Craftspeople as Technical Collaborators: Lessons Learned through an Experimental Weaving Residency

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ABSTRACT
While craft has had increasing influence on HCI research, HCI researchers tend to engage craft in limited capacities, often focusing on the juxtapositions of "traditional" craft and "innovative" computing. In this paper, we describe the structure and results of a six-week "experimental weaving residency" to show how HCI practitioners, engineers, and craftspeople perform similar work and can productively collaborate to envision new technological interfaces at early stages of development. We address both social and technical challenges of residencies and critically reflect on biases about technical and craft labor that we held prior to the residency. We share our experiences and lessons learned in the hopes of supporting future collaborations with craftspeople and broadening the techniques we use to address design challenges.

Author Keywords
Artist Residencies; Feminist HCI; Collaboration Models; Electrodes; Weaving; Smart Textiles

CCS Concepts
•Human-centered computing → Interface design prototyping;

INTRODUCTION
As HCI researchers continually look towards the integration of "smart" digitally enabled or responsive components within "traditional" material domains (paper [51], clay [54], fabric [52, 66], etc.), they are increasingly turning their attention to craft for inspiration and collaboration. However, as researchers approach craft, they tend to engage it within specific capacities, often unintentionally emphasizing its romantic, poetic, or primitive associations to create thought-provoking juxtapositions between the technological new and the craft old [28, 26, 48]. In other cases, researchers aim to bring technological expertise to the craft amateur [49, 18] particularly when they use craft as a platform for women and non-westerners to become introduced to more technical concepts and techniques [53, 23]. While such work has offered new approaches and perspectives on computing systems, this paper aims to support a broader perspective of craft practitioners as *technical* in their own right.

We (the authors) believe HCI's vision of craft has been limited by the gendered legacies of craft and its frequent association with amateurism [18, 56]. As researchers within and beyond

Figure 1. One of the sampling prototypes created during our "Experimental Weaving Residency." This paper describes how collaborating with a weaver led us to reconsider what we believed to be technical knowledge and provides insight on how researchers might productively structure residency based collaborations in the future.

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HCI have chronicled, craft has historically been performed by women [20, 64], "little old ladies" [56], and indigenous people [48] has been regarded as mere labor in relationship to technological innovation. While HCI has a growing interest in engaging craft and applies many computational modes of design *to* craft practice (e.g. generative design, tool making), or engaging craftspeople as users or their systems, there is less known about the sociotechnical challenges of *including* craftspeople in research partnerships—specifically, how HCI might meaningfully include craftspeople in the early stages of technical research in a mutually beneficial capacity (or what "mutually beneficial" might even mean within this context). These questions have particular value as a growing number of artist residencies are emerging within the academy and industry (at Microsoft [12], Facebook [40], Google [9], and Autodesk [7, 59] to name a few), but tend to emphasize the creative capacity of craftspeople to discover applications and visions for the technology *after* it is developed, rather than serve as core developers of the technology from the early stages.

With artist-collaborations Xerox PARC as an early example [19], and a growing amount of innovation taking place outside traditional STEM fields (e.g. [31, 62, 5]), we see evidence to suggest that early-stage collaboration with craftspeople can be particularly productive in addressing technical problems as well as envisioning entirely new modes of engagement with technology (e.g. [19, 29, 63]). Yet, HCI needs to know more about how to make these collaborations both productive and supportive for all parties involved.

This paper details what we learned about supporting craft collaborations by reflecting on a six-week artist residency hosted within the Unstable Design Lab, an HCI lab hosted within the ATLAS Institute at the University of Colorado, Boulder. This residency was focused on *including* a craftsperson, specifically a weaver and textile designer, in smart textiles innovation. The focal point of this collaboration was a smart woven headband for sensing muscle activity in the forehead.

Working with the resident helped the HCI/engineering researchers involved understand ways to approach a solution that ran counter to approaches they had initially considered. Specifically, where the HCI/engineering team would turn to established best practices and hardware, the resident would turn to materials, demonstrating how the materials and structures of weaving, themselves, could provide alternative approaches. For the resident, Sandra Wirtanen, the residency offered a broader range of methods and perspectives to enter into her own artistic work. We considered this residency to be successful because it expanded the solution-space of our design challenge, inspired new directions and future foci for HCI/engineering/arts research, and resulted in each collaborator feeling that the collaboration was successful and meaningful within their personal practice.

Rather than focusing on the core technical outcomes of this residency, this paper turns, instead, to the social structures and understandings of craft practice that we believe enabled our productive collaboration. First, we reflect on how the idea of "technology" was enrolled throughout the residency, what the HCI/engineering team understood to be relevant to technological development, and how that changed as a result of the collaboration. Second, we reflect on the structural organization of the residency and the specific supports the organizers provided for the craftsperson that acknowledged the risk they took in collaborating with our lab and attended to the needs they would have to develop their own practice. These insights have emerged by looking at our own biases with a critical eye and reflecting on how those biases shaped our selection processes. Specifically, how we came to see that our assumptions about what counted as "technical" were more narrow than they ought to have been. Furthermore, we found that our own knowledge and experience with weaving brought more value to the collaboration than the resident's knowledge of digital technology. As such, we urge HCI researchers to see the capacity for craftspeople to be *technical* collaborators and use a feminist lens to draw out the implications of that call. We use the term *technical* here to make an argument that the knowledge and competencies held by craftspeople may be expressed through different media, but are ultimately compatible and comparable with our own practices of design iteration and innovation. Therefore, its less a matter of "high" or "low" tech, but the modes of practice and ways of knowing that emerge through a rigorous practice with particular material sets and tools.

We present this as a contribution to HCI in order to broaden awareness of HCI's practices of integrating craft and to show how researchers might do this in ways that are of particular benefit to craftspeople, as well as researchers. In doing so, we hope to demonstrate the possibilities for innovation held in investigations of textile structures and build the social foundations upon which a new kind of smart textiles/materials research can emerge, one that looks towards past and future techniques for solutions and ideas that may prove to be more sustainable, robust, and viable within existing infrastructures of manufacturing.

ART, CRAFT AND HCI

The field of smart textiles offers an excellent history of artists and craftspeople leading innovation as opposed to adapting to innovations made elsewhere. For the past two decades (at least [43]), smart textiles innovation has taken place on the fringes or outside of the purview of HCI (e.g. [14, 3, 17, 16, 65]). Galleries have been displaying interactive textile prototypes and groups such as e-textiles summer camp [8], e-textiles spring break [4], and the e-textiles swatch exchange [30] have fostered communities devoted to the open source development of textile based computing resources such as Hannah Perner–Wilson and Mika Satomi's *Kobakant* [10]. Despite the key role craftspeople have played in forming the foundations that make present day innovation possible, the majority of work emerging under the banner of smart textiles has emphasized the development of novel materials which are simplistically integrated into the structure of fabrics (e.g. [45, 46]). In engineering applications, the textile structures are treated like the vehicle upon which the *a priori* determined solution can be applied. This gap between communities, the craftspeople who deeply understand the textile structures but have limited access to state–of–the–art materials, and the engineers with access to new materials but a lack of knowledge of textile structures, is evidenced in the nature of the prototypes themselves. Our work is motivated by a desire to bring these two communities together (like [44, 58]) to envision a future of smart textiles that are both robust and richly crafted.

Residencies and Collaboration Models in HCI

HCI's "turn to the arts" [22, 35] has emphasized the benefits of integrating artistic approaches within HCI's repertoire of design methods. This work, often, draws directly from the study of art/craft practice, such as: studies of how robotics participate with furniture makers [24] or how artists are re-engaging outmoded electronics [34];offering art historical perspectives to shed light on HCI research practices [39, 26]; and describing first-person reflections on one's improvisational/open-ended art and craft practices [38][add probing]. Other work reports directly on ongoing collaborations with artists in HCI related projects, such as Rachel Jacob's work comparing climate change visualizations developed by artists vs. HCI researchers and the values exhibited within each approach [37, 36].

Perhaps most relevant to our work is the growth of artist residencies within academic and industrial research venues. A survey of university artist-in-residency programs conducted by Golan Levin and contributors in 2013 describes several of these program structures, particularly in relationship to how intellectual property is handled [41]. Within HCI more recently, craft collaborations have directly contributed to and become co-authors on research findings (e.g. [56, 32, 57]). For instance, Audrey Desjardins collaborated with ceramicist Timea Tihanyi to create novel physicalizations of Internet of Things data [25], Vasiliki Tsaknaki worked closely with a silversmith to envision new wearables [61], and Daniela Rosner worked closely with quilter Helen Remick in re-fabulating histories of woven core memory [56]. Furthermore, art residencies within the Studio for Creative Inquiry at Carnegie Mellon [11] or the SubnetAIR program at the Center for Human-Computer Interaction in Salzburg, invite artists to conduct their work alongside an HCI research teams [13].

Examples of art and HCI or engineering collaboration also exist within arts programs, such as Marianne Fairbanks' Weaving Lab at the University of Wisconsin-Madison, which "spans the fields of art, design, and social practice, seeking to chart new material and conceptual territories, to innovate solution-based design, and to foster fresh modes of cultural production." [15] Furthermore, institutions like the Maryland Institute College of Art (MiCA) have been teaching courses in technology integrated textiles for over a decade [6].

While interest in residencies grows, HCI researchers have little information about what structural setups do and do not work to support collaboration, particularly in settings where a specific set of craft skills is sought after for a specific engineering or HCI project. **How are the different expertise and backgrounds of the collaborators negotiated in the ongoing emergence of novel technology? How can we ensure these collaborations are mutually beneficial to *all* parties involved?**

RESIDENCY TIMELINE AND OVERVIEW

We conducted our "Experimental Weaving Residency" in the summer of 2019 [1]. We introduce the collaborators who co-wrote this paper, as well as the timeline for our project below to provide context to the claims we will make in following sections.

Collaborators

To understand the specific perspective that shaped our work, and what we report here, it is necessary to give some background on the expertise and focus of each author. Laura Devendorf is an HCI researcher and director of the Unstable Design Lab with past experience developing smart textiles and participating in artist residencies in tech organizations [1]. Katya Arquilla is a PhD student in Aerospace Engineering Sciences, focusing on developing wearable sensors to measure biophysical signals that can indicate psychological stress. Sandra Wirtanen is our selected researcher-in-residence, who recently graduated from a textile design program at Aalto University. Steven Frost is a weaver and performance artist who frequently participates in exhibitions and residencies. Allison (Allie) Anderson is a faculty member in Aerospace Engineering Sciences focusing on body-worn sensing, who worked with Laura and Steven to craft the proposal enabling the residency. References to the "organizers" specifically reference Laura, Steven and Allie.

Timeline and Phases

Our residency was first conceptualized in 2017 and executed in 2019. The following sections outline the key points within these two years of development.

Weaving Disciplines Workshop

The "Weaving Disciplines" workshop began a conversation about what made craft/engineering collaborations meaningful for the different parties involved. The workshop brought artists, community members (Boulder Public Library representatives, local handweaving experts, a DIY electronics company, artists, designers, and engineers from CU Boulder) to discuss collaboration opportunities in teh specific area of smart textiles. Our core finding was the importance of shared space, play, and collaboration before formal deliverables of the collaboration are established.

Learning to Jacquard Weave

Following the workshop, and in relationship to university initiatives, the organizers worked together to purchase a TC2 digital jacquard loom to support their textiles research. A TC2 is a computer controlled loom, meaning that one can design files on a computer and "print" these on the equipment [50]. While the machinery stores and executes the pattern, a human is still responsible for manually "throwing" the yarn in each row to create the textiles. We used this machine to make in-house prototypes and smart textiles samples but quickly realized the limits of our knowledge. It became clear how much an expert on such machinery would bring to our collaboration so we began to more seriously seek opportunities to involve

[1] More information and documentation can be found at http://unstable.design/experimental-weaving-residency/

craftspeople into our research. It should be noted that this machinery is currently rare to find outside textile programs and specialized research labs. Because of this, we felt that access to this equipment might be a large draw for craftspeople to apply.

Experimental Weaving Residency

Insights from our workshop, as well as Laura and Steven's personal experience in residencies, shaped a funding proposal for a 6-week "practice-based research" residency to the Center for Craft "Materials-Based Research Grant" program. The proposal expressed our desire to offer a visiting fiber artist or textile craftsperson a working space within the Unstable Design Lab during the summer of 2019. Specifically, we proposed the residency as a "research residency" rather than an "art residency" in order to emphasize the role the craftsperson would play as a productive member of our research team. We proposed compensating our visitor at the same working rate as our PhD-level research students while also providing them housing and travel funds. Further, we made specific promises and commitments around access to equipment to ensure the selected resident would have priority access to our machines during their visit. We decided on a six-week residency term as a balance between available funding, housing resources, and duration we felt capable of achieving meaningful research results. To ensure we did not prescribe the form this residence would take, we left the qualifications for the practice-based researcher-in-residence open-ended, emphasizing that we wanted to hear from fiber artists who engaged digital technology in *some* capacity within their process. That included using computational design tools, integrating digital materials into their work, or producing work that provided contemporary commentary on digital culture. Thus, we did not predetermine a project to which the resident would contribute, but instead, tried to recruit based on who we thought would be best suited to spark new collaborative projects with lab members. Our assumption was that we could make sufficient headway in six-weeks on a set of research inquiries and investigations and, in alignment with Levin's findings in [41], we saw these collaborative investigations providing more value than the creation of a completed artwork or research prototype.

We were awarded the funding and followed by assembling a board of advisors, creating a public call for researchers-in-residence, selecting our specific collaborator, and conducting the residency.

Assembling an Advisory Board

It is common for arts organizations to assemble advisory boards in relation to specific opportunities. This board fulfills roles like advising the organizers, offering material resources (in terms of publicity, exhibition space, or other support), and review of the applications. Thus, we felt it important to integrate this practice into our proposed residency to ensure it was a true merging of the traditions associated with the two communities we were trying to integrate more fully. We assembled our board to include a group of fiber artists, media artists, and local "maker" leaders and they became an important resource.

Figure 2. (Left) Artists, engineers, and hand weavers convened at the "weaving disciplines" workshop to envision productive collaboration structures.(Right) Allison Anderson describes open challenges in bioastronautics during an initial brainstorming meeting during the residency.

Their primary role in our process was to provide reviews and feedback on the top twenty applicants.

Selecting our "Practice-Based" Researcher In Residence

We widely disseminated our residency over a variety of platforms roughly six-weeks before the application deadline. The word of the residency spread rapidly and it wasn't long before people were sending us examples of our residency being posted on mailing lists and institutions we had not originally contacted. By the deadline, we had received 200 applications from across the globe, a number that led us to discover just how many craftspeople are interested in participating in smart textiles research. We noted that at least 48% of our applicants had experience working with computational design tools and/or interactive materials and at least 80% of our applicants would be considered minorities in STEM (women, people of color, queer (LGBTQ+)). These anecdotal data suggest that in addition to advancing innovation, residencies can be a useful method for bringing diverse perspectives into innovation work.

The initial downselect of applicants was based on their level of experience with non-traditional materials or design practices (computer integrated, e-textiles, etc.), their experience with weaving specifically, and the degree to which we appreciated their aesthetic and conceptual stance. We sent the top 20 applications to a review by the entire advisory board, asking for specific feedback about this person's promise as an artist, the quality of their work, and the degree to which they would like to engage them during their visit. After this round, we culled the list to our four top applicants. Laura, Steven, and Allie interviewed each finalist to get a sense of their practice, approach, and desires to participate in research. We selected Sandra based on her prior experience with integrating solar cells into woven fabrics, interest in similar techniques that we had grown interested in exploring, and enthusiasm for participating in research.

Conducting the Residency

In the first week of the residency, we held a large meeting to discuss the different projects taking place in the HCI lab (Figure 2). Sandra shared her swatches, and the authors (as well as members of the research lab more broadly) speculated on different collaborative projects and areas of interest. Ultimately, Katya's existing project exploring electrode design held the most appeal to Sandra, and they quickly began to work together. Throughout the residency, she participated in lab meetings, gave input on various projects, and began to

Figure 3. The design challenge that Katya and Sandra focused on was weaving head-worn electrodes for sensing muscle stimulation in the forehead. This image shows a detail how silver threads were integrated in conjunction with elastics, wool, and cotton to rest comfortably and firmly on the forehead.

learn more of the techniques we used in the lab, like programming Arduinos and making circuitry. After the residency term concluded, we hosted and live streamed a public talk about the research and Laura interviewed Sandra in order to get a greater sense of what aspects of the residency were and were not successful.

The Engineering Challenge

Over the course of the residency, Katya and Sandra developed a project concept that was of mutual interest, based on their individual backgrounds and desired future work. The focal point of collaboration was a headband that sensed muscle actuation of the forehead. With each heartbeat and muscle twitch, the body produces electrical signals that can be mapped to motion, emotion, and intent with the use of simple electrodes in contact with the skin. The muscles in the forehead, such as the frontalis muscles (located above the eyebrows, in line with the pupils), can indicate surprise, fear, or sadness, depending on which other muscles are activated simultaneously. The forehead muscles are desirable for use as hands-free actuation to control display systems especially because users are often already wearing head-mounted gear.

System design began by mapping out the required elements for an EMG circuit to detect activation of the frontalis muscles. Two electrodes are required for each muscle, with an additional electrode at the top of the forehead to act as the ground. The system is run using an Arduino Pro Mini (5V) microcontroller, which had to be integrated into the headband as it was woven. For the first iteration of the design, the Katya laid out the circuit and its necessary parts, and Sandra incorporated them into the weave structure by mapping out in a diagram the size of each component and its necessary connections.

PERFORMING TECHNICAL KNOWLEDGE

When we recruited for the residency, and judged the applications, we felt strongly that the person we would select should have a baseline understanding of digital technology in order to productively collaborate. We looked for evidence of this knowledge in applicants' portfolios by studying their use and integration of smart materials, physical computing hardware and circuitry, and/or the development or integration of computational design tools into their practice. In this capacity, we considered technical knowledge as awareness and comfort with "non-traditional" practices, explicitly casting technological development as something novel coming to be integrated with textile craft.

Over the course of residency, we began to realize how limiting our initial judgement of "technical" comptency had been and the particular way that it reinforce divisions between "low-tech" craft and "high-tech" technology. The following excerpts describe specific moments in our collaboration where our thinking about what *counted* as technical became more broad by describing how Sandra performed technical competnecy without the use of materials and objects for which we had given the special mark as "technical." Specifically, we describe how her approach to fibers, structures, and the integration of soft and hard components could be understood as technical in its own right.

Locating Solutions in Textile Structures

One of the primary design challenges with wearable sensors is the need to minimize noise from the sensor by limiting movement against the skin. The traditional engineering solution to this problem is to make the electrodes sticky. Commonly used gel electrodes have an adhesive backing that sticks to the skin and keeps the electrode in one place. Yet, this adhesive can impact comfort and irritate the skin and does not provide a solution feasible for most daily contexts. When we opened our process to Sandra, we began to consider how fabric structures and materials would enable the materials to sit firmly on the skin, hopefully eliminating the need for gels. We turned to an investigation/integration of two woven structures specifically: elastic ribbing and double woven pockets. The idea was that integrating elastics would push the fabric against the skin while the pockets would add additional support and pressure.

Troubleshooting Elastics

Woven fabrics are not traditionally stretchy, so Sandra experimented with both weaving elastic yarns in the weft direction and developing weave structures that create stretch as

Figure 4. Test swatches exploring (top) various shapes of stuffed pockets and their integration within elastic structures and (bottom) several stitches to test in terms of the flexibility they provide to the overall weave.

an approach to maintain skin contact. Initially, from Laura, Katya and Allie's novice-weaver perspective, replacing the weft threads with elastic threads seemed like a clear way to add stretch to a garment. We imagined that this would be as easy as integrating elastic yarns in place of rigid yarns. However, we learned that this was quite a bit more complicated than it sounded. First, the behavior of the fabric is emergent depending on the materials together with weave structures and other parameters (e.g. density). The only way to truly be able to locate a solution quickly is to have prior experience working across many types of materials, stitches and densities. Second, we learned though our collaboration that the elastic threads must be woven into the textile already stretched, which adds tension to the warp threads that can cause breakage and loss of threads in the weave structure. Incorporating elastic threads in only some rows in the weft direction adds some stretch without causing too much tension across the warp threads. Knowing exactly how much elastic thread to incorporate and at what tension to weave it also required Sandra's feel and skill for weaving.

Sandra approached these challenges by testing various stitch structures and combinations, guided by both material intuition and aesthetic taste (See Figure 4). Each swatch was evaluated qualitatively for its behavior and judged in relation to how well it might perform in response to different tasks.

The finalized structure that resulted from these experiments was a multi-layered textile structure. It utilized plain woven cotton on one side. On the other side, Sandra integrated satin woven elastics (e.g. a stitch in which long lengths of elastic "float" over the width in regular intervals). While two layered, the structure was bound together across the width of the fabric, meaning that every nth yarn on the top layer was attached to every nth yarn on the bottom layer. Because of the properties of elastics and cotton, this caused the plain woven, non-stretchy layers, to pucker up and create ridges when the elastic was at rest. When pulled, the plain woven sections would become flat and limit the elastics for over stretching or breaking.

Troubleshooting Pocket Structures

A second approach we considered to reduce sensor noise was integrating pockets that would be filled with a shape conforming material. These pockets would be created with a technique called "double weaving" which can be used to create pockets of arbitrary shape. This is achieved by splitting the warp into two layers and weaving each layer separately. More details about this particular technique can be found in [47, 27, 3].

Sandra developed two pocket types. The first pocket concept was filled with material to improve skin contact by morphing to the shape of the forehead. Sandra and Katya evaluated several material and pocket shapes, and integrated an electrode pad by weaving silver coated yarn on one side of the pocket. The padding served the dual purposes of keeping the electrode against the skin while also shielding the conductive elements from other components in the headband and effectively disguising them on the side that does not contact the skin. This design inspired a second padded pocket concept for storing and concealing the microcontroller. Sandra inserted the hardware (an Arduino Pro Mini) into a padded pocket during weaving to completely encase it in the fabric structure, limiting its ability to shift and move and providing a comfortable, wearable solution. Furthermore, by integrating the microcontroller into the fabric, instead of attaching it on top, we could keep it close to our electrode pads while keeping it hidden from view, limiting noise resulting from long signal wires.

Sandra's knowledge was exhibited in the ability to implicitly imagine how a pocket shape when woven flat would shift when stuffed and attached to the forehead. This had to be re-tested every time a material or structure change occurred and became the most time consuming task of our collaboration. While Laura, Katya, and Allie could conceive of pockets within fabrics prior to the residency, Sandra's approach in laying out and testing the pocket structures, sizes, and shapes to facilitate the insertion of electronics and stuffing during weave time, relied on a detailed knowledge of the hardware and material properties. These examples demonstrate specific technical solutions and creative textile innovation that would not have been achieved had Katya or Sandra had been working independently.

Why Call it Technical Knowledge?

At the outset of our project, the organizers anticipated that we would appreciate the technicality and skill Sandra would provide to the collaboration, but they underestimated the magnitude of its truth. Furthermore, we found that Sandra did not need training with code or hardware to effectively collaborate. What was far more useful to our team was that she brought the deep knowledge of weaving that we lacked. What was most important for Sandra was that the organizers and collaborators had enough knowledge of weaving to both appreciate, ideate, and understand the concepts she presented.

While HCI researchers might already consider craft to be technical and relevant, the actions researchers take (including our own actions prior to the residency) tend to frame craft knowledge as other or different from our own—a pre/anti-digital practice, a discipline that is more interested in aesthetics, or an idle hobby. Perhaps most prevalent is the description of craftspeople as a special class of users who "push the limits of what our tools can do" [2] or inspire us to create new kinds of tools. This cut between user/craftsperson and developer/engineer comes with strong implications in terms of power, credit, and financial support. Artists and craftspeople receive substantially less funding and support as user testers or artists-in-residents than HCI researchers do in temporary research roles and collaborations. This seems to emerge from the assumption that craftspeople can't or won't want to participate on engineering teams when in fact, we tend not to make those possibilities available in ways that would be mutually respectful and supportive.

We call for HCI to consider a feminist rethinking of collaboration with craftspeople as a way of broadening access and participation [42, 21, 60]—a rethinking of what "counts" as knowledge relevant to engineering/HCI collaborations [55] as well as how we, as HCI researchers, acknowledge our privilege and power within these collaborations. To emphasize, it

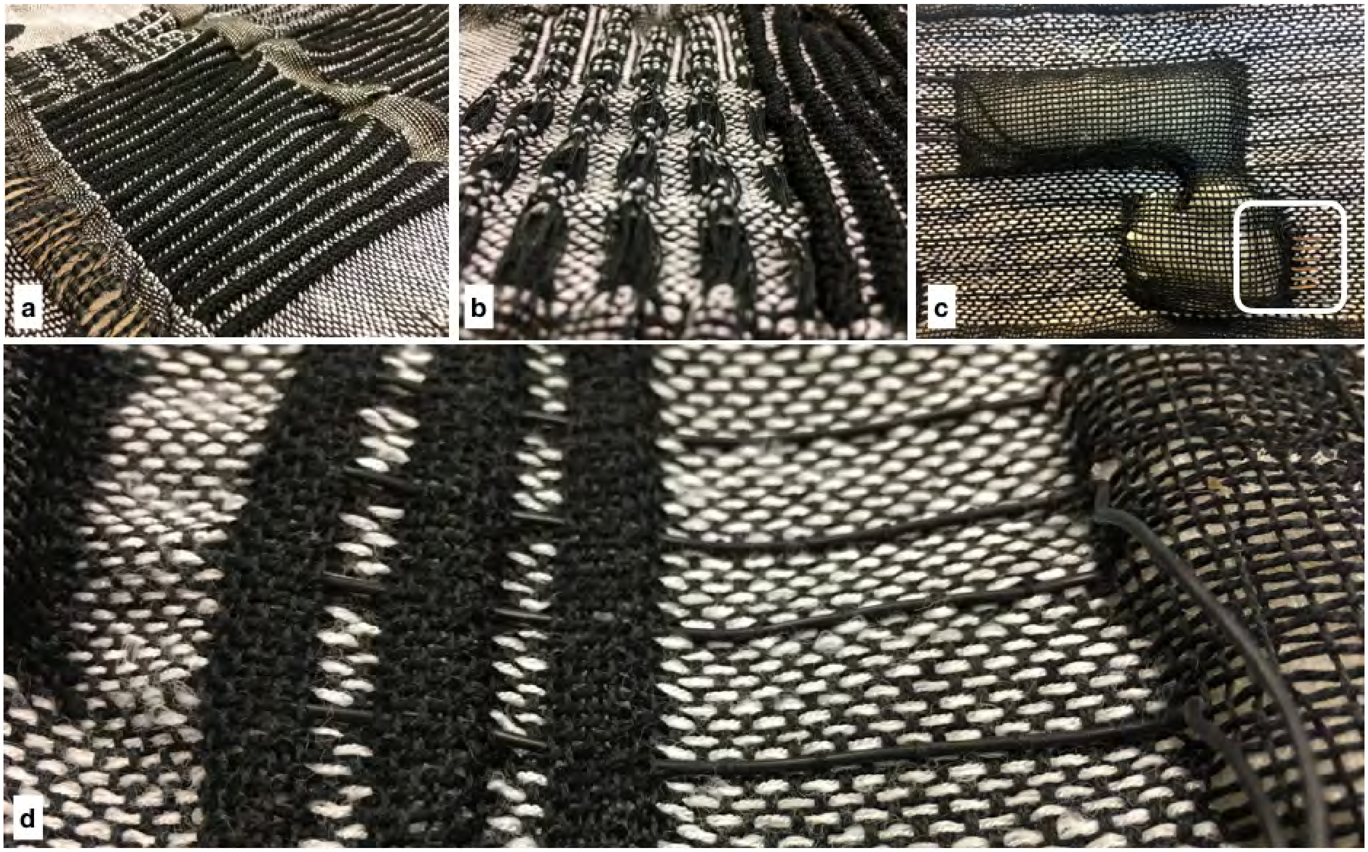

Figure 5. Details of woven structures developed in the residency. (A) demonstrates the ribbing created by pairing rigid cotton with long lengths of elastic. (B) shows a second approach to puckering based on combining elastic and non-elastic threads. (C) shows a detail of the pocket containing the microcontroller, with programming pins revealed to enable software changes. (D) shows silicone coated wires being routed through the fabric to connect the electrodes and microcontrollers.

is not *just* about giving the coveted label of "technical" to craftpeople, but fundamentally rethinking the programs and modes of participation that honor this knowledge. While utopian and optimistic, we believe rethinking HCI's ideas about and structures for collaboration will have societal benefits because it will broaden the possible solution space for a given problem. We hope this may lead to processes of innovation that are more equitable for the parties involved as well as outcomes that are more inclusive, imaginative, and sustainable.

In the following sections, we offer concrete tactics we learned from our residency that might help HCI move towards supportive and mutually beneficial collaborations.

DISCUSSION: BENEFITS, RISKS, AND TACTICS

Outside of the sensing headband project described here, Sandra and all lab members discussed ideas, developed prototypes, and brainstormed experimental project ideas such as "action weaving", an interface for running laps between weave pics, and various new methods for capturing and documenting experimental weave structures. The residency created a space for these ideas and practices to percolate side-by-side and to blend ideas, inspirations, and interests between lab members and Sandra.

Each member of the collaboration felt honored to be part of the collaboration and took a different set of benefits from the experience.

The benefit to the engineering team (Katya and Allie) was opening their process to new pathways of inquiry:

> "the opportunity to shed the structure of the engineering design process and begin making without a clear picture of what the product would be. Sticking to the typical requirement-driven design produces functional technology, but it loses the benefit of organic development there is room for within the artist's process."

The benefit of the HCI team (Laura and Lab Members) was related to the insights they gleaned about weaving and materials:

> "a greater knowledge of the capability and possibilities of textile structure that could be leveraged for novel smart textile interactive projects and the kind of design tools and supports that might need to be created to support this work more broadly. While we still remain novice weavers, we cultivated a much better sense of how we could approach our own testing and prototyping practice in moments where we didn't have access to expert knowledge."

Figure 6. Details of the front and back sides of our final prototype, in stretched and nonstretched states.

The benefit for the resident (Sandra) was centered on being part of dynamic environment and having access to address fundamental engineering challenges:

> "being able to integrate material and design knowledge into the process from the beginning. Often times, even in textile-based research, the design process is skipped entirely or conducted in a later phase after developing the technology. In some cases the opportunities to utilize the textile material in an effective and meaningful way are missed, which may have a negative effect on usability and user experience later. An open, collaborative process with a more holistic approach to engineering, design, materials, fabrication, and HCI is powerful for testing and gathering ideas that could potentially result in research around multiple fields."

These quotes reflect the benefits that emerged from a shared sense of openness and interest. In terms of openness, the engineering team was open to undertaking a research process that may have been less specifically function driven than their previous work; Sandra was open to sharing her practice and ideas; and the HCI team was open to sharing our resource es and collaborating on other small side projects (not listed in the paper) apart from advancing any particular lab project. In terms of interest, we all felt that we had something to gain and learn from the other: the HCI/engineering team wanted a better understanding of the textile development process and its opportunities and Sandra was interested in having the space to experiment a design challenge that, she felt, would advance her practice.

There were several risks involved in this work: the risk the HCI/engineering team faced in devoting time and resources to a project without knowing for certain what might emerge; the risk all parties faced in being exploited (e.g. the HCI team wanting Sandra to simply build their ideas or vice versa); and the risk that we all simply would not get along or share values resulting in experiences of which neither party valued.

We mitigated these risks, as many do [41], by focusing on sharing our practices rather than centering on a single outcome. We were also supported in this by our funding agency, who expressed a desire for us to pursue research with a craftsperson and the possibility of including any work we produced (including protoypes and process documentation) in a show devoted to this granting program. Since the residency, Sandra has started a job developing performance textiles and we have continued to envision new ways of documenting, sharing, and integrating textile knowledge within digital design platforms.

We also made an informal contact that treats her as an equal lab member. Both she and the lab will continue to be co-authors on the developed work and/or documents and exhibits.

Structural Foundations of Mutual Benefit

While previous work, particularly [41], highlights several core benefits and tactics for supportive collaborations that resonate with our experience, the following tactics go beyond this work, highlighting features that we found to be particularly relevant in our own case.

Cultivating Humility and Respect

In our follow up interviews with Sandra, one of the most valuable feature that supported her in our lab was our own knowledge of weaving: "the biggest reasons for me to apply for the residency was to get a new outlook on textiles by getting to know people from different backgrounds with a similar passion for weaving. Seeing the creative opportunities in using weaving as a method for research in HCI Design, Engineering etc. helped me deepen my practice and find new ways of working...It inspired me to continue exploring the field in-between art, design, craft, technology and science."

Figure 7. (Top) Sandra and Katya work together to test the prototype. (Bottom) The collaborators of this project and beyond from left to right: Ruth Hunsinger, Katya Arquilla, Sandra Wirtanen, Shanel Wu, Laura Devendorf, Steven Frost, Rona Sadan, Nathalia Campreguer, Lea Albaugh, Mikhaila Friske, and Josephine Klefeker.

This suggests that the HCI/engineering team's knowledge of weaving was perhaps of more importance to the successful collaboration than Sandra's knowledge of engineering. Laura, Steven, and Katya (as well as most of the lab members present during the collaboration) have spent significant time learning to weave, and have found this experience deeply humbling. Specifically, they had looked around their environments and seen different weave structures on items like clothing, dish towels and upholstery and naively assumed that if they could just repeat the pattern (or run the code so to speak) that they could get those products out. This is not the case, as weaving is deceptively simple in appearance and complicated in construction.

Textile craftspeople have unique access and experience with these techniques, and struggling through the craft from a first-person perspective gave Laura and Katya a deeply embodied respect for their years of experience. Craft theorist Tim Ingold might refer to this as "knowing [weaving] from the inside" [33]. This suggests that knowing *about* craft may not be enough to fully appreciate the value offered by a craftsperson. Furthermore, by knowing the foundations of weaving, we could focus on residency on new emergent ideas and challenges (rather than Sandra needing to educate us about the very basics). By knowing in a tacit and embodied sense, experience the time and labor of successful and failed weaves, cultivated the soil upon which a fertile collaboration could flourish.

Time and Support

This residency was not born on a whim and required a coordinated effort between several academic and administrative bodies. It took years to cultivate the relationships and partnerships that allowed the organizers to successfully recruit and support Sandra in our practice. The organizers had support from their institution, which was important in managing the Herculean bureaucratic hurdles of Sandra's Visa, pay, etc. that we needed to make our program successful. Also, having a key organizer of our residency (Steven Frost) identified as an artist and craftsperson also proved to be very important. Their support not only provided us credibility, but gave us access to local arts organizations that they could call on to support our effort. Furthermore, Steven was central in supporting Sandra's own career ambitions during their visit, organizing trips and meetings with arts organizations in the area.

We Encouraged Oversight from Other Artists

Part of effective collaboration is knowing what you don't know and the organizers genuinely didn't know how this collaboration could be productive within the resident's practice a priori. Furthermore, there are tensions between those working in tech who have access to much larger streams of support and funding than those working in the arts. The organizers wanted to be especially mindful of these dynamics and create a structure that would not be considered exploitative. The advisory board was central in this capacity. In one sense, it helped demonstrate to our applicants that the organizers sought the advice and feedback of those outside of engineering. In another, it offered oversight to the organizers in each stage of development to make sure wording and program structures were fair. The advisory board also provided several points of contact through which the word to a much broader community of artists and weavers could be spread. Furthermore, the evaluation process which involved the board became a place where terms like "artist", "craftsperson" and "designer" became more clearly delineated and meaningful in terms of how they manifested in the organizers mind. Specifically, it highlighted that HCI's own treatment of the terms as starkly different is much more blurry in practice. Instead, the orientation towards art, craft, or design, simply emerged in addition to their material practice.

Pay Parity and Housing

We offered the selected resident the same that a PhD researcher would earn for the same duration of work ($3750 USD) in addition to providing free housing if they were willing to stay with the organizers, funds for the flight and a materials budget for the residency. This resulted in a stipend that was much higher than what many residencies compensate. Yet, the organizers felt like it was essential to create a dynamic in the lab that didn't privilege one viewpoint as more valuable than another (despite the economic differences in those fields).

FUTURE RESIDENCIES AND ROOM FOR IMPROVEMENT

While the organizers found the residency to be successful, we noted a number of ways in which the structure we developed was not as inclusive of artists and craftspeople as it could have been. Specifically, in the way we offer housing support. We, like many others, assumed the craftspeople we would recruit would be mobile and (likely) without families. Yet, many of the people who applied had families, partners, or performed work in collaborative teams. In the future we plan to fund raise and/or build more collaborations locally to provide artists with their own housing. A second approach might be to fund raise for "flex" funding, which can be used in the event of an artist with needs that cannot be satisfied with the accommodations we provide.

The next factor to consider is the duration of the residency. Six-weeks went by quickly, and Sandra expressed the potential of better solutions, particularly in exploring elastics specifically developed for textile machinery, opening Laura and Kayta's eyes to the specificity of materials for particular tasks (e.g. not all elastics are created equally). Ultimately, the residency ended before we had completely worked out a solution. The collaboration, though, was so enjoyable and fruitful, the authors will continue to move forward in our work, and further deepen the interdisciplinary knowledge transfer. We will hold what we learned from Sandra and we were able to encode the structures, arrangements, and modifiable patterns for our design in a way that we intend to manipulate for future iterations. In this way, the knowledge we learned became "encoded" to some degree within a tool that we built to support future prototyping in this context.

Reflecting on the appropriate duration prompts reflection on the limitations of a residency structure itself. These opportunities are typically short term, aligned to provide focus and support for a limited time, and function as a kind of temporary or "gig" job for people trying to making a living as artists or craftspeople. The kinds of artists that *can* consider these opportunities are limited by their own demands or family commitments. As we work towards a future of productive collaboration, we should not consider the residency as an ending point, but a stepping stone that might help enable a broader appreciation of the technical knowledge of craft. In this sense, we might see other technical domains, engineering or otherwise, creating more stable and supportive opportunities for integrating those with craft degrees and training into their programs.

CONCLUSION

We have described and reflected on a six-week "experimental weaving residency" to highlight the specific capacities and benefits for including craftspeople as technical collaborators within HCI/engineering contexts. We emphasized the degree to which a textile craftsperson's knowledge of textile structures and materials can greatly broaden the solution space for designers, while also inspiring broader and more radical visions of new technologies that we need. We advocate for the growth of programs of this kind, particularly in the domain of smart materials research where material knowledge is central to innovation work, and provide readers with a set of guiding principles for structuring these kinds of collaborations to make sure that the parties involved find mutual benefit. In doing so, we broaden our perspective design inspiration gleaned by collaborating with a craftspeople, to reflect on the broader institutional and social structures that enabled such work to come forward.

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