sample of over 3000 knitters was over 98% female [31]). Their ages ranged from 20-69 (M=47.8), and their experience level ranged from 1-60 years (M=24). Knitters were compensated with a $15 gift card to Amazon or a local crafting store. Interviews typically lasted between 45 minutes and one hour and were conducted in-person, using video conferencing (*e.g.,* Zoom, Skype, FaceTime), or through email. We asked participants to bring a recent or current pattern and project to the interview.

3.1.2 Interview Questions and Analysis. We asked participants demographic questions to learn about their knitting background (how long they have been knitting, if they designed their own patterns, *etc.*). Next, we asked questions about their knitting process. To keep their answers concrete and grounded we asked specifically about the project they had brought with them. We asked about topics such as how and why modifications were made and difficulties or errors that occurred. We also asked participants to describe the different elements of the associated object's knitting pattern and about pattern alterations and the motivations behind these modifications. Then we asked participants to recall the last time they experienced difficulty with particular knitting skills or techniques and how they recovered. We concluded the interview with a variety of questions about the accessibility of the knitting process, tools that participants use and how these tools help or hinder the user.

We were particularly interested in how accessibility impacted the knitting process, and what opportunities exist to improve accessibility. Following the completion of all interviews, the interviews were transcribed.

3.2 Forum Data Collection and Analysis

Since the interviewee population was primarily knitters with visual impairments, we collected forum data to extend our sample size and complement our interviews with more motor and cognition related data. Previously data scraped from Reddit forums have been used in addition to interview data when studying gig workers and worker anonymity [21, 26].

We collected data from six forums for crafters with disabilities with discussions ranging from the group's date of creation through July 30, 2020. These groups included the majority of accessibility focused forums identified on the social network we studied. To select which threads to analyze, we searched for threads with "Accessible" in the title. A researcher read through all of the thread titles that matched, adding words to the key words list if deemed relevant. Since not all posts are related to knitting, we increased the likeliness a post would be relevant by requiring that their titles contain a combination of two of the words/phrases identified. Our final list of words is listed in Table 3. In total, we selected and analyzed 795 posts from 20 forum threads.

All quotes from the forums are slightly altered without changing the meaning to preserve anonymity. Quotes taken from the forum data are labeled with F-[N] where N is a unique thread number. Main themes overlapped with the interview data.

3.3 Analysis Approach

From our interview data we extracted 5,755 quotes from our 16 participants along with 795 posts from scraping 20 forum threads. We followed principles of open and axial coding [35] in our analysis. Three researchers worked together on the open coding over a period of four sessions. Researchers began sorting all of the statements into groups based on noticeable emerging themes. Statements were allowed to be duplicated if its contents fit into two different themes. Themes were broken up into sub-themes when too many statements (more than 10) aligned with them, and sorting continued until no new, major themes emerged. Two researchers independently recoded 10% of the data to check for consistency and achieved a 96% inter-rater reliability using Cohen's Kappa [15].

Our analysis led to the creation of six top level categories under which we grouped 37 subthemes made up of 500 codes. These categories were: benefits of knitting, the accessibility of knitting patterns themselves, the accessibility of the knitting process, the accessibility of the resulting objects, experiences of the knitting community, and "Other" (not relevant to our focus on accessibility), which are shown along with subthemes and example topics in Table 2.

Analysis of the forum data led to the creation of 227 new codes, all of which were grouped into the subthemes and themes from the interview analysis. Examples of these new subthemes include: pattern accessibility formatting, unique tools and solutions used by disabled knitters, and a designer's pre-existing knowledge of a11y design.

4 FINDINGS

In the following section we describe some of the significant themes that emerged from our analysis of the interviews and forum posts. First and foremost our participants, just like any knitting hobbiests, were skilled and knowledgeable about their craft. Knitting was an important and enjoyable part of their lives, and disability was not necessarily central to why or how they knit. That said, the focus of this paper is on accessibility, and for that reason our results focus on the intersection of knitting and disability. We list some of the topics that we do not report on in the **Other** category of Table 2 for completeness. We cover the remaining themes listed in Table 2, including motivations for design selection and knitting; how knitting can be used to modify or adapt patterns to fit a recipient's needs; difficulties experienced finding and executing patterns; using specific materials or tools; pattern accessibility; modifications to knitting that minimize errors or to make knitting more accessible; and microaggressions and bias that participants experienced in the knitting community.

4.1 Benefits of Knitting

Both the process and outcomes of knitting have direct benefits to participants. In terms of process, our findings confirmed existing works showing that knitting is enjoyable and known to have positive mental and therapeutic physical health benefits [22, 31]. However, these works did not explore the benefits of knitting for coping with disabilities, which we provide data on. Further, past work has not looked at knitting design. We show how design can

Table 1: Participant demographics. Participant ID - self-described disability, age, years knitting, interview style (which varied due to participant preference and feasibility), any major craft variants they use (such as only knitting with a loom, or only using circular needles). The MVC initials represents how the participant self-described their disability: M-motor, V-visual, or C-cognitive.

PID	Age	Years	Interview	Craft variant	Disability as Described by Participant
P1-MVC	31	17	In person	Loom knitter	Limited mobility; tremors; double vision; memory loss
P2-V	38	8	Virtual	Loom knitter	Blind
P3-M	42	20	Virtual	Circular only	Carpal tunnel; arthritis
P4-V	58	20	Virtual	Straight circular	Blind
P5-M	64	30	Virtual	Straight only	Carpal tunnel; arthritis; bone spurs
P6-V	20	6	Virtual	Circular and DPNs	Blind
P7-V	51	30	Virtual	All	Blind
P8-MVC	55	50	Virtual	All	Fatigue, Focal cognitive deficits; some vision loss
P9-V	28	5	Virtual	Loom knitter and crochet	Blind
P10-M	34	16	Virtual	All	Fatigue, arthritis
P11-V	67	1	Virtual	Loom knitter	Blind
P12-V	68	60	Virtual	Circular only	Blind
P13-MVC	27	14	Virtual	All	Fatigue; tremors; brain fog; some vision loss
P14-M	51	40	Virtual	Straight and circular	Mobility impairment (wheelchair user); central nervous system damage; hand pain
P15-M	62	8	Email	Straight and circular	Fatigue, Spinal stenosis
P16-V	69	60	Email	Straight and circular	Blind

Table 2: Themes and example Sub-themes. *A11y* is used as an abbreviation for *accessibility* and *mod* for *pattern modification* in the table. Numbers are the number of quotes assigned to that subtheme, and some example topics are given for subthemes. All of the participants mentioned at least one subtheme in every theme except Knitting Accessible Objects, which six participants did not mention (P1-MVC, P2-V, P4-V, P11-V, P12-V, P15-M).

Theme	Example Subthemes
Benefits of Knitting	**Ability to customize**: aesthetic or personal preference; **Motivation**: difficulty finding patterns; coping with disability
Knitting Pattern Accessibility	**Pattern a11y**: dependent on visual information, prefers different actions on different lines; **Pattern formatting:** font size, headings, margins, color contrast, grouping, audio file; **Pattern selection**: preference for visual information/visual learning, simple to understand, no charts, written instructions for charts
Knitting Process Accessibility	**Hacks and Tools**: stitch markers, stitch repeats, needles, braille labels, preference for circular needles; **Counting**: counting rows, row counter a11y; Difficulty: video tutorial a11y, understanding abbreviations; **Emotion**: frustration, self-doubt; **Errors and recovery**: loom a11y, dropped stitch, shaping; **Technique**: preference of knitting technique because of a11y
Making Accessible Objects	**Customize** : designing for someone with a disability, representative toys; **Motivation**: make objects accessible, designing for someone with a disability
Knitting Community	**Community**: collaboration/sense of community, swapping project with friend; **Bias**: ableism, backlash for error caused by disability
Other	**Cost**; **Planning**: texture, sizing; **Design**: math, pattern design; **Measurements**: stitches needed for stitch type, gauge; **Difficulty**: learning new skill, pattern complexity; **Colorwork**; **Knitting Technique**: decreases, knitting style; **Tools**: video tutorial, charting software; **Materials**: yarn choice, acquisition/storage; **Next steps**: donate/gift knitting

help make the hobby itself more accessible, or help to create objects that fulfill unmet needs.

Participants (P8-MVC,P10-M) described how knitting mentally or physically helped them with their disability in some form. Knitting both mentally and physically helped P10-M because it was *"a really good way to deal with... I spent a lot of time waiting in doctor's offices or on the couch because I'm having a flair and I can't move that well. So it really started as an activity to help me kill time while I dealt with my illness"* providing her with a productive way to pass the time. P8-MVC also finds mental benefits from interacting with her

Table 3: Key words/phrases and the number of threads scraped with the key word/phrase in the thread title.

Key Word/Phrases	No. of Threads
Fogginess/Fibro fog/Brian fog	4
Fibro/Fibromyalgia	7
Accessible	5
PDF settings/formatting	3
Knit/knitting	6
Hand/wrist/finger pain/ache	2
Low vision/partial vision/Blind	5
Low vision	3
Patterns	4
Other (WCAG Standards, Alt text, Chart)	3

knitting projects in some form even if she is unable to physically knit. Even when she is not well enough to actively craft she still finds a way to *"show up and be present with my crafting a bit."* She found that interacting with her knitting in some form while unable to physically knit *"worked really well. It made me feel less crazy and miss my knitting less, because I was still handling the yarn and making my crafting area better"* P8-MVC. Finding alternative ways to engage with her knitting *"even on days when I'm too ill to do anything, I look at patterns. So I always participate in it somehow, and that really gives me some continuity"* shows the mental benefits experienced in other stages of the knitting process such as pattern selection and interacting with the materials involved in the craft. As for physical benefits, P10-M also used knitting as a form of physical therapy noting *"Now I knit basically every day for at least some period of time and I notice that if I don't do that my hands start stiffening up really bad and it makes it harder to hold the needles later. So it's really like the constant exercise of my hands seems to be good for it"* continuing with a comment about how much her Rheumatologist loves that she knits because it *"exercise is one of the things that is really helpful to rheumatic joints everyday basically."*

Participants were also motivated by difficulties with finding patterns that fit a specific disability related need or that matches what the knitter envisioned. P4-V was motivated to design patterns because she had difficulties finding patterns that were presented in an accessible format for her, *"it's not that easy always to find braille knitting patterns;"* by designing all of her own knitting patterns ensures that the pattern will be accessible for her. Many visually impaired knitters have difficulties finding patterns that meet certain accessibility requirements such as including written text describing the stitches pattern depicted in a chart, written in large font, *etc.* P9-V encounters difficulties finding accessible patterns that match the picture in her mind of what she wants to create *"And if I can't find it, then my own brain figures it out. It creates its own idea, I will create my own idea."* Again designing her own pattern has the benefit of ensuring that the pattern she follows is accessible for her as well as a creative opportunity to experiment or make something novel. A forum user F-[7] also posted on a forum asking for advice about how she could design a winter hat for a child with hearing aids in a way that would not interfere with the child's ability to hear *"A mom wants me to knit her child a winter hat with slit openings above the ears to expose their hearing aids. I've tried to find a pattern on Ravelry as well as other external knitting pattern sources but I'm not having much luck".* She received many design ideas from other users such as *"Instead of a slit perhaps do an area around the ear in a lace stitch. For me personally, this seems to let in plenty of sound* F-[7], *"I could see doing a drop stitch band about ear height to allow sound to more easily reach the aids"* (F-[7]), or to incorporate small *"stretchy holes which would fit snugly around the hearing aid or which you could slip the hearing aid through"* F-[7].

All participants but P2-V mentioned motivation to modify patterns for various reasons such as for preference or certain aesthetic, by request of the recipient, to make the pattern her own, and to make knitted objects that are more accessible. These modifications typically included changing sizing, shaping, gauge, yarn weight, or needle size used other than what was specified in the pattern. Six participants (P4-V,P5-M,P7-V,P13-MVC,P14-M,P16-V) chose to customize a pattern so the resulting object fit a specific aesthetic or met specific criteria identified by the knitter based on personal preference or unique requirements. For instance P13-MVC chose to modify the shaping of her pattern by adding an extra repeat of the stitch pattern *"It's a very lacy pretty shawl and I wanted a little wider than it was so I added in an extra repeat of the pattern"* because she tends *"to be cold all the time so I like a little more- to be able to wrap it a little tighter around me."* Her modification was made to satisfy a preference for a particular fit of the shawl. P4-V also modified the shaping of a hat for aesthetic purposes *"I forgot exactly what I did, but I changed it so it wasn't three weird points, it was more flat kind of, with three corners, but not sticking up in a weird way."*

Through designing or modifying a pattern, participants can create a knitted object that fulfilled specific, individual needs. Interviewees and forum posts described and showed examples of knit objects designed for wheelchair users, people with autism, and people with medical needs. Several interviewees explained that they were motivated to knit because it allowed them to customize knitted objects so they would be accessible for the recipient. People with disabilities have individual, unique requirements which are not often met with mainstream clothing or items and thereby create the objects on their own. P10-M frequently knits clothing for a child with autism and she commented *"That's the nice thing about being able to modify or make up your own patterns is he has a lot of very specific requirements for clothing that isn't always met by being able to buy clothes, so it's nice to be able to make stuff".* Similarly P13-MVC when asked if she had ever knitted an accessible object she replied *"I mean accessibility being able to knit to your needs and that sort of thing definitely helps".* We discuss some of the types of accessible objects knitters made in Section 4.5.

4.2 Making Patterns Accessible

Knitting requires the knitter to follow a pattern and keep track of various pieces of information such as what type of stitch is supposed to be knit in the moment versus what kind of stitch comes next according to the row's stitch pattern, how many repeats of a stitch or row pattern have already been done. Thus, pattern accessibility was a concern of both blind and low vision knitters, as well as those with cognitive impairments. Many patterns are provided in a format that is not accessible by default, such as PDFs or visual

charts, which makes manipulating patterns or extracting their text more difficult.

In our forum analysis, accessible pattern formatting discussions mentioned font size, line spacing, margins, written instructions/descriptions describing pictorial information (not just color, but also symbols in charts), good contrast, justification, and proper use of alt-text and headings for screen readers . Several posters desired versions reflowable text similar to an e-Book: *"text where you can change the font yourself to whatever works for your eyes"* . Interviewees had similar concerns. Forum posters mentioned 47 separate formatting guidelines for ensuring document accessibility.

Among participants with visual impairments, a variety of strategies were used. P4-V preferred to convert her patterns to Braille and (P12-V) used AIRA (a service that provides visual information to those with visual impairments) to create accessible versions of previously non-accessible patterns. Other participants enlarged charts or entire patterns so they are easier to read or annotate.

A final aspect of making patterns accessible is modifying them. These modifications act as a form of error prevention reducing the amount of information the knitter needs to mentally keep track of. For example, P14-M modified patterns to accommodate her cognitive impairment by printing double spaced and then then *"[writing out] each and every direction in detail… I even go as far as, if it says you need to go and knit 16 rows, I'll write out 1, 2, 3, 4, 5, 6 and then I'll mark them off as I go"*. Other participants annotated patterns with various types of information such as modifications made to the pattern, notes about stitch types or number of stitches, marking up charts, or using multiple colors to indicate different pieces of information. More ambitious modifications included changing a pattern to reduce the number of purl stitches by knitting in the round, or to produce an accessible object (see Section 4.5).

4.3 Finding Accessible Patterns

While participants were willing to modify patterns when necessary, the ability to search for accessibility patterns was also valued. Participants sought patterns from various sources such as Ravelry, knitting books, Facebook groups, crafting groups, or other online shops such as Etsy. Blind knitters also used organizations such as the National Library of the Blind, Krafters Korner hosted by the National Federation of the Blind, Horizons for the Blind, and acquaintances to find accessible patterns. However, knitters with disabilities may need to search for patterns that aren't as easily manipulated as described above, or patterns that have certain features that make knitting them easier.

Participants experienced several difficulties when searching for accessible patterns on standard pattern sites, due to a lack of relevant meta-data, and this was seen across all types of disabilities. For example, many visually impaired participants could not easily avoid patterns that have charts or other visual diagrams without a written equivalent: *It would be nice if patterns didn't say 'pick up the stitches in the manner shown in the picture,'"* P12-V. Such visual elements are not screen reader accessible. The techniques or stitch pattern types required to execute the pattern also affected pattern accessibility. One participant with motor impairments avoided patterns that used techniques or stitch types that she knew would cause her pain or that would be difficult to physically execute. For example P3-M does not like purling because *"it's harder on [my] hands than stitches are. And so [I] tend to choose top down and around with a pretty heavy prejudice."* Similarly P8-MVC has a difficulty finding texturally interesting patterns that she can follow based on her cognitive impairment, *"especially because for complicated texture and cable patterns, one line of instructions often runs into two or three lines of text, and it's really easy to get lost in that two or three lines, like where am I in that row of knitting that's still only one row of knitting."* P8-MVC also avoids patterns with standard colorwork in favor of mosaic colorwork because switching between colors or remembering when she needs to switch colors in the middle of a row is too difficult for her to actively focus on while knitting *"So I tend to avoid standard color work, the color work that I do is usually mosaic, so that I can only work with one color at a time, and finish my two rows and get all done with that and then start another color."* Participants with each type of impairment all experience some form of difficulty with various aspects of knitting patterns which makes the pattern difficult to follow, thereby limiting the variety and number of patterns they can choose from.

Few commonly used pattern search tools mark which patterns are accessible for screen readers and other tools that need access to a simple text representation. For example, it is possible to exclude patterns with charts in Ravelry, but this also excludes patterns which have charts that are redundant and thus do not pose an accessibility concern. Searching for a patterns knit in the round, or that exclude a certain type of stitch, or yarn weight is easier. Sometimes these pattern search tools also pose accessibility challenges. For instance, one popular knitters' site is *"… nearly impossible for people who rely on screen readers to properly navigate the site"* F-[1]. Additionally, websites that are not built with accessibility in mind may not allow for multiple renditions of a pattern, such as audio recordings: *"[the site] doesn't currently offer any support for [audio] and the file would have to be hosted elsewhere"* F-[1]. Allowing designers to include audio files dictating their patterns would increase the number of accessible patterns for visually impaired knitters as well as provide a new format in which to digest a knitting pattern.

4.4 Knitting Accessibly

Knitting encompasses all of the steps that go into the physical executing the construction of a knitted object. In this context, accessibility concerns can include difficulties working with a particular tool and with executing particular kinds of stitches. Further, for some knitters, these needs may change dynamically. For example, P13-MVC keeps multiple projects going at once, each with a different yarn weight, so that she can always knit regardless of how her motor or cognitive impairment is affecting her: *"So I'd have one that was fairly simple that was a little chunkier so that on days my hands were too shaky or something like that, then I'd work with the thicker yarn on the simple. I'd just like knit straight across and nothing that causes you to have to think much kind of pattern."* Her comment illustrates how her disability can impact the accessibility of multiple aspects of a pattern including its complexity and the yarn thickness.

Four participants (P1-MVC,P2-V,P5-M,P11-V) discussed difficulty working with particular tools. P2-V specifically had trouble executing specific stitch types using a small gauged loom which requires dexterity for fine manipulation and means that you need to use smaller weighted yarn, *"a lot harder to feel, for me, the finer details of the yarn and the thinner pegs and the closer the pegs are, it's just a little bit harder to also pop loops off to make the purl."* P1-MVC and P11-V also experienced difficulty working with smaller gauged looms. P5-M experiences difficulty with small gauged needles because they cause her pain *"the real tiny needles really hurt my hands."*.

Another common concern was counting. Counting stitches is an integral part of knitting from patterns because patterns often specify when to do something in those terms. Although row counters are a common tool available in digital and physical form, most assume a knitter can see. As P6-V explained, *"they're the row counters where you press the button and it counts the row, i wish there was a talking one."* As a result, two of the blind knitters used an abacus to help them keep track of rows or stitch counts. P4-V uses two columns of her abacus to track what row in the pattern she is on and how many times she has repeated a row's stitch pattern. Typical row counters only store counting information for a single item (stitch count, row count, or repeat count), however her mental model of storing information about her knitting includes an additional piece information. Besides annotations on the pattern, as described above, row counters help with this by showing a number that is manually incremented at the end of each row. P11-V made her own row counter with items from around her home "*What I did is I took a little hard plastic tray that's about six by nine and I had a bunch of Velcro, like big strips of Velcro, so I put Velcro, I put six strips of Velcro on there and then I just cut up little pieces of Velcro.*" (P11-V). Other participants used a magnetic pattern board (P13-MVC) and and pegs (P12-V).

Participants used other tools to help improve the accessibility of the knitting process. For instance, four participants (P4-V,P9-V,P11-V, P12-V) used braille labels to differentiate between two balls of yarn of different colors. Braille labels allowed participants with visual impairments to work with colorwork *"I put them in the bag, I label the plastic bag, I label the bag with dymo tape and braille for the color"* (P12-V). Two other participants (P1-MVC,P14-M) mentioned other physical aids such as the KnittingAid and the Scottish Knitting belt. Both the KnittingAid and Scottish Knitting belts are physical solutions that are typically used by *"people who've had strokes, or even people who want to start knitting that have an arm that's either gone or not working;"* the tool holds one needle steady so the user only needs to manipulate a single needle. This reduces the dexterity required to knit and provides a one-handed way to knit.

Participants also reported difficulties executing particular types of stitches; specifically the purl stitch. Both circular needle knitters and loom knitters experienced difficulty executing the purl stitch. For instance P3-M avoids purl stitches because of the grip change and the pinching motion needed to execute the stitch causes her pain *"...when I purl I'll hold, even if I have my yarn wrapped around my finger like I normally would, I would then have to push my thumb down like that to get tension. Whereas when I knit flip it in the back I can use my thumb to hold my needle, and I can just wrap with the yarn around my middle finger. I don't have to pinch it at all. And so there's a lot more pinching for me when I purl... and that definitely causes discomfort the fastest."* P1-MVC also has trouble executing the purl stitch due to the level of dexterity it requires for loom knitting. Purling on a loom is much more complicated to execute, because it involves forming a loop which *"you end up taking it off and having to put it back on the back"* P1-MVC. Purling with a loom also typically requires the use of two hands. For someone with limited dexterity or who experiences tremors, this increases the likelihood of errors and can be frustrating to experience.

While some knitting accessibility challenges make knitting painful or impossible, others simply made it more error prone. This provided knitters with the opportunity to make tradeoffs – the frustration of correcting an error (which often requires undoing many stitches, or manipulating the knitting using physically difficult techniques) *versus* the impact of the error. While some errors may cause a project to unravel, others only impact the texture, color, or shape. Participants would sometimes choose to leave errors in the project. For instance *"If it's an error that only I will see and care about, a lot of the time I leave it... If it's going to be an item that I see all the time... I will go back and fix it"* P10-M. Another participant (P2-V) embraces her errors and keeps them in her projects as her "signature".

4.5 Making Accessible Objects

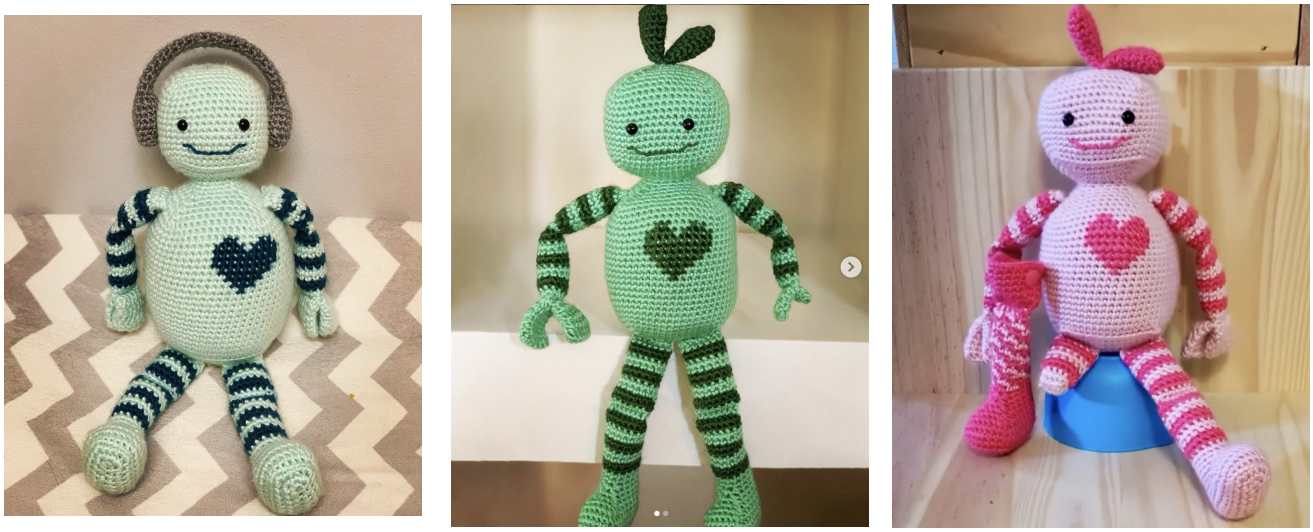
Participants told us about a variety of patterns that specifically address accessibility concerns. P14-M described accessibility considerations when designing for wheelchair users such as making a shirt or sweater with a shorter back and longer front because *"if your sweater is too long in the back at all and it goes underneath you, it makes it hard to transfer, so you want to shorten the back"* (P14-M). These types of clothing modifications are not found in mainstream clothing styles, by knitting she can create clothing suitable for wheelchair use (*e.g.,* clothing that does not get in the way with wheelchair transfers or that would get caught in the wheels).

P10-M designed patterns for toy robots with disabilities *"So I have a whole list to design for. So far I've done the earmuffs, we have one that has a prosthetic leg, we have the one with the little lucky fin, right now I'm working on one that has an insulin pump"* (see Figure 4). She also plans to release the main pattern robot so a knitter could then customize or add whatever accessories they wanted to it. By creating robots with disabilities as well as a base pattern that can be customized based on the what the knitter envisions, increases the inclusion and representation of disability in the knitting community.

4.6 Sense of Community and Ableism

Knitting is often a social act, and collaboration and interaction within the knitting community was a theme participants discussed. Participants actively engaged in group projects, swapped a knitting project with a friend and participated in forum discussions. However, for many participants this led to microaggressions and experiences of ableism.

Participants primarily participated in communities of knitters to learn, as support networks, project collaborators, and as a way to increase inclusion. Three participants (P8-MVC,P11-V,P12-V) were knitting to contribute to a group project in their crafting groups. As P11-V describes *"Basically they wanted everyone to contribute*



(a) (b) (c)

Figure 4: Examples of inclusive robots made by P10-M. (a) A knitted robot with removable headphones. (b) A knitted robot with a limb difference in it's left limb. (c) A knitted robot with a prosthetic leg. The leg is re-attachable with a clip.

like seven by nine inch squares, or rectangles, and then this one lady's going to sew them together." This sense of community expanded beyond group projects but also as a support system. P8-MVC noticed that someone in her online community group "was having a really hard time, so I started a secret blanket project for her to send her a blanket that we had all made together" as a way to show that they were there for her. Another participant (P3-M) swapped knitting projects with friends who incrementally add onto the project *"So she ended up with a sweater as well and like I did this section and then she did this section. I did this one and she did this one and so on, so we just we swap back and forth every few weeks."*

Two participants (P2-V,P9-V) used communities as a source of learning. For instance, P2-V is part of a group that hosts classes for visually impaired crafters *"I'm part of the division of blind crafters called Krafters Korner and they host classes over the telephone or via email and teach blind people how to non visually craft. Mostly knitting and crocheting."*

However, not all community encounters were positive. For instance P12-V faced bias from a sighted knitter while trying to learn how to knit, *"…[she] did not believe blind people could learn to knit patterns, pick up stitches, you know fix dropped stitches, sew together …she taught classes. She would never let me sign up. One of the things I know is, she taught people how to design things. Without using a tool and by using a calculator I would do that in a heartbeat if I knew how and where to start and where to finish."* A forum user described asking a designer for an easier to read digital format: *"The designer said no and that they have no intention of changing the digital version to be accessible. They told me to make a photocopy and enlarge it or use a sharpie to fill in in the squares (neither of which will work and the suggestions themselves were pretty dismissive)"* (F-[6]). Because of similar experiences, P16-V refuses to buy patterns that are not accessible because *"If the designer wants to discriminate against me, why should I pay her to do it?"* A second forum user described a when she was discriminated against because of her disability. A designer refused to work with her as a test knitter because they *"didn't like the idea of a wheelchair being in the shot,"* referring to images that would be displayed in the pattern illustrating examples of the pattern (F-[11]). These examples illustrate a range of ways in which the knitting community itself enforces abled defaults and creates accessibility challenges.

5 CASE STUDY

To complement our interviews, we conducted a case study to address the needs of a knitter who could not find existing tools that supported her in her craft. Our goal here was to conduct exploratory design to learn about design parameters and requirements that might not have arisen in the retrospective accounts collected during our interviews. Multiple distinct groups of researchers (co-authors) worked on different prototypes. All prototypes were tested empirically and iteratively by the researchers for viability & ease of use before deployment.

We selected P1-MVC because she has a visual, cognitive, and motor impairment, she was local and willing to try prototypes across multiple sessions with us. P1-MVC started knitting when she was young and created beautiful, complex works such as cabled and textured socks. Due to a traumatic brain injury (TBI), P1-MVC now has double vision, low mobility, pain and tremors in her hands, and short term memory loss. Now she primarily knits hats and dish cloths, both using looms. P1-MVC identified knitting related tasks that she struggles with but would like to be able to do more easily in the future. These tasks included knitting with needles, knitting stitches other than the knit stitch on the loom, keeping tension in the working yarn in loom knitting, and the ability to follow patterns. Both P1-MVC and her parents would like to see her knit more complex works with patterns again.

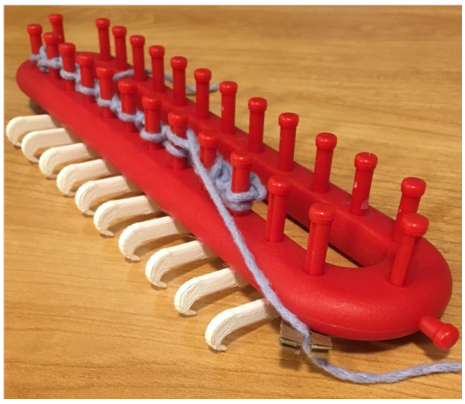


Figure 5: A loom with our tension and purl attachments. The red piece is the original loom. The pieces of cardboard are used to maintain tension in the yarn. The white S-hooks attached to the bottom of the loom assist with the purl stitch.

5.1 Iterative Prototyping

We worked closely with P1-MVC across several sessions, between which we iteratively developed prototypes. We also sent many emails asking specific questions and relevant to our designs.

5.1.1 Pattern Reader. To simplify the interaction for pattern following, we developed a physical interface that could trigger visual or audio feedback. Following knitting patterns is particularly difficult with short term memory loss due to the need to keep track of what has been done and what is left to do. P1-MVC has difficulty remembering where she is in a pattern while knitting, particularly if the pattern is complex (*e.g.*, stitch type changing within a row). We used a wizard of oz approach to iterate on interface features collaboratively. We created a controller that consisted of a cardboard box with two buttons. This device had straps so it could be easily attached to an arm, leg, etc. A computer was placed on a table in front of P1-MVC and she was asked to go through the pattern displayed on the computer. As the participant pressed buttons on the cardboard device one researcher would press a key on the keyboard corresponding to the direction in the pattern the user indicated in her button press. She preferred the stitch-by-stitch reading and liked having both the visual and auditory cues for which stitch type to knit.

5.1.2 Loom Modifications. To support purling, we developed a prototype for a modified loom (see Figure 5). This prototype was designed to address the participant's desire to execute the purl stitch and help maintain consistent tension using the loom. Our objective was develop a prototype in which she could execute a purl stitch using only the hook, thus reducing the need for fine motor control, and which could be executed with one hand.

We first brainstormed ways in which we could modify the design of the loom or the hook to reduce the overall fine motor control needed to purl on a loom. Purling is difficult to execute because in the last few steps required to execute a purl stitch on a loom, the stitch is removed from the peg, then the loop made by the working yarn is then placed back on the peg and the working yarn is pulled to tighten the loop around the peg. While watching the participant execute a purl stitch, we observed that she had difficulty working with the yarn with one hand. Several aspects of knitting require you to keep tension in the working yarn while doing something with your needle or knitting hook. Similarly, some of the more complex stitches like purling on the loom are often demonstrated with two hands to pull loops of yarn in different directions. She also expressed that the wrist rotation required to place the loop back on the peg was painful. We brainstormed ways that the stitch could be executed with less wrist rotation required as well as stabilize the loop when the stitch is pulled off the peg.

We prototyped and tested design ideas using a loom, wire, cardboard, tape, and glue. To address purling with the loom, we tried modifying both the loom and hook until we found a solution that required less wrist rotation and could stably hold the loop in place while the stitch is removed from the peg. Our final design consisted of a modified S-hook that we 3D printed and attached to the bottom of the loom. The S-hook allows the user to rest the loop around the hook holding it steadily in one place (traditionally what the non-dominant hand does in the purl stitch) while the user removes the stitch from the peg. Without a rotation of the wrist the user could then grab the loop from the S-hook, place it back on the peg, and then pull the working yarn to tighten the new stitch around the peg. Our low-fidelity tension device consists of a small piece of cardboard with slits cut out and attached to the bottom of the loom. The user can slide the working yarn into one of the cardboard slits quite easily, the cardboard will maintain the tension, and the user can pull more yarn out without much strain or damage to the yarn.

Before testing the modified loom we first demonstrated how to use the S-hook and tension device. Afterwards we gave the loom to the participant and asked her to try to purl. Since the addition of the S-hooks required an alteration to her normal stitch-making process she struggled to successfully use our prototype and expressed frustration during the testing session. She also did not attempt to use the yarn anchor to help keep tension in the working yarn.

5.1.3 From Loom to Knitting Needles. As an alternative to the augmented loom described above, we also began iterative development of a second more involved prototype device shown in Figure 6. In addition to making purling easier, our goals were to support a return to needle-based knitting, which allows a wider range of patterns to be created and was an express goal of P1-MVC.

As with loom knitting, we knew it was necessary to fix the objects holding the stitches in place. To do this, we used a hybrid approach that leveraged the shape of loom pegs but arranged them similar to knitting needles. In particular, the pegs on a loom normally contain a ridge or knob at the top of the peg which more securely holds loops. As shown in Figure 6(a) we adopted a modified form of this shape at the end of our (custom shaped, 3D printed) needles to solve this problem.

We next considered the actions required for various stitches, focusing on knit, purl, increase and decrease (the four most commonly used stitches). These stitches can be decomposed into four stages: capture existing loop(s) by placing a hook under them, remove loop(s) from a needle, pull feed yarn through loop(s) (back-to-front for knit, or front-to-back for purl), and place loop(s) on a needle.

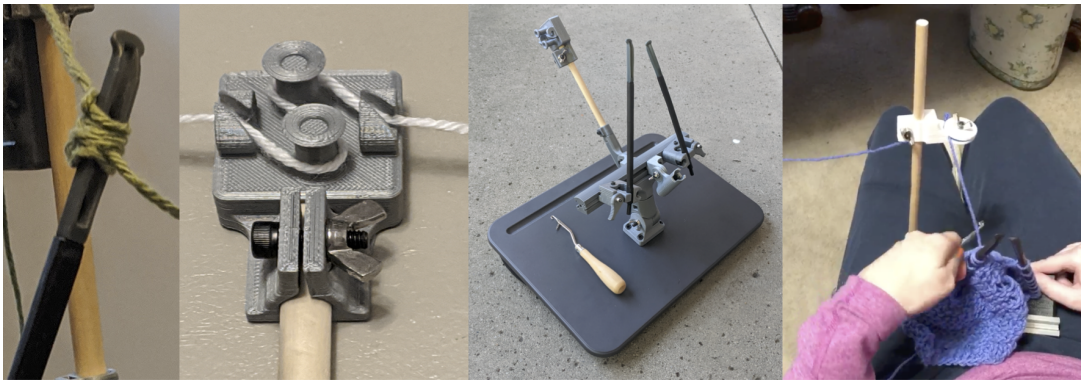


Figure 6: Pictures of the one handed knitting prototype. (a) the needles include an indent allowing a hook to travel under the thread; (b) the tensioner makes it possible to hold the thread at the proper taughtness for knitting; (c) The final iteration of the device is attached to a lapboard; (d) the device in use.

Similar to loom pegs, our needles have a small vertical indentation or slot facing the knitter that allows the knitting hook to be positioned with less precision than would be needed otherwise, and allows the hook to slip under a loop held on the peg more easily. As seen in Figure 6(a), we use a deep and wide slot within the needle which allows less precision when placing a hook under a loop. Removing and placing loops is similar to analogous actions in loom knitting. This leaves what is by far the more difficult action, pulling new yarn through the existing loop. Fortunately, a device for simplifying this process was invented as a part of early knitting machines over 200 years ago: the *latch needle* (see Figure 6 (c)). A latch needle's hooked end is closed by a small swinging latch component. Once an existing loop has been captured on the hook and removed from the needle it was stored on, the latch needle is pushed through the loop, freeing the hook to grab the new yarn. Pulling it towards the existing loop causes that loop to slide back towards the tip, folding the latch over, and closing the hook so that the new yarn can be directly pulled through the existing loop, which then comes off the top of the latch needle. Although this action seemingly has many parts, the clever design of the latch automates the process and allows these to happen quite easily.

An important part of producing good quality knitting is regulating the size and tightness of stitches. This is accomplished in part by the diameter or gauge of the needles used, but also by regulating tension on the feed yarn, which is usually done by wrapping the yarn around a finger. After several iterations we settled on replacing this capability with the adjustable friction tensioner shown in Figure 6 (b). Tension can be adjusted by changing the number of posts the yarn is wrapped around, or the number of times it is wrapped on a post. The tensioner also positions the incoming feed yarn where it can be easily be hooked, directly behind the needles on a short (adjustable) pole as shown in Figure 6(c).

A final aspect of needle knitting supported by our prototyping is the action of knitting back and forth across rows. When knitting a sheet, knitters flip the fabric over at the end of each row so that they are always knitting in one direction (by convention usually left-to-right). Knitting patterns always assume this action (knitting stitches change to an equivalent but reversed stitch when the garment is reversed; for example a knit must be changed to a purl when the garment is reversed). To support this we built in a means to flip the needles – a spring loaded rotation that snaps into two positions is provided (in the middle of the main mounting post for the device). When the work is flipped, the tensioning pole can also be moved.

The first iteration of the device, which did not yet have a lap desk, or the more refined tensioner 6(b), was demoed to P1-MVC, who kept it and later sent a video showing that she had knit successfully with it, as shown in 6(d). Based on the in-person session and later design feedback, we identified the following areas for improvement: Her comments and our observations caused us to realize that the lapdesk was critical for stability. The initial design of the tensioning device held the yarn at a good angle but provided either too much or too little tension. We refined the design to have multiple pegs to provide an appropriate amount of tension. Our observations of her use shows that she preferred to knit without making use of the deep, wide slot we had hoped would reduce error in the presence of tremor. Finally, our observations of when the device failed her and the loops did not move as expected caused us to add a ring on the latchhook to prevent the loops from moving too far down the hook and becoming difficult to retrieve.

6 DISCUSSION AND FUTURE WORK

Our work is unique in focusing on the intersection of disability and knitting, but parallels themes from other fabrication domains including the need for accessibility to be considered in pattern/model design [10], the crafting process itself [29], and the object being created [25]. These studies lowered the access barriers to regarding both the materials and the knowledge needed to engage in the craft itself for disabled crafters. The workshops designed to introduce visually impaired crafters to e-textiles [11, 12] apply these values in their workshop design and by the end of the study participants had created objects that were accessible and personally meaningful, while also gaining confidence in their crafting skills.

Our findings demonstrate how knitting gives participants an outlet for creative expression, allows them to customize knitted objects based on the needs of the recipient, helps them cope with their disability, and provides a community through which they can learn, collaborate, and provide support for each other through. Our study showed the importance of accessibility across multiple aspects of knitting, from pattern accessibility to the creation process itself knitted object being created.

Although knitting with a disability is most definitely already done, and do-able, by people with a variety of disabilities, our findings also highlight areas throughout the knitting process where technical advances could increase the range of patterns disabled knitters can knit, or the range of knitters who can knit a pattern. Below we discuss limitations and domains for further inquiry supported by our work.

Study Limitations. Our study had a limited number of participants with cognitive impairments. The difficulties, hacks, motivations, *etc.* of two participants may not be representative of the entire population of knitters with cognitive impairments. Further work should explore knitting within this population. We also acknowledge that our analysis of forum data is biased towards disabled knitters who have access to the Internet and a computer as well as the ability to use the technology. To help mitigate this bias we used both online and offline recruitment methods during the recruitment process such as word of mouth, phoning and emailing crafting groups, and through forum posts.

Pattern creation. The ability to customize a knitted object to fit the unique needs of the recipient is one of the main reasons knitters customize patterns. However, the tools available for knit pattern construction today are still fairly limited. Past work has explored the ability to generate a pattern from a shape (*e.g.,* [20, 27]), but these do not fully capture the range of expressiveness used in knit patterns today. Future research should expand on work in knit pattern parsing [17] to provide the expressiveness to understand, modify and add to the diverse library of patterns found on sites like ravelry.com. This is difficult because knitting patterns are typically described using a combination of English and variations on a language called KnitSpeak [17]. If the vast library of free patterns on sites like ravelry.com could be labeled, it should be possible to develop approaches that can learn to understand patterns. Given such an ability, a tool could support modifications to the texture of patterns, the shape of patterns (such as lengthening the front and shortening the back of a sweater) and changing how patterns are presented by supporting audio presentation, physical controls and so on. This could help lower the entrance barrier to pattern design, not only for accessibility but for knitting fabrication research in general.

Making Patterns Accessible. Making accessible knitting patterns is a second area that could be supported by automatic parsing of knitting patterns. The results from both the interviews and forum data reveals an overwhelming number of accessibility issues that make knitting pattern PDFs inaccessible such as font size or text, charts, paragraphs of text, incompatibility with screen reader, *etc.*. If automatic parsing of a pattern could be used to then generate an accessible mark-up version of the pattern, which a user could manipulate to match their preferred pattern formatting style (e.g. removing unnecessary text, render written instructions for charts, separating instructions so each new line in the document consists of a new instruction). This capability would increase the data available for learning to parse knitting patterns; and potentially also help inform efforts to make documents accessible outside of the fabrication space. Further, it would widen the range of patterns currently available to disabled knitters.

Pattern understanding during knitting. Our findings indicate some knitters could benefit from a tool that keeps track of their place in a knitting pattern as they knit. It would be interesting to build on the physical devices produced in our case study by adding sensing. Past work has demonstrated a loom with embedded LEDs to provide row-by-row patterning instructions; specifically stitch type and the color of yarn to knit each stitch with [14]. Users can draw their own colorwork pattern and incorporating this tool into their knitting process to remove the need to constantly look at a pattern and reduce number of errors made. However, this hybrid tool only outputs information (*i.e.* the type and color of each stitch in the pattern). Building on this work, we could add input recognition to the loom by instrumenting the loom's pegs with conductive materials. It should be possible to detect when a metal hook touches a peg, which in turn could provide automatic support such as detecting stitch type or advancing to the next stitch in a pattern. This could provide both error prevention and memory support to help knitters ensure they are knitting the correct stitch on the correct peg, that they are knitting the correct stitch type as dictated by the pattern, and also eliminate the need to continually reference a pattern. Such real-time feedback during construction has been used in other fabrication contexts such as woodworking (*e.g.,* [32, 34, 37].

7 CONCLUSIONS

In this study, we explored how experienced knitters with disabilities knit today, accessibility concerns that they have, and solutions they have found to make the knitting process more accessible. Through interviews with disabled knitters and analysis of five disability focused knitting forums we identified many accessibility challenges that disabled knitters face throughout finding patterns, reading through patterns, and throughout the knitting process. We present the results of our cases study in which we iteratively develop and test a modified loom and one-handed needle solution with an interviewee.

Although this research has focused specifically on the craft of knitting, our results have reflected themes in other crafting and fabrication domains. These considerations include the need for accessibility to be considered in pattern or model design and in terms of access, the crafting process itself, and the object itself being created [12].

ACKNOWLEDGMENTS

The authors thank the participants. This work was supported by UW CREATE and was funded in part by the National Science Foundation under grants IIS-1718651,1907337 and 1836813.

REFERENCES

[1] [n.d.]. V&A · The history of hand-knitting. https://www.vam.ac.uk/articles/the-history-of-hand-knitting

[2] 2020. Boye® Small Long knitting Loom Tool. https://www.herrschners.com/product/boye%26%23174-+small+long+knitting+loom+tool.do

[3] 2020. Dritz KT-2 Norwegian Knitting Thimble. https://www.amazon.com/LoRan-KT-2-Norwegian-Knitting-Thimble/dp/B00114OO10

[4] 2020. Genuine Knifty Knitter Round Loom Set with 4 Looms, Hook & Bag. https://www.amazon.com/Genuine-Knifty-Knitter-Round-Looms/dp/B003IH8A5E

[5] 2020. How To Use A Knitting Belt | The Principles of Knitting. http://www.principlesofknitting.com/how-to-use-a-knitting-belt/ Library Catalog: www.principlesofknitting.com.

[6] 2020. knitCompanion knitting & more. https://apps.apple.com/us/app/knitcompanion-knitting-more/id1058142783 Library Catalog: apps.apple.com.

[7] Knitting Aid. 2019. Helping You Knit Again. Stitch by Stitch. https://www.knittingaid.com/

[8] Swamy Ananthanarayan, Nathan Lapinski, Katie Siek, and Michael Eisenberg. 2014. Towards the crafting of personal health technologies. In *Proceedings of the 2014 conference on Designing interactive systems*. 587–596.

[9] Leah Buechley and Hannah Perner-Wilson. 2012. Crafting technology: Reimagining the processes, materials, and cultures of electronics. *ACM Transactions on Computer-Human Interaction (TOCHI)* 19, 3 (2012), 1–21.

[10] Xiang'Anthony' Chen, Jeeeun Kim, Jennifer Mankoff, Tovi Grossman, Stelian Coros, and Scott E Hudson. 2016. Reprise: A design tool for specifying, generating, and customizing 3D printable adaptations on everyday objects. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*. 29–39.

[11] Emilie Giles and Janet van der Linden. 2015. Imagining future technologies: eTextile weaving workshops with blind and visually impaired people. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition*. ACM, 3–12.

[12] Emilie Giles, Janet van der Linden, and Marian Petre. 2018. Weaving Lighthouses and Stitching Stories: Blind and Visually Impaired People Designing E-textiles. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 470.

[13] Elizabeth Goodman and Daniela Rosner. 2011. From garments to gardens: negotiating material relationships online and 'by hand'. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. Association for Computing Machinery, Vancouver, BC, Canada, 2257–2266. https://doi.org/10.1145/1978942.1979273

[14] Jordan Graves and Anne Sullivan. [n.d.]. eLoominate: Tools for Casual Creation in Hybrid Craft. ([n. d.]), 5.

[15] Kevin A. Hallgren. 2012. Computing Inter-Rater Reliability for Observational Data: An Overview and Tutorial. *TQMP* 8, 1 (Feb. 2012), 23–34. https://doi.org/10.20982/tqmp.08.1.p023

[16] Peregrine Hawthorn and Daniel Ashbrook. 2017. Cyborg pride: Self-design in e-NABLE. In *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility*. 422–426.

[17] Megan Hofmann, Lea Albaugh, Ticha Sethapakadi, Jessica Hodgins, Scott E. Hudson, James McCann, and Jennifer Mankoff. 2019. KnitPicking Textures: Programming and Modifying Complex Knitted Textures for Machine and Hand Knitting. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*. ACM, New Orleans LA USA, 5–16. https://doi.org/10.1145/3332165.3347886

[18] Yuki Igarashi. 2020. Computational Handicraft. In *Emotional Engineering, Vol. 8: Emotion in the Emerging World*, Shuichi Fukuda (Ed.). Springer International Publishing, Cham, 43–64. https://doi.org/10.1007/978-3-030-38360-2_4

[19] Yuki Igarashi, Takeo Igarashi, and Hiromasa Suzuki. 2008. Knitting a 3D Model. *Computer Graphics Forum* 27, 7 (2008), 1737–1743. https://doi.org/10.1111/j.1467-8659.2008.01318.x _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-8659.2008.01318.x.

[20] Yuki Igarashi, Takeo Igarashi, and Hiromasa Suzuki. 2008. Knitty: 3D Modeling of Knitted Animals with a Production Assistant Interface.. In *Eurographics (Short Papers)*. 17–20.

[21] Mohammad Hossein Jarrahi, Will Sutherland, Sarah Beth Nelson, and Steve Sawyer. 2020. Platformic Management, Boundary Resources for Gig Work, and Worker Autonomy. *Computer Supported Cooperative Work (CSCW)* 29, 1 (2020), 153–189.

[22] Anna Kalma, Bernd Ploderer, Laurianne Sitbon, and Margot Brereton. 2019. Probing Yarns about Ageing and Making. In *Proceedings of the 31st Australian Conference on Human-Computer-Interaction (OZCHI'19)*. Association for Computing Machinery, Fremantle, WA, Australia, 173–183. https://doi.org/10.1145/3369457.3369472

[23] Alexandre Kaspar, Liane Makatura, and Wojciech Matusik. 2019. Knitting Skeletons: A Computer-Aided Design Tool for Shaping and Patterning of Knitted Garments. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*. ACM, New Orleans LA USA, 53–65. https://doi.org/10.1145/3332165.3347879

[24] James McCann, Lea Albaugh, Vidya Narayanan, April Grow, Wojciech Matusik, Jennifer Mankoff, and Jessica Hodgins. 2016. A compiler for 3D machine knitting. *ACM Transactions on Graphics (TOG)* 35, 4 (2016), 1–11.

[25] Janis Lena Meissner, John Vines, Janice McLaughlin, Thomas Nappey, Jekaterina Maksimova, and Peter Wright. 2017. Do-it-yourself empowerment as experienced by novice makers with disabilities. In *Proceedings of the 2017 Conference on Designing Interactive Systems*. 1053–1065.

[26] M Möhlmann and L Zalmanson. 2017. Hands on the wheel: Navigating algorithmic management and Uber drivers'. *38th ICIS Proceedings* (2017).

[27] Vidya Narayanan, Lea Albaugh, Jessica Hodgins, Stelian Coros, and James McCann. 2018. Automatic machine knitting of 3D meshes. *ACM Transactions on Graphics (TOG)* 37, 3 (2018), 1–15.

[28] Kate Orton-Johnson. 2014. Knit, purl and upload: new technologies, digital mediations and the experience of leisure. *Leisure Studies* 33, 3 (May 2014), 305–321. https://doi.org/10.1080/02614367.2012.723730

[29] LAUREN RACE, JOSHUA A MIELE, CHANCEY FLEET, TOM IGOE, and AMY HURST. 2020. Putting Tools in Hands: Designing Curriculum for a Nonvisual Soldering Workshop. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility*. 1–4.

[30] Sadhan C. Ray. 2012. *Fundamentals and Advances in Knitting Technology*. CRC Press. Google-Books-ID: zkf7CAAAQBAJ.

[31] Jill Riley, Betsan Corkhill, and Clare Morris. 2013. The Benefits of Knitting for Personal and Social Wellbeing in Adulthood: Findings from an International Survey. *British Journal of Occupational Therapy* 76, 2 (Feb. 2013), 50–57. https://doi.org/10.4276/030802213X13603244419077

[32] Alec Rivers, Ilan E Moyer, and Frédo Durand. 2012. Position-correcting tools for 2D digital fabrication. *ACM Transactions on Graphics (TOG)* 31, 4 (2012), 1–7.

[33] Daniela K. Rosner and Kimiko Ryokai. 2010. Spyn: augmenting the creative and communicative potential of craft. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. Association for Computing Machinery, Atlanta, Georgia, USA, 2407–2416. https://doi.org/10.1145/1753326.1753691

[34] Eldon Schoop, Michelle Nguyen, Daniel Lim, Valkyrie Savage, Sean Follmer, and Björn Hartmann. 2016. Drill Sergeant: Supporting physical construction projects through an ecosystem of augmented tools. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 1607–1614.

[35] Anselm Strauss and Juliet Corbin. 1994. Grounded theory methodology. *Handbook of qualitative research* 17, 1 (1994), 273–285.

[36] Thingiverse.com. [n.d.]. Thingiverse - Digital Designs for Physical Objects. https://www.thingiverse.com/ Library Catalog: www.thingiverse.com.

[37] Rundong Tian, Sarah Sterman, Ethan Chiou, Jeremy Warner, and Eric Paulos. 2018. Matchsticks: Woodworking through improvisational digital fabrication. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–12.