Needle as Input: Exploring Practice and Materiality When Crafting Becomes Computing

Sarah Schoemann
Georgia Institute of Technology
Atlanta, GA 30308
sschoemann3@gatech.edu

Michael Nitsche
Georgia Institute of Technology
Atlanta, GA 30308
michael.nitsche@gatech.edu

ABSTRACT
A growing body of research combines craft and interaction design. The "Stitch Sampler" project, a sew-able musical instrument and craft platform, stands in this context. In particular, the project serves to underline the importance of two conceptual themes that have emerged in HCI over the last decade, specifically the "material turn" of research on computing and the "practice" or "action-centric" turn in HCI. We present that our prototype and its evolution process as an example of a third trend in HCI research that has developed closely along-side these shifts, with relation to research specifically on craft practice. We discuss the Stitch Sampler and related work that couple electronics and smart materials with craft practices. In that way the act of crafting has in some cases *become* a form of computation.

Author Keywords
Craft; Materiality; Practice; Design; Tangible Computing.

ACM Classification
H.5.m. Information interfaces and presentation Miscellaneous

INTRODUCTION

This paper chronicles the research and design process behind the creation of a series of iterative prototypes designed to connect computing with fine crafting. The prototypes, created as part of an artist-informed research project are sewable, soft circuit interfaces that function as instruments for digital music performance, while simultaneously acting as surfaces to practice the traditional handicraft work of decorative hand-sewing (Figure 1). This series of interactive objects were created as part of a five months long collaboration with artisan clothing designer Karen Glass, the creator of a sustainable fashion brand Zerowaste and a small staff of part-time studio assistants who principally manufacture the company's unique garments. Our iterative design process which included multiple meetings with the designer and two sessions of informal user testing with staff members, lead to a series of prototypes which were influenced by both the mission and studio technique used in the creation of these handcrafted clothes. In a series Glass contributed to the prototyping process by discussing and demonstrating various garment construction techniques on site in Zerowaste's studio and provided feedback at several key points in the design process, directly informing the iterative design of our multiple prototypes.

TEI '17, March 20 - 23, 2017, Yokohama, Japan

ACM 978-1-4503-4676-4/17/03...$15.00
DOI: http://dx.doi.org/10.1145/3024969.3024999

The potential for the material practices of fine artists and crafters to inform and contribute to the design research process is a promising topic within the field of human computer interaction [28, 31, 34, 35]. But it remains critical for tangible interface development and much in need of conceptual approaches to structure this cross-domain collaboration. In sharing our experience, learning from Glass, and prototyping interactive technology in response to the fine craft practice of her and her studio staff, we seek to demonstrate the potential of craftsperson-researcher collaborations for generating new knowledge in the form of designed artifacts [16]. We emphasize the material and situated qualities of this collaboration and how they affected the evolution of these artifacts over time.

Through our work with Glass and her staff, we explored new possibilities for integrating computing into traditional handiwork crafts – and vice versa. The project builds on the rich discourse within HCI on practice-based and material exploration as well as hybrid computational and craft objects. The development of hybrid objects like the Stitch Sampler combine computational resources with traditional modes of craft. They serve an important role in developing conversations about both situated practice and materiality in computing. Zoran and Buechley use the hybrid nature of their project to "restore" a ceramic object by means of 3D printing. They "subvert" digital fabrication [46] as the material and functionality of 3D printed components conceptually clash with that of the handcrafted materials. Rosner et al. use hybrid approaches towards "new understandings of expressivity, skill and value" [34]. Our case adapts their critical use of the hybrid object to develop an educational project.

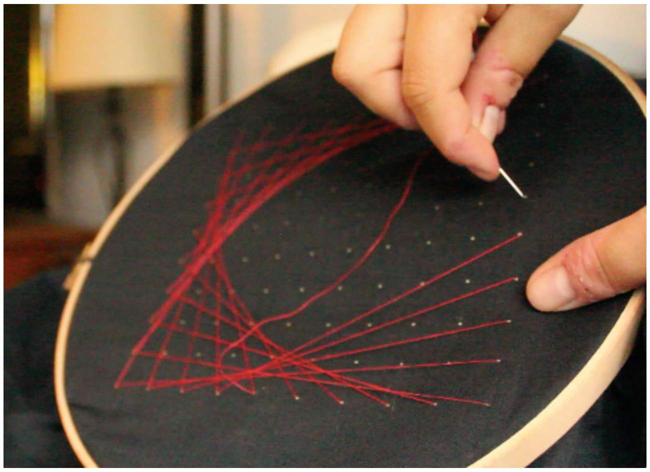

Figure 1. The fourth and final iteration of our prototype, a decorative sewing instrument which generates tones when the needle enters the fabric.

Through our collaboration with Glass, we had to adjust our thinking about the process of creating this novel interface itself. The result, an amalgam of computing input, performance object and fine-craft tool, exemplifies the generative and explorative possibilities best realized through a research through design approach, in which one is "renegotiating reality rather than hypothesizing about it." It connects to the concept of *craft research* defined as "research into, for and through craft practice" [13, 22].

Following a research through design methodology, Stitch Sampler operated through iterative prototyping in response to particular situated context, in our case a studio employing artisan hand-crafters. In this method, Stitch Sampler is tied to recent shifts towards action and practice based design research as well as the turn towards materiality. Both have become integral dimension of human computer interaction research.

These two "turns" concern an erosion of previously-held binaries, the first the between the individual and the social context of computing and the second between the digital and tangible interaction experiences that ultimately push an interface's material qualities. Our prototype can be viewed as one example of an emerging conversation around these collapsing boundaries between the practice of interfacing with a device and the practice of traditional creative practices, such as fine-craft techniques. In the context of our prototype the act of crafting itself (in this case hand-sewing) is transformed into a form of input that not only generates output in the form of traditional needlework, but also acts as a computational input, controlling the output of digital audio and adding a performative dimension to the activity of crafting.

The paper will first discuss the underlying two shifts in HCI discussion and will briefly contextualize the work in relation to other craft-based interface development. The main focus will be on the design and development process as an example for a new hybridity where the craft materials become part of the computational thinking and the interactive functionality relates to (and interrogates) the cultural framework of the crafter. We close with a claim to re-envision craft practices as practices of computing and a novel perspective to the integration of craft and interaction design.

BACKGROUND

Practice and Action Centric Turns in HCI

Research approaches that are similar to the so-called "practice turn" in HCI, have long been a feature of community based research in the social sciences and relate to theoretical frameworks developed by figures such as Vygotsky, Lave and Wegner.[42]. Existing frameworks contextualize individual actions and shared practices within the larger sociocultural conditions in which individuals exist and participate. Only in recent years however, have these themes become a prominent focus of research in the context of computing. In a call for a more unified research agenda Kuutti and Bannon note that the primacy of the "interaction" model of computing (i.e. computing construed as occurring between user and interface) has been supplanted by methods more attendant to the situated nature of technological practices [20, 39] Because of its regard for both the physical and social context of computing, the 'practice turn' has been advanced particularly by researchers focused on computer supported collaborative work (CSCW) [24].

Within interaction design research the rise of ubiquitous computing, particularly in the last decade, has led to an increased awareness of the importance of context [6]. Innovations in novel methods of input, as part of the larger shift from the desktop to mobile devices have lead design researchers to focus on the role of embodiment within computing practices. Tangible interactions in particular have signaled a shift towards more situated forms of computing as they are designed for more diverse and more specific physical and social contexts. As Fernaeus, Tholander and Jonsson note, the use of tangible objects in computing has gone hand in hand with this turn towards action-oriented methods and ontologies [10, 11]. As new technologies allow manipulation to become more central to the work of computing the purpose of these devices has shifted from one of simply mediating the manipulation of information, to tangibles becoming what Fernaeus et al. call "resources for action" in which tangibles objects themselves are capable of generating knowledge through their ability to reflect changes in state mediated by the human hand [10]. They are not only a combination of representation and control – as outlined in early frameworks of TEIs, but they are also in conversation with the material practices such as craft that operate within them [41].

Consequently, in the context of working with craft materials that also double as computing tools, “state changes” might come to mean more than changes registered computationally but also the creative act of mark-making by drawing, sewing, or any other means.

The Material Turn

The transition from the desktop paradigm towards ubiquitous computing via increasingly varied forms of input has also led researchers in HCI to extend questions once reserved for the interaction between user and machine to the role that the materiality of technology itself plays in computing practices [17]. This so called “material turn” in interaction design has animated discussions about the need for new methods and vocabulary with which to better analyze and understand ‘material interactions’ as well as the need to develop new methods for designing towards material considerations [45]. Asresearch focused on this interstice between computation and crafting have noted, craft materials create new stress points and limitations that designers may not experience when working with more traditional computing “hardware,” while at the same time, introducing novel uses and unique affordances that are a direct result of the unusual character of the material [8, 25].

Crafting with Electronics

Scholarship on both the “practice-turn” and “material-turn” cite the entrée of traditional craft, art and industrial design techniques into computing contexts (often through the development and increased availability of “smart” materials and hobbyist electronics development platforms) as an important dimension of the turn towards materiality within computing and an important addition to design research more broadly [17, 10, 23].

Hybrid practices can cut both ways between traditional forms of making and contemporary technologies. Fine craft practitioners may make use of digital fabrication techniques like computer aided design to augment traditional production methods for non-computational objects, while digital technologies are easily embedded in clothing designs, architecture or other designed objects using traditional fabrication techniques [37]. Given this slippage between high and low tech materials and practices and between technical and non-technical domains it stands to reason that the categorization of practices of design, whether on the scale of buildings or handmade objects as fundamentally separate from practices of computing is perhaps already a false binary.

Vallgårda traces this idea of conceptualizing computational technology as simply another “material” of the built environment back to the research of educational technology pioneer Seymour Papert [43]. Papert, when asking students to construct devices to solve open ended problems by developing their own tools, promoted the idea of the computer as just another of the suite of materials available with which his students could work, alongside basics like string, plastic containers, or weights. “Just as pendulums, paints, clay, and so forth, can be “messed around with,” he proposed “so can computers.” [24]. With the turn to and ongoing rise of physical computing, the “messiness” goes both ways as those artifacts also work through what Polanyi termed “tacit” knowledge and remain part of a cultural practice and frame[28].

Contemporary research into alternative forms of electronics tinkering that eschew the pre-made ecosystem of commercially manufactured components also argue for a view of computing as materially integrated with everyday forms of creativity. For example, Mellis et al. advocate for the idea of an “un-tool-kit” in which flexible sensors and circuits are crafted with paper and conductive ink [21].

Following this call, Perner-Wilson suggests what she calls a “kit of no parts” approach to computing, which positions the act of constructing interactive objects with textiles and paper-crafts in a framework of handcrafting. Perner-Wilson advocates the use of a creative method in which crafts and electronics are fully integrated and which “emphasizes the expressive qualities of diverse materials as well as the skill and creativity of the builder” [25]. Our sewable prototype, in marrying the act of stitching with digital music-making, also seeks to leverage these combined material affordances and creative possibilities through an explicitly hybrid craft/ computing practice.

THE PROJECT

Soft circuitry as an intervention into a fine-art/fashion context aligns with existing explorations of digital craft practice for wearable and other non traditional devices by academic researchers, designers and hobbyists [4, 14].

This series of prototypes, created by our team of student designers and titled the “Stitch Sampler” are tangible interfaces that allow multiple users to perform music by interacting with traditional needlework materials. Because the design process was informed by the working process of a specific designer and a team of studio-based practitioners the inspiration for our prototype was (in part) an early request from Glass for a tool to teach newer studio assistants the rhythmic and methodical practice of decorative hand-sewing technique. Although our research team declined the invitation to create a design intervention that would be potentially more oriented towards increasing manufacturing productivity than supporting the agency or creativity of users, we were nonetheless inspired to attempt to augment the process of hand sewing with interactive technology.

By applying the technology of soft-circuitry to a craft-based production, our prototype draws on the work of digital craft innovators such as Buechley and Perner-Wilson, Tan and Peppler and others [21, 25, 26, 27, 29, 40] who have pioneered the integration of electronics into traditional craft, utilizing materials such as conductive fabric and thread as intermediaries between off the shelf parts and hand fabricated objects.

As with many pre-existing projects that incorporate soft circuitry, our design transplants a straightforward input mechanism (a handmade switch) into an unexpected material context (a traditional embroidery stitch sampler) which interfaces with manufactured components (in our case the Lilypad MP3 microcontroller and Bluefruit Keyboard HID). The prototypes appear, at first glance, indistinguishable from decorative needlework projects where fabric is stretched across a wooden embroidery hoop that one interacts with using a sewing needle and thread. The unobtrusiveness of the computing hardware is one of the more unique aesthetic qualities of the device of our prototypes awhich arose naturally from our design research process working directly with the Zerowaste studio assistants. While our prototype was a playful interface rather than a direct answer to [Anon]'s request for a teaching tool for workers. It retained a commitment to faithfully representing the hand making process and respecting the skillset of the Zerowaste staff by incorporating their existing practice into the interaction. We hoped the craftspeople at Zerowaste would be able to interact with the piece without the burden of navigating an unfamiliar interface or needing to learn any unnecessary techniques. Thus, we modeled our prototype's use on their existing practice without alteration of the key tools or handling.

THE DESIGN PROCESS

Working with Craft Practitioners

Much of the research on craft practitioners in the field of HCI has investigated the use of technology to "mediate" existing craft practices, such as those of recreational crafters [32, 33, 35, 36, 37]. They provide a rich background of existing technologies an approaches but Stitch Sampler also leans on work of artist-practitioners such as Becky Stern in the design of our collaboration with Atlanta-based fashion designer and social entrepreneur Karen Glass. Stern, a developer of tutorials for hobbyist tinkerers on the consumer electronics website Adafruit.com, focuses on creative uses of computing technology as integrated subtly into store-bought clothes. Input methods often play off the garments natural affordances and features, with for example, a zipper doubling as a covert on/off switches [38]. In designing an appropriate form of interaction with computing elements, we also looked to the material affordances of a pre-existing object (the embroidery hoop) employing a research through design process approach to investigate the practice of our collaborator and to understand the material encounters associated with her work process.

The Philosophy and Material Practices of *Zerowaste*

Zerowaste apparel is created locally in Atlanta, Georgia and is described not as a company but an artistic "life-work" project of Glass' the brand's founder and a former fashion industry veteran. Zerowaste operates out of a studio space at the Goat Farm, a twelve acre mixed use development and arts venue in the converted buildings of a former cotton gin factory adjacent to downtown Atlanta [18]. In addition to hosting regular public arts programming, The Goat Farm is home to the city's largest community of both individual fine artists and small companies belonging to local creative professionals. The context of this community speaks to Glass' positioning of her work both within the world of fine craft as well as embracing the ethos of a small business owner. An answer to the wasteful excesses of "fast-fashion" manufacturing practices common to contemporary ready-to-wear brands, the title Zerowaste represents Glass' commitment to creating ethically sourced and manufactured clothing [1]. It emphasizes a holistic and environmentally aware approach to fashion that defines the "spirit" of Zerowaste's operation.

Zerowaste's line of clothes is characterized by a distinctive deconstructed aesthetic, in which one-of-a-kind pieces are assembled from existing used and vintage garments through a studio-based practice of hand-sewing and embellishment, Even the fabric scraps left from her work are later donated to other creatives, such as assemblage artists and papermakers within the Atlanta community, and Glass emphasizes this, displaying images of the mixed media artwork that has been created with her textile remainders on the company's website as a testament to her commitment to sustainable entrepreneurship [15].

Designing an Object for *Zerowaste's* Hand-Making Context

Student designers underwent an initial period of getting acquainted with Glass and the story of the *Zerowaste* project. This involved a series of meetings including hands on presentations by Glass about her studio's working methods, close examinations of her garments and explanations about her process of sourcing materials and training staff.

As part of *Zerowaste*'s commitment to sustainability, Glass works primarily with local residents on her upcycled creations. In the interest of seeing Atlanta's own fashion and creative economy grow, Zerowaste employs women who lack previous experience as seamstresses through a local non-profit organization that provides job placement to women dealing with trauma or life disruptions that have impacted their careers. [anonymized] offers on the job training to support their development as "freelance entrepreneurs build[ing] their businesses as independent contractors" [15].

Through the process of becoming familiar with Glass' methods it became clear that the place she was most interested in facilitating a technology-based intervention was within the company's local manufacturing practice. Describing the process of cultivating new talent in her shop, Glass showed examples of samples which illustrated the range of quality possible in hand-stitching, which she defines in terms of consistency and accuracy. Even, uniform stitching is one of the skills most difficult to master as a novice. Yet it is precisely this attention to detail which she sees as crucial to the production of her garments.

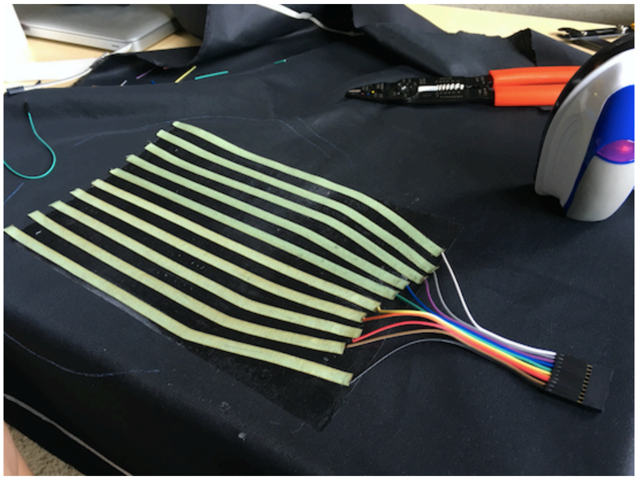

Figure 2. Using iron-on fusible interfacing to connect the conductive fabric to wire jumper cables.

Initial Design

Responding to this request for a digital intervention that could enhance the experience of apprenticing seamstresses in-situ by helping them to develop steadier and more consistent hand-stitching, our team sketched ideas with pens and paper as well as through experimentation with conductive and conventional textiles for preliminary prototypes. This prototyping process, of "sketching in hardware" as a method of discovering through the process of design was particularly important to our project, given the unique design context. Prototyping allowed us to experiment with the affordances of both the traditional crafting context of hand sewing and more unusual conductive textile materials to discover the design possibilities and affordances offered by integrating these conductive materials and manufactured components to the context of fine hand-stitching [45] (Figure 2).

In a context in which fine motor skill and attention to visual detail was key we aimed for an interaction that would provide the most physically unobtrusive augmentation possible. Like existing design artifacts that are integrated into traditional craft practices such as Pschetz et al.'s augmented knitting interface known as the "movement crafter" we wanted to design a technology that could be introduced into the process of crafting without inhibiting the crafters actions or interrupting their pattern of movement [30].

Our prototyping experiments lead us to investigate the material affordances of the sewing needle, itself already a conductive material, by augmenting the core interaction of stitching with a normal needle and thread. Sandwiching two layers of conductive fabric, one powered, the other grounded on either side of an insulating layer of non-conductive fabric, we settled on a design in which the act of plunging the needle through the fabric layers acted as the closing of a switch. This turned the practice of stitching through the fabric into a novel form of input. It, thus, inherently included crafting in the tangible design and used the "logic" and experience of sewing as its starting point. However, it did not touch on the cultural or aesthetic themes of Zerowaste nor its holistic production philosophy.

First Prototype: Adding Sound

Although an LED was initially used to test the material interaction between power source, fabric and needle, we decided on sound-feedback for our prototype, so as to allow users to focus on the stitching itself as a form of self-generated visual feedback, rather than complicating it with a digital intervention. Adding a visual element (LED) to the already visual practice of perfecting the stitch was superfluous and did not connect to the cultural production philosophy of Zerowaste.

Glass maintained, in discussions with the researchers, that when it comes to sewing, rhythm and pacing are skills developed as part of an advanced seamstress' practice. This feedback led to a turn to acoustic "signaling." Audio, in the form of sampled musical notes, triggered by the needle's closure of the circuit was chosen by our team as a way to inject the practice of rhythmic sewing with a temporal element. To match Zerowaste's "handmade" and "organic" aesthetic we initially chose recording samples of analog instruments such as guitar string plucks, brass bells and chimes.

Initially the sounds were imagined as sort of user-activated metronome or time-keeping device, but based on knowing Glass aesthetic, we erred towards sound samples that included a long audio decay, lasting two to four seconds from their start to their fading to silence. Users, could time their stitches by the ebbing volume or, when sewing more quickly, create a layering effect of the sample over time. Instead of a metronome, the tool organically turned into an instrument to respond to the crafter's personality.

As a musical instrument or performance object, the prototype fell within a rich tradition of experimentation by researchers and artists in the NIME (New Interfaces for Musical Expression) community, who have innovated the use of novel forms of computation for creative and performance-based practices. But it arrived in that context through the lens of crafting. Stitch Sampler combines musical interaction with craft-based activity, not as sonification but in response to the given limitations, and specific cultural context of the material practice [4, 5].

Second Prototype: Adjusting Materials, Going Wireless

We started by testing our initial prototype on a normal Arduino Uno board communicating via USB to a laptop. While testing our conductive circuit, being wired to a laptop via Arduino proved useful as we found that not all fabrics performed equally at insulating our conductive materials. A swatch of recycled cotton Oxford shirt (we adhered to the Zerowaste's methods of using recycled materials for all non-conductive textiles used in the prototypes) but the thin cotton of the shirt lead our switch to register as indefinitely closed, for example, which forced us to switch to using the Arduino's analog pins and adjusting the values needed to trigger a sound file according to the computer's serial read. Notably, this change of hardware and code was purely called for by the materials in use.

Once we had swapped our cotton fabric for some considerably thicker boiled-wool (sourced from a felted waistcoat) we moved to using a micro controller with portable power and on board sound (the Lilypad MP3 board) which would allow us to de-tether from the laptop. Unfortunately, this hardware solution was also quickly discarded when we realized that the board would not allow for polyphonic sound, meaning that overlapping sound feedback would be unmanageable.

Material Trade-offs and Moving Towards a Multi-Tonal, Multi-User Experience

The next phase of physical "sketching" or prototyping included two builds of a second iteration of our interface design, each of which featured multiple sewable "inputs" (parallel strips of fabric adhered with fusible interfacing to a non-conductive panel with embedded jumper wires for leads). As Buechley has noted in extensive research on E-Crafts, it is often in interfacing between the flexible conductive materials of crafters and the rigid off-the-shelf parts from traditional electronics, that projects tend to break down [2]. Such was the case with our initial prototypes. The conductive panels and fusible interfacing were too tough and thick to sew through, and as a result this second version of the Stitch Sampler was visually compelling but lost much of its appeal as a sewing practice aid. Feedback from a visit to Glass' studio where we conducted the first of two testing sessions with the studio assistants (they were invited to try out the prototypes without any more specific prompt) confirmed our suspicion that it was not a faithful representation of their sewing practice, they noted the stiff fabric, in particular. However, the integration of multiple musical inputs was well received. Notes were faint because of the board's low-powered audio output, but Zerowaste testers enjoyed triggering different tones, even while struggling to sew through the overly thick material.

Momentarily setting aside the question of the thick conductive panels, we decided to switch technology platforms, from the Lilypad Mp3 with its on-board but weak audio, to a simple low-power keyboard-emulator board, the Bluefruit EZ-Key HID, which would allow further develop the potential for playing multiple notes simultaneously by triggering sounds samples wirelessly from a nearby laptop.

Switching to this hardware had several advantages for the Stitch Sampler project, beginning with the board's relatively low cost of approximately $20, which allowed us to develop and test multiple prototypes in parallel. Two boards were wired up with rechargeable li-poly batteries and header-pins which allowed them to be transferred between different iterations of our design. Because the board came pre-loaded with WASD and arrow key inputs among its twelve pins, we were able to integrate it directly with our prototype.

We also found that when pairing the board with a laptop it was possible to connect multiple Bluetooth devices at once, allowing two users to collaboratively play notes from their respective Stitch Samplers through the same computer. Such shareable "at hand" quality is noted as a particular affordance of tangible interfaces which distinguishes them from traditional one to one desktop computing [10]. It also exemplifies one of the many overlaps of material condition, interaction design, and hybrid functionality which are exposed by the process of conducting design research in situ.

Capacitive Sensing and Emergent Interactions

As users tested the second iteration of the device, pricking the fabric panels to activate sounds, we became aware of another affordance of the Bluefruit board, it has enabled the Stitch Sampler to accept capacitive input. A user's hand would make contact with the grounded fabric backing when gripping the embroidery hoop during use. This meant that fully piercing both layers of fabric with the needle was no longer necessary to register a key press. While this pushed our design further from its original intent as a training device (it was now only necessary to lightly touch the surface of the fabric with the needle to create sounds and a stitch did not need to be completed) it supported the musical control of the prototype. As one participant noted: the interaction had become so intuitive and engaging that "it was hard to put down" When asked to give feedback about the Stitch Sampler, users would continue poking out notes while answering questions. The interaction design proved to be engaging on an almost tacit, unconscious level in these cases. While the original functionality had been compromised, the tangible nature of sewing and touching materials had shifted into the foreground through the ongoing exploration.

Third Prototype: Adjusting the Design of the Interface

In order to compromise between the affordances of a fully-sew-able teaching tool with easily pierced layers and a playful performance object with multiple musical inputs, a third prototype was created in which a decorative pattern of eyelets was cut into the black fabric in circles that corresponded to rings of conductive fabric which we ironed into place creating six concentric connectors. Those activated six different notes that a user could activate by sewing into or between the rings.

Unfortunately, even though the conductive fabric (no longer coated with fusible interfacing) was easier to penetrate in this third version, users were still uninterested in stitching through the hand-cut eyelets. Rather than inviting sewing

Figure 3. (Left to Right) Prototype three and the exposed fabric circuitry during the building process.

between them to create melodies, this new version simply made for a more appealing surface to lightly pluck at with the sewing needle. The act of *stitching*, ie. plunging the needle completely through all layers of the fabric, was not necessary to produce sound. When the project was presented back to the seamstresses at the Zerowaste studio during the second user testing session, it became clear that this iteration of the Stitch Sampler was not a more inviting sewing surface (the staff was still not inclined to sew through the fabric) but had become a more interesting musical interface to playfully interact and perform with.

Through this emerging use, the Stitch Sampler had turned into a kind of speculative design object on sewing itself [7]. It might interrogate notions of materiality and practice but it no longer leaned on the craft as productive action itself in the actual interaction method. While this prototype was a success in the sense that it captured the imagination of users and inspired playful, performative interactions, it was not successful at merging a platform for craft production with computing (in the form of digital music-making) because the design did not encourage users to produce actual stitches (figure 3).

Figure 4. Our third prototype being tested by *Zerowaste* staff.

Fourth and Final Prototype: Stitching Sounds

The emerging use of the third prototype at Zerowaste made it clear that the staff of Zerowaste was not experiencing the Stitch Sampler as a sew-able object. Building on the ongoing material-computational evolution, the final task had to be to encourage a more robust connection between the act of sewing and music-making. Our final version of the prototype was created using the same techniques as version three, however the sewable eyelets through which the conductive fabric traces were visible were made considerably smaller (around 2mm diameter) and organized into a grid (see Figure 1). Ten conductive fabric contacts, each assigned to a different note, run horizontally across the grid (see Figure 2). In this final version, the conductive ground fabric on the back of the prototype is covered, preventing capacitive touch and encouraging users to stitch fully through much smaller, laser-cut holes, encouraging users to sew between them and create decorative geometric designs while generating digital music. The act of sewing was not only referenced but re-integrated as a necessity of the piece (Figure 5).

This design no longer addresses Glass' initial request for a teaching aid as stitching is constrained to the holes in the fabric and thus it can no longer emulate stitching practices of a professional seamstress. The final artifact instead represents the material and conceptual compromises' that were negotiated while trying to merge a craft practice with a form of digital interface, embodying our findings and subsequent considerations and compromises in both its limitations and affordances.

CONCLUSION

The development of Stitch Sampler traces a narrative of how craft and interaction design intertwine. The detailed description of the process illustrates the moments when crafting and computing merge, diverge, and form hybrids. This can happen on the technological level of the artifact (e.g. the thickness of the cloth might demand analog contact detection, as outlined in the second prototype), on the level of practice (e.g. in the returning to the act of sewing as interaction method in the fourth prototype), or on the level of personal and cultural framing of the craft (e.g. in the move to sound as digital output in response to Zerowaste's "spirit" in the first prototype). Notably, the design did not only respond to the craft but allowed the craft to emerge as the interaction "logic."

By beginning the process of material and situated exploration early, and iterating often, we avoided a possible pitfall of interaction design with novel materials and technologies: namely the issue of trying to force materials and practices to conform to the designer's concept rather than letting them guide the exploration. Ultimately, our prototypes did not succeed as a digital tool for practicing a fine craft technique as we had intended to. But this initial projected usage adjusted itself along the way as the bare utility was replaced by a more holistic inclusion of craft as practice in the design.

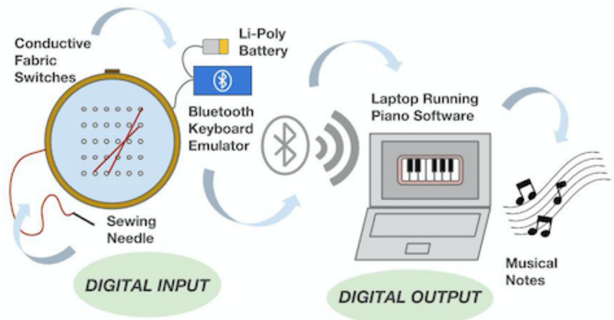

Figure 5. Diagram of digital input and output in prototype 4

The resulting prototypes of the Stitch Sampler simultaneously fall short and exceed our expectations in terms of their practical application and expressive possibilities, respectively. Because of the way it constrains use towards a deliberately recreational and expressive end, our final prototype of the technology signifies the biggest departure of our project from Glass' original request for a tool that would increase the efficiency and uniformity of a craft production technique. At the same time, it demonstrates the clearest integration of craft practice into the tangible interaction design as a result of the evolutionary process.

If research through design is valued for how it allows the possibility of objects "creating a design space around themselves" [14], then this project succeeded and the expressive, and performative aspects of the tool were ultimately crucial to this success. Through its evolution it created a context in which material qualities, craft practices and notions of utility could be explored and held in tension.

No matter how well-intentioned the desire to increase the efficiency of Zerowaste's production might be for a socially conscious entrepreneur like Glass, the playful and ultimately somewhat disruptive quality of the tool that emerged through our design-research process functioned as a safeguard of sorts. It prevented the TEI from becoming simply a functionalist tool for disciplining the hands of workers or, vice versa, the craft becoming reduced to a fashionable reference cleared of its own multi-layered messy practice.

Through collaboration, ongoing discussion and feedback sessions with Glass and informal tests with the staff of her studio we discovered that there may not be a seamless way to digitally augment the craft of professional hand sewers without introducing other material challenges and complications to the craft process that interfere with a users ability to produce conventional results. And that, in order to integrate craft to tangible interaction design, the process has to step beyond utilitarian perspectives. In the here presented case study, this was achieved through a gradual conversation between design and craft practice and materials. It settled on a playful expressive output coupled with a productive practice.

Following the natural through-line from HCI research on craft and technology that posits historic manufacturing technologies as the predecessors to modern computing and analysis suggests, that the contemporary act of programming might itself be likened to a form of craft practice [8, 19]. We suggest that more research should be focused on hybrid forms of computation and crafting. Not just through explorations of how we can utilize the combined material elements of crafts and computing to create new hybrid objects, but rather to explore the ways in which the *context* and *actions* involved in crafting and computing can be brought into synch so as to create new kinds of hybrid activities and practices.

REFERENCES

1. Allie Bashuk. 2016. zerøwaste: use everything until it's non-usable. *Creative Loafing Atlanta* (April 2016).
2. Leah Buechley and Michael Eisenberg. 2009. Fabric PCBs, Electronic Sequins, and Socket Buttons: Techniques for e-Textile Craft. *Personal Ubiquitous Comput.* 13, 2 (February 2009), 133–150. DOI:http://dx.doi.org/10.1007/s00779-007-0181-0
3. Leah Buechley and Hannah Perner-Wilson. 2012. Crafting Technology: Reimagining the Processes, Materials, and Cultures of Electronics. *ACM Trans. Comput.-Hum. Interact.* 19, 3 (October 2012), 21:1–21:21. DOI:http://dx.doi.org/10.1145/2362364.2362369
4. Angela Chang and Hiroshi Ishii. 2007. Zstretch: A Stretchy Fabric Music Controller. In *Proceedings of the 7th International Conference on New Interfaces for Musical Expression*. NIME '07. New York, NY, USA: ACM, 46–49. DOI:http://dx.doi.org/10.1145/1279740.1279746
5. Perry Cook. 2001. Principles for Designing Computer Music Controllers. In *Proceedings of the 2001 Conference on New Interfaces for Musical Expression*. NIME '01. Singapore, Singapore: National University of Singapore, 1–4.
6. Paul Dourish. 2004. What We Talk About when We Talk About Context. *Personal Ubiquitous Comput.* 8, 1 (February 2004), 19–30. DOI:http://dx.doi.org/10.1007/s00779-003-0253-8
7. Anthony Dunne. 2008. Hertzian Tales: Electronic Products, Aesthetic Experience, and Critical Design, MIT Press.
8. Ylva Fernaeus, Martin Jonsson, and Jakob Tholander. 2012. Revisiting the Jacquard Loom: Threads of History and Current Patterns in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '12. New York, NY, USA:

ACM, 1593–1602. DOI:http://dx.doi.org/10.1145/2207676.2208280

9. Ylva Fernaeus and Petra Sundström. 2012. The Material Move How Materials Matter in Interaction Design Research. In *Proceedings of the Designing Interactive Systems Conference*. DIS '12. New York, NY, USA: ACM, 486–495. DOI:http://dx.doi.org/10.1145/2317956.2318029
10. Ylva Fernaeus, Jakob Tholander, and Martin Jonsson. 2008a. Beyond representations: towards an action-centric perspective on tangible interaction. *International Journal of Arts and Technology* 1, 3-4 (January 2008), 249–267. DOI:http://dx.doi.org/10.1504/IJART.2008.022362
11. Ylva Fernaeus, Jakob Tholander, and Martin Jonsson. 2008b. Towards a New Set of Ideals: Consequences of the Practice Turn in Tangible Interaction. In *Proceedings of the 2Nd International Conference on Tangible and Embedded Interaction*. TEI '08. New York, NY, USA: ACM, 223–230. DOI:http://dx.doi.org/10.1145/1347390.1347441
12. Ylva Fernaeus, Anna Vallgårda, Mili John Tharakan, and Anders Lundström. 2012. Touch and Feel Soft Hardware. In *Proceedings of the Sixth International Conference on Tangible, Embedded and Embodied Interaction*. TEI '12. New York, NY, USA: ACM, 359–362. DOI:http://dx.doi.org/10.1145/2148131.2148217
13. C. Frayling. 1993. *Research in art and design*, Royal Coll. of Art, London (United Kingdom).
14. William Gaver. 2012. What Should We Expect from Research Through Design? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '12. New York, NY, USA: ACM, 937–946. DOI:http://dx.doi.org/10.1145/2207676.2208538
15. Karen Glass. zerøwaste. Retrieved July 24, 2016 from http://www.zerowastekarenglass.com/
16. Connie Golsteijn, Elise Hoven, David Frohlich, and Abigail Sellen. 2014. Hybrid Crafting: Towards an Integrated Practice of Crafting with Physical and Digital Components. *Personal Ubiquitous Comput.* 18, 3 (March 2014), 593–611. DOI:http://dx.doi.org/10.1007/s00779-013-0684-9
17. Shad Gross, Jeffrey Bardzell, and Shaowen Bardzell. 2014. Structures, Forms, and Stuff: The Materiality and Medium of Interaction. *Personal Ubiquitous Comput.* 18, 3 (March 2014), 637–649. DOI:http://dx.doi.org/10.1007/s00779-013-0689-4
18. Lynne Guey. 2013. A 12-Acre "Goat Farm" Is Transforming The Arts Scene In Atlanta. (June 2013). Retrieved July 27, 2016 from http://www.businessinsider.com/goat-farm-leads-atlantas-arts-scene-2013-6
19. Nicolai Brodersen Hansen, Rikke Toft Nørg\a ard, and Kim Halskov. 2014. Crafting Code at the Demo-scene. In *Proceedings of the 2014 Conference on Designing Interactive Systems*. DIS '14. New York, NY, USA: ACM, 35–38. DOI:http://dx.doi.org/10.1145/2598510.2598526
20. Kari Kuutti and Liam J. Bannon. 2014b. The Turn to Practice in HCI: Towards a Research Agenda. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems*. CHI '14. New York, NY, USA: ACM, 3543–3552. DOI:http://dx.doi.org/10.1145/2556288.2557111
21. David A. Mellis, Sam Jacoby, Leah Buechley, Hannah Perner-Wilson, and Jie Qi. 2013. Microcontrollers As Material: Crafting Circuits with Paper, Conductive Ink, Electronic Components, and an "Untoolkit." In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction*. TEI '13. New York, NY, USA: ACM, 83–90. DOI:http://dx.doi.org/10.1145/2460625.2460638
22. Kristina Niedderer and Katherine Townsend. 2014. Designing Craft Research: Joining Emotion and Knowledge. *The Design Journal* 17, 4 (December 2014), 624–647. DOI:https://doi.org/10.2752/175630614X14056185480221
23. Nithikul Nimkulrat. 2012. Hands-on Intellect: Integrating Craft Practice into Design Research. *International Journal of Dsign* 6, 3 (2012), 1–14.
24. Seymour Papert. 1988. Computer as Material: Messing About with Time. Retrieved July 27, 2016 from http://www.papert.org/articles/ComputerAsMaterial.html
25. Hannah Perner-Wilson. Kit-of-No-Parts. Retrieved July 27, 2016 from http://kit-of-no-parts.at/
26. Hannah Perner-Wilson and Leah Buechley. 2010. Handcrafting Textile Mice. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems*. DIS '10. New York, NY, USA: ACM, 434–435. DOI:http://dx.doi.org/10.1145/1858171.1858257
27. Alan Poole and Anne Poole. 2016. Functional Interactive Tatting: Bringing Together a Traditional Handicraft and Electronics. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*. TEI '16. New York, NY, USA: ACM, 551–555. DOI:http://dx.doi.org/10.1145/2839462.2856529
28. Michael Polanyi. 1967. *The Tacit Dimension*, Anchor Books.
29. Ernest Rehmi Post, Margaret Orth, P.R. Russo, and Neil Gershenfeld. 2000. E-broidery: Design and Fabrication of Textile-based Computing. *IBM Syst. J.*

39, 3-4 (July 2000), 840–860. DOI:http://dx.doi.org/10.1147/sj.393.0840

30. Larissa Pschetz, Richard Banks, and Mike Molloy. 2013. Movement Crafter. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction*. TEI '13. New York, NY, USA: ACM, 393–394. DOI:http://dx.doi.org/10.1145/2460625.2460709
31. Gabriela T. Richard and Yasmin B. Kafai. 2015. Making Physical and Digital Games with e-Textiles: A Workshop for Youth Making Responsive Wearable Games and Controllers. In *Proceedings of the 14th International Conference on Interaction Design and Children*. IDC '15. New York, NY, USA: ACM, 399–402. DOI:http://dx.doi.org/10.1145/2771839.2771926
32. Daniela Rosner, Jean-François Blanchette, Leah Buechley, Paul Dourish, and Melissa Mazmanian. 2012. From Materials to Materiality: Connecting Practice and Theory in Hc. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems*. CHI EA '12. New York, NY, USA: ACM, 2787–2790. DOI:http://dx.doi.org/10.1145/2212776.2212721
33. Daniela K. Rosner. 2010. Mediated Crafts: Digital Practices Around Creative Handwork. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems*. CHI EA '10. New York, NY, USA: ACM, 2955–2958. DOI:http://dx.doi.org/10.1145/1753846.1753894
34. Daniela K. Rosner, Miwa Ikemiya, and Tim Regan. 2015. Resisting Alignment: Code and Clay. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*. TEI '15. New York, NY, USA: ACM, 181–188. DOI:http://dx.doi.org/10.1145/2677199.2680587
35. Daniela K. Rosner and Kimiko Ryokai. 2009. Reflections on Craft: Probing the Creative Process of Everyday Knitters. In *Proceedings of the Seventh ACM Conference on Creativity and Cognition*. C&C '09. New York, NY, USA: ACM, 195–204. DOI:http://dx.doi.org/10.1145/1640233.1640264
36. 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. New York, NY, USA: ACM, 2407–2416. DOI:http://dx.doi.org/10.1145/1753326.1753691
37. Daniela Rosner, Marco Roccetti, and Gustavo Marfia. 2014a. The Digitization of Cultural Practices. *Commun. ACM* 57, 6 (June 2014), 82–87. DOI:http://dx.doi.org/10.1145/2602695.2602701
38. Becky Stern. 2013. Smart Textiles Talk (slides) #WearableWednesday. (May 2013). Retrieved July 25, 2016 from https://blog.adafruit.com/2013/05/29/smart-textiles-talk-slides-wearablewednesday/
39. Lucy A. Suchman. 1987. *Plans and Situated Actions: The Problem of Human-Machine Communication*, Cambridge University Press.
40. Verily Tan and Kylie Peppler. 2015. Creative Design Process in Making Electronic Textiles. In *Proceedings of the 14th International Conference on Interaction Design and Children*. IDC '15. New York, NY, USA: ACM, 327–330. DOI:http://dx.doi.org/10.1145/2771839.2771908
41. B. Ullmer, and H. Ishii Emerging frameworks for tangible user interfaces. *IBM Syst. J.*, 39, 3-4 (2001), 915-931.
42. Anna Vallgårda. 2014. Giving Form to Computational Things: Developing a Practice of Interaction Design. *Personal Ubiquitous Comput.* 18, 3 (March 2014), 577–592. DOI:http://dx.doi.org/10.1007/s00779-013-0685-8
43. Anna Vallgårda and Johan Redström. 2007. Computational Composites. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '07. New York, NY, USA: ACM, 513–522. DOI:http://dx.doi.org/10.1145/1240624.1240706
44. Mikael Wiberg et al. 2012. "Material Interactions": From Atoms & Bits to Entangled Practices. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems*. CHI EA '12. New York, NY, USA: ACM, 1147–1150. DOI:http://dx.doi.org/10.1145/2212776.2212408
45. Mikael Wiberg. 2014. Methodology for Materiality: Interaction Design Research Through a Material Lens. *Personal Ubiquitous Comput.* 18, 3 (March 2014), 625–636. DOI:http://dx.doi.org/10.1007/s00779-013-0686-7
46. Amit Zoran and Leah Buechley. 2012. Hybrid Reassemblage: An Exploration of Craft, Digital Fabrication and Artifact Uniqueness. *Leonardo* 46, 1 (October 2012), 4–10. DOI:https://doi.org/10.1162/LEON_a_00477