In Harmony: Making a Wearable Musical Instrument as a Case Study of using Boundary Objects in an Interdisciplinary Collaborative Design Process

Clint Zeagler
clintzeagler@gatech.edu

Maribeth Gandy
maribeth.gandy@imtc.gatech.edu

Scott Gilliland
scott.gilliland@gatech.edu

Delton Moore
delsomo@gmail.com

Rocco Centrella
roccocentrella@gmail.com

Brandon Montgomery
montgomery.bradon@gmail.com

ABSTRACT
Working on a wearable technology interdisciplinary project team can be challenging because of a lack of shared understanding between different fields, and a lack of ability in cross-disciplinary communication. We describe an interdisciplinary collaborative design process used for creating a wearable musical instrument with a musician. Our diverse team used drawing and example artifacts/toolkits to overcome communication and gaps in knowledge. We view this process in the frame of Susan Leigh Star's description of a boundary object, and against a similar process used in another musical / computer science collaboration with the group Duran Duran.

Author Keywords
Design Process; Musical Garment; E-Textile Interface; Boundary Objects

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

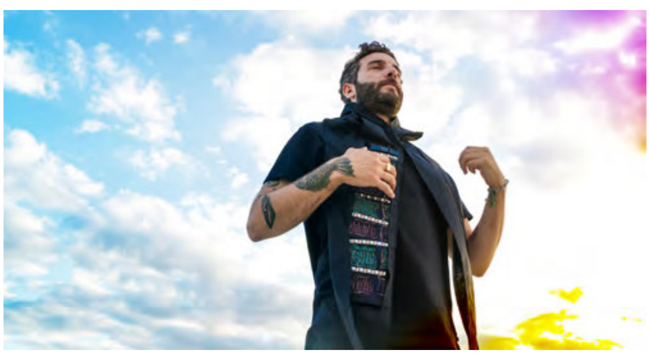

Figure 1: Rhó interacting with the 'Hood' a musical garment developed through interdisciplinary collaboration.

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INTRODUCTION
This short case study explores the deliberate use of a "boundary object" as a prescriptive device for aiding interdisciplinary collaborative design. Many expected themes and observations about interdisciplinary design and group work also emerge, however our focus here is on the pilot investigation of using the framework of boundary objects within the context of design process.

Over the course of one week an Italian musician named Rhó, an architect, a computer scientist, a fashion designer, an engineer, and a digital media expert came together to create one wearable musical instrument "the Hood". There were communication and ideation challenges to overcome in a team with such diverse skill sets. Wearable technology is a unique working space, allowing for, and often requiring diverse participants who may have fundamental differences in their formal training. A fashion designer has a different thought process, different product goals, and even a different vocabulary than a computer scientist. A musician has a very creative process and his/her time scale for creation might diverge from all other design fields. On top of disciplinary differences there are also cultural (American and Italian) variances in process, which this multicultural team also highlights. These conflicts must be reconciled for true collaboration to take hold. We cannot expect everyone on the team to learn the skills of the other team members, especially over such a short time frame. This paper describes the use of drawing and artifacts framed as disciplinary boundary objects [41] allowing for discussion and shared understanding, leading to a productive creative team process.

"This is an analytic concept of those scientific objects which inhabit several intersecting social worlds and satisfy the informational requirements of each of them. Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" [41]

RELATED WORK
Much of the value of this work comes in the framing of how an interdisciplinary team might view their creative

process. However we also need to know about the specific interdisciplinary context within which the team is working.

Work Related to Wearable Technology and Musical Instrument Interfaces

While we are interested here in discussing interdisciplinary teams and the unique opportunities boundary objects afford the design process for wearable technology, it is important to note that there have been numerous projects that look at wearable technology for musical instruments. Serafin, Mitchel, and Heap describe the evolution of a very successful glove instrument used by Imogen Heap in her performances and music creation [31, 40]. An interest in interactive textiles can also be seen in projects such as the music textile seen on talk2myshirt.com and the devices which stem from the Musical interaction and e-textile workshop developed on the RHYME platform [32, 33]. Many glove-based wearable systems are also described in the archive of NIME New Interfaces for Musical Expression [14, 21]. There has also been wearable technology research into how gloves may help teach musical abilities. Markow and Huang created a set of gloves with vibration motors which they found help participants learn piano through passive haptic learning [22, 29].

Within the larger community of wearable technology and specifically electronic textile applications much work has been done over the years. It was 1997 when Post and Orth described the use of interactive textiles and e-broidery [36, 37]. Jayaraman and colleagues also worked on incorporating technology with fabric to produce their "wearable motherboard" smart t-shirt [20, 28]. Zeagler and colleagues also researched the use of such embroideries and textile techniques for on-body interfaces, including material and wash-ability studies [18, 24, 25, 43–45]. Buechley has focused much of her e-textile work on the democratization of technology within education, and using wearable tech as a way to make inroads with typically non-tech-enthusiast communities [7]. Buechley's work has lead to the very popular Lilypad Arduino microcontroller, making designing and working on wearable technology easier and more inviting [27].

Dunne and Profita look into the social acceptability of textile based on-body interactions [12, 13, 38], which could be important to designers when thinking about placing on-body interfaces. Within the context of a performance garment the social acceptability of body touch, and presentation of self within a social group become very important aspects of design. Goffman would say that it is the presentation of ourselves that gives others cues as to how to interact with us [19]. He goes on to explain that most people take this inferential information as a fact of whom one is and act accordingly. "The others find, then, that the individual has informed them as to what is and as to what they *ought* to see as the 'is'"[19]. Fashion designers on the team will find this expression of self at the heart of their discipline, where as an engineer might not.

Work Related to Interdisciplinary Design Process

Martin et al. speak to both the need for interdisciplinary teams while working on wearable technology projects and the nature of the current educational system producing engineers and designers. *"Practitioners in these fields gain their interdisciplinary team experience by trial-and-error and sheer luck, if at all. The deeply disciplinary nature of universities does not prepare students for working on the types of design teams that are required for successful wearable computing systems."*[30].

When asked "Why work on performance led research in the wild" Benford et. al give three reasons [4]. First among them is that *Artists' uses of emerging technologies are often highly innovative and unusual, stretching the technology in unforeseen ways, highlighting new design values and approaches that are sometimes contrary to received wisdom in HCI (e.g., ambiguity or discomfort as we discuss later), and opening up new areas of application* [4]. The use of boundary objects hopefully magnifies the creative nature of ambiguity through their flexible and plastic nature.

Many could see this wearable musical device case study as a participatory design workshop. Placing the artists in the role of participator, and the computer scientist in the role of facilitator. Much valid and celebrated work has been completed under this framework. Disalvo eloquently states "*In this light, design, inclusive of both the process of making artifacts and the artifacts made, can be considered a discursive activity and participatory design can be cast as using design to enable people to take part in public discourse in new or more effective ways.*" [11]. We could also view our project as a participatory corporative prototyping case study. "*Prototyping: the construction of the future through the preliminary and iterative design of potential systems enabling concrete experience and modification by prospective users*." [6, 10]. Rhinow et al. describe a prototype as a way to converge thinking stating that "the prototype as a model helps to visualize the focus of exploration" [39]. These are certainly well founded ways of framing our work. However, the spirit of our collaboration wasn't to enable (technological advancement, or to give agency to the artist in directorial notion), but to truly work together in an interdisciplinary collaboration. All of us learning and acting on and with technology. All of us adding to the process by being creative and expressive. Pobiner might understand our meaning of this inclusive design process when he argues "*Design in many cases comes from intuition, which is not a quantitative factor and there is often no (or little) rationale that can be associated with why something is the way it is, or how one derived a specific idea. Such an experiential model may be flawed in its construct but may work better in the real world – mostly because our existences are, thus far, infinitely more* *complex than current models for human interaction provide. Perhaps it is time to, once again, revise the notion of 'Design' in order to incorporate other disciplines that encounter and apply its values."* [35]. Baker and Gandy discuss this form of inclusive participatory design in their work on incorporating policy within the methodology of the design process. By thinking about how design will affect the community, and thus policy, at the onset and throughout the design process. Baker poses that innovative interdisciplinary teams begin design 'use case ideation and visualization' with the broader community in mind, and this also helps the diverse teams communicate across disciplines more effectively [2, 16]. Working through the guidelines of this proposed collaborative policy/design framework could in itself be seen as a boundary object bringing together the methodology of different disciplines, and creating a way for them to work together more effectively.

One example project that seems to exemplify the use of what could be described as a boundary object for design collaboration is Gandy's DART. Gandy explains the development and use of an augmented reality (AR) toolkit (DART) for designers new to the medium [17]. Many of the choices made for DART came from an effort to allow easy entry to designers and performers, such as working on top of a well-known platform for media (at the time Macromedia Director). DART's success in part shows the importance of toolkits speaking to different and new communities in a local way, while holding onto a common identity for all communities. In this way a toolkit can act as a boundary object, allowing for artists to work directly on design iterations with technologists. DART was in part informed by work Gandy did previously with a team building AR experiences for Duran Duran (a well known rock band) performances, this was a collaborative process with many different stakeholders including members of the band. Based on the comments from the Duran Duran interviewees it was clear that a significant challenge in creating AR applications with diverse teams is the need to *convey ideas and technical constraints to other contributors so that they may participate effectively*. In working with Duran Duran there was a critical initial step, which was helping the non-technical collaborators to fully understand the affordances and technical constraints of AR. It was important to build their enthusiasm for the project and to get to the point where they could actively contribute to the design and development process. As a member of the Duran Duran team (project manager) described, the system was improved in an iterative process (taking place over several live performances) due to the contributions of the other stakeholders. An authoring ecosystem for this type of project must accelerate and improve this process. Communication and collaboration among a diverse team is challenging, yet it is imperative that everyone be able to contribute to early ideation. However, for non-technology focused collaborators to be able to contribute effectively they must have a solid grasp of the *affordances and constraints* of augmented reality. For example, in the Duran Duran project they urged the band members to test the boundaries of marker tracking with technology prototypes so as to set realistic expectations and to inform their brainstorming activities. So authoring ecosystems that either convey this information and/or guide the team towards appropriate design choices are ideal. [15]

In relation to working on wearable technology in interdisciplinary teams Cochran and Zeagler described the use of a LED calibration system as a boundary object for teamwork. *"Such interdisciplinary artifacts can act as boundary objects and the process of making these tools can create a shared meaning that facilitates product development."* [9]. Gilliland and Zeagler created an interdisciplinary e-textile toolkit of sorts in developing the E-Textile Interface Swatch Book [18]. Zeagler went on to use the ESwatchBook to run a series of workshops with teams of fashion designers and computer scientist [34, 42], and while he did not describe the ESwatchBook as a boundary object at the time it is clear that it was used as such an artifact.

HOOD DESIGN PROCESS

Day one – Understanding and Ideation

Using a copy of Gilliland et al's ESwatchBook [18] we began the collaboration by allowing the musician and architect to explore the possibilities of sensing with fabric. The ESwatchBook also be came a launch point for a discussion about what was possible using this sensing technique. Here just as with Gandy's work with Duran Duran, the artists were able to quickly figure out the *affordances and constraints* of the e-textile interface medium. The ESwatchBook allowed each of the team members to build a *shared understanding* of how the technology worked, including a platform to create ideas about textile based interactions. It was less effective in helping provide inspiration for the aesthetic design of the garment.

Figure 2: Gilliland et al's ESwatchBook [18] **became a boundary object** [26, 41]**, creating shared understanding.**

Figure 3: Drawings by the fashion designer and architect on the team investigating textile texture, color, and mood.

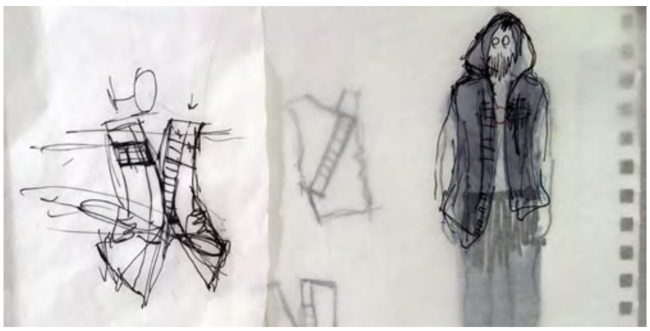

Figure 4: Drawings by the fashion designer exploring silhouette and interactive textile placement.

Just as Zeagler found in his E-textile workshops, drawing became a medium through which designers and non-designers could explain and communicate. *Drawings like these were mandatory to overcome points at which the technical requirements of practitioners from one domain were not clear to those from another* [42]. The act of drawing and specifically sketching actively together as a team can be viewed as creating a boundary object together. A schematic, or aesthetic plan created together can have the shared meaning and plasticity needed for true collaboration to take hold. It also gives the group some since of shared timescale (for instance an electrical schematic is just simple lines and shapes, but it might take some thought while sketching, thus adding time to a simple drawing, and therefore imparting weight or importance beyond the perceived simplicity of the schematic). The Architect on the team was familiar with the musician's self-presentation [19], style and music. While the musician focused on how he would play the garment, the CS and HCI experts were drawing to explain to the fashion designer how circuits might work and needed to be connected. The fashion designer was also working in tandem with the architect and musician to pick fabric and develop the touch sensitive textile's appearance (Figures 3&4). The musician wanted the ability to don and doff the garment with ease, so a vest like silhouette was chosen. The musician, architect, and fashion designer, liked the dramatic element of adding a hood, as the architect put it "story telling through dress", a musical vestment of sorts, "taking the formalism of the past and moving it to the present". The designers were also shown research about the social acceptability of male on-body interaction [38] so they could plan the best place on the body for the touch sensitive textile.

Day two & three – Prototyping and Iteration

In research through design, researchers make prototypes, products, and models to codify their own understanding of a particular situation and to provide a concrete framing of the problem and a description of a proposed [46]. In prototyping the touch sensitive textile, and LEDs the team became excited to see the signals show up on the computer screen, even if they were not yet making music. This explorative iterative process allowed the team to begin to understand the scope, abilities, and timescales of the incongruent disciplines involved. The garment muslin was also created and fitted to Rhó, and the team liked the shape.

Day four & five – Construction and Troubleshooting

Initially, the technologist on the team did not know how the system would be connected to the software Rhó was accustomed to working with for live performances. They started with the assumption that the hardware could provide access to the sensor input via HID joystick, and that Rhó's software could handle it accept these inputs. We quickly discovered that Rho's software was designed for MIDI input only, and we sought out a laptop-side software to help convert our joystick input to MIDI.

Rhó believed that the engineers, computer scientists and HCI professionals would know how to hook the garment up to his software easily. On the contrary the engineers thought Rhó (who specializes in musical composing using computer programs) would be able to take what they gave him and make it connect. Each group did not quite understand the scope of the others knowledge, this is a reoccurring theme in interdisciplinary work. Team members often had a hard time understanding what the others knew, and more specifically in estimating the amount of time tasks outside their personal disciplines would take. The digital media designer was instrumental in helping bridge this gap in knowledge when it came to connecting the finished garment to Rhó's software.

Description of Use:

The 'Hood' is played by touching the interactive textile portion of the garment that is separated into six touch pads. The top touch pad cycles through three different states allowing for the bottom five touch pads to act as 15 selection points. These touch pads act as a MIDI controller turning on and off preprogramed sounds in a program called Abelton Live [1]. The distance sensor acts as a volume control for each selection, saving the volume of the sound/beat at release. To control the volume the wearer pulls his hand towards or away from his chest at the location of the sensor.

Day five & six –Playing and Composing

After the garment was working Rhó took the 'Hood' and learned to play. He also used the garment to create new music for the concert. During the process it was evident to the team that Rhó was very interested in the concept of wearable technology and the tactile nature of interacting with fabric textures. However, he and the architect on the team were hunting for a reason, some authentic need, for the instrument to be on the body instead of on sitting on a stand like a keyboard. When Rhó had the prototype to use he found that he could make grand gestures to activate the touch surfaces. Because the touch activated areas made selection on release, Rhó decided to use release from his chest as a theatrical aspect to accentuate musical additions selected through the Hood.

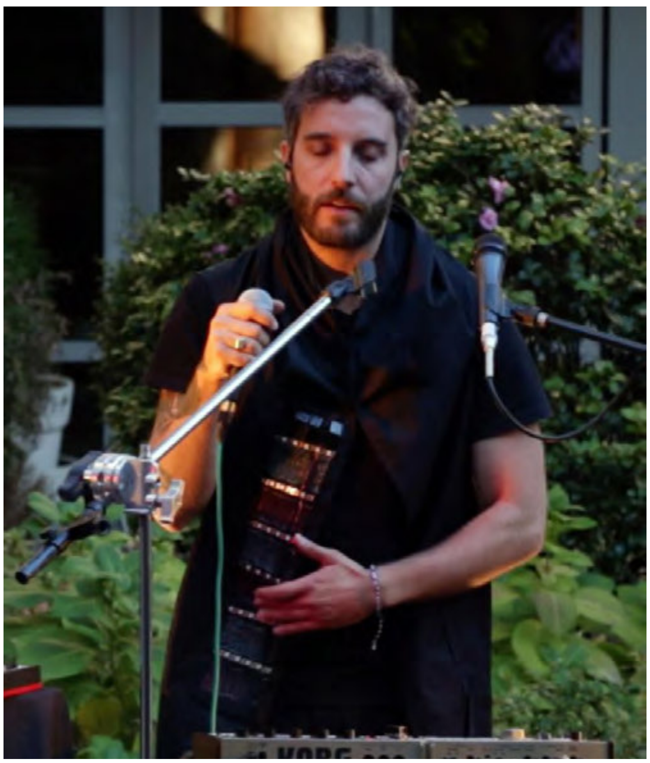

Figure 5: Rhó in concert using the 'Hood'

Day seven - Concert

Rhó used the 'Hood' in concert for 100 people. There was only one mishap right before he began his set. He left the stage to hug a friend, breaking his Bluetooth connection. Rhó states "I forgot". The team sees this as a testament to the clothing like nature of the 'Hood'. Rhó would have set down a guitar before leaving the stage, but as he was wearing the instrument he forgot about its digitally connected characteristics. Benford explains another reason why doing performance led research in the wild is useful, in that "*the public deployment of artworks offers a test-bed for putting emerging technologies into the hands of users in a "realistic" situation, meaning a situation in which the technology needs to be made to work and is treated in some sense a professional product - this is the "in the wild" aspect of the approach"*[4]. Here the pressure of performance and the public nature of the presentation heightens the "real" or "in the wild" nature of HCI research, the stakes are higher when everyone is watching.

PERFORMANCE PROTOTYPE CONSTRUCTION

The hardware consists of a microcontroller to drive the system, a Bluetooth module to communicate with a laptop. On the front of the garment, 'smart LEDs' were included for visual feedback, sewn-in wiring was used to make touch points for discrete input, while a proximity sensor was included for continuous input. The entire system runs from a rechargeable lithium-ion battery, charged via USB.

Figure 6: Interactive touch sensitive textile.

Thin un-insulated wire is used to create interlacing touch points much like the pattern for selection points chosen in Komor et al.'s "is it gropable" study [24] only at a much larger scale. The wire was chosen over conductive thread used in the ESwatchBook because the 'Hood' needs to be made more robust for performance. Conductive thread used in the ESwatchBook has proven to not stand up to repeated use and cleaning as of yet [43]. The wire was hand stitched onto yarn and fabric and then sewn down with a domestic sewing machine.

Enameled magnet wire was chosen for leads to the touch points due to its size and malleability as compared to other insulated wiring, thus interfering less with the drape of the garment figures 7 & 8. The leads were soldered to a connector so that the micro controller and battery could be removed easily from the garment. Because we decided to incorporate LED display of interaction this means this performance prototype cannot be washed or submerged in water. The Hood is to be worn on the outermost layer only during performance so as a team we were not too concerned with durability for cleaning, but again were more concerned with durability for performance.

Figure 7: Incorporating the conductive touch points and connecting the enameled lead wires.

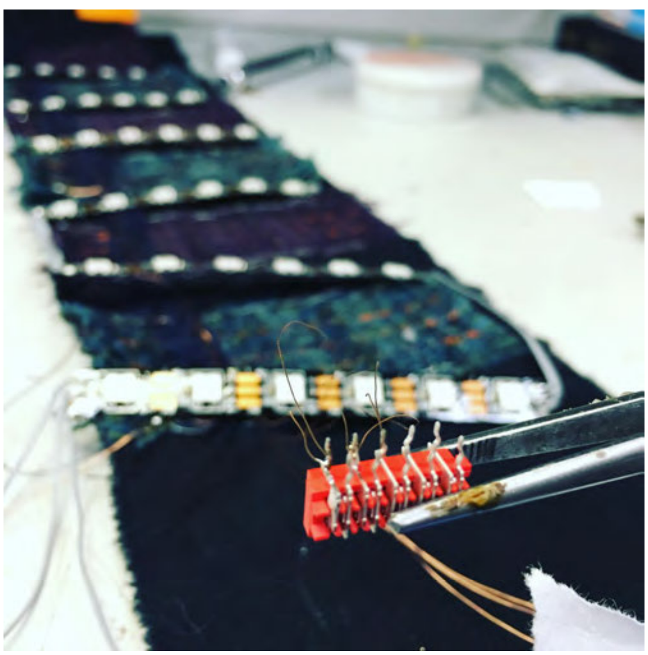

Figure 8: wiring the conductive elements to the connector used to attach the microcontroller.

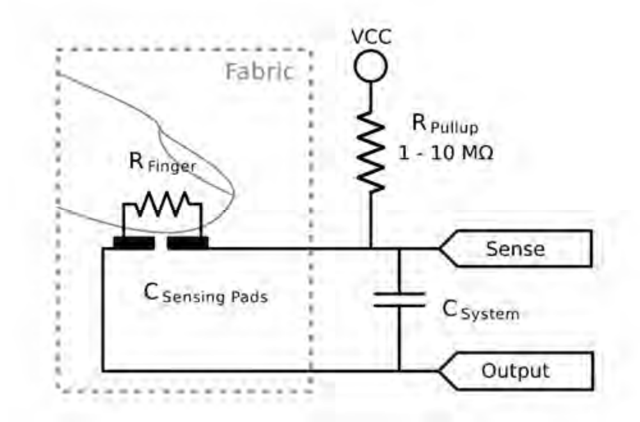

Figure 9. Resistive-capacitive technique used for all other touch sensitive swatches. *From* [18]

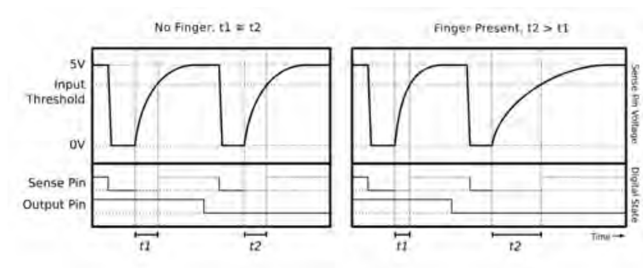

Figure 10. When the fingertip is not present, t1 = t2 (left). Otherwise, t2 > t1 (right). *From* [18]

The touch points utilized hybrid capacitive sensing, as described by Gilliland for the ESwatchBook [18]. For a simple capacitive sensor, one general-purpose input/output (GPIO) pin is needed on a microcontroller, which we will call the 'sense' pin. We connect this pin through a high resistance to the system's power supply (labeled as Rpullup), and begin by driving the pin to GND using the microcontroller. This fully discharges the capacitor formed between the pin and the GND of the system. We then switch the pin to input mode, and continuously sample it until it reads 'high'. As the resistor charges the line to higher and higher voltages, the pin eventually reads as a digital 'high', with the time determined by the capacitance of the line.

To make this into a hybrid resistive-capacitive sensor, we use a second GPIO pin, labeled as 'output' in figure 9. We run the sense pin and the output pin out to pads in the fabric such that a user's fingertip can contact both at the same time. When a fingertip is present, it behaves as a very high resistance between the two pins, labeled as Rfinger. When we drive the output pin high, this acts like a second Rpullup, causing the capacitance charge time (t1) to be slightly faster. When we drive the output pin low, this acts against Rpullup, causing the capacitance charge time (t2) to be slightly slower. By taking two capacitance readings, one with the output high and one with the output low, we can take the delta between the two times and determine if there is a finger contacting both pads.

The main advantage of this sensing technique is that it can be done with any embedded processor with GPIO pins. It also allows for many connections using relatively few GPIO pins, as multiple sense and output lines can be connected in a matrix.

The proximity sensor was an ST VL6180X, a time-of-flight IR distance sensor. The VL6180X was chosen for its ability to measure distance to an object up to 100 mm away, with accuracies of <5mm. Also ambient lighting and the reflecting object's color/tone do not overly affect this proximity sensor. This means that we could get a reliable and accurate measurement of the distance that Rho's hand was held from his chest, without concern for the dynamic environment.

A custom ARM Cortex microcontroller development board is used running the ChibiOS real-time OS. That board also contains a Laird BTM441 bluetooth module, chosen to provide the flexibility of several Bluetooth profiles. While initially used as a Bluetooth Serial Port Profile (SPP) device, we ended up using the BTM441 as a Bluetooth Huan Input Device (HID) device with a custom HID descriptor. This allowed the device to appear to any computer as a joystick with 'buttons' representing the touch points, and linear axes corresponding to the proximity sensor.

We also implemented a stateful interface on the device: the top touch point was used to cycle through three 'sets', allowing to five remaining touch points and the proximity sensor to show up as 15 buttons and three sliders. This also lined us up for using the color LEDs to indicate the state to Rho while he was using them, although we did not get the LEDs completely working in time for the live performance.

OUTCOMES AND DISCUSSION

The HCI expert on the Hood project noted that "People like me are not going to invent the future of this medium, we need all of the creative people from different domains and expertise."

On looking back over the process Rhó states: "*My time on the project was exciting and inspiring, but also hard. It stressed me in a way, when I got here I did not know how to deal with the guys (engineers / computer scientist), I thought they were really talented people, so I had to prepare myself to learn. When I met them, I had to deal with a new language, new stories, with a new environment, which is not a usual one for a musician. It's not only about using one software or another, but it's how to translate a process, something artistic, to people who come from technology, and how to transform a technology process in to music*."

Boundary Objects used in the Creative Design Process.

Star's original description of boundary objects [41], and many subsequent use cases focus around interdisciplinary work, but not necessarily design work. Carlile [8], Barrett and Oborn [3] enumerate how to view boundary object in use. Carlile makes a clear point valid to our work. "*First, knowledge in new product development is localized around particular problems faced in a given practice. The effective development of knowledge in organizations demands that individuals specialize or localize around different problems. To say localized does not mean that knowledge is limited to only one situation or location; rather, knowledge can be quite similar across practices if it is localized around a similar set of problems; knowledge is local in character, not global.*" [8] But in his description of product he talks more of engineering, and Barrett and Oborn are focused on software development teams. This type of teamwork might need cross-cultural and interdisciplinary collaboration, but are very different from the creative design process of disciplines closer to the arts. Bergman, Lyytinen, and Mark do describe the use of boundary objects within design. *Through a synthesis of design they formulate four essential features viable for design boundary objects. First is the capability for common representation* [5]. We also found this to be true, especially within the context of drawing to create boundary objects. Drawing can also exhibit the second and third of Bergman's features *the capability to transform design knowledge and the capability to mobilize for action* [5]. Drawing acts as means to plan and exchange knowledge after a shared meaning is developed. *The capability to legitimize design knowledge* [5] might arrive from the combined acceptance of a design schematically drawn, which through an iterative drawing process now contains understandable elements from all disciplines collaborating.

We agree with Johansson et al. "*In a collaborative design session bringing together a diverse group of professionals, each with their own practices of framing and representing their respective design games, it is not obvious how such a conversation can become a collaborative endeavor, and the alternation between participation and reification has to be taken into account.*" [23]. Johansson also advocates for the use of design materials "so rich in content" that they act as a boundary object. In our work here we hoped to show the use of the ESwatchBook as an effective boundary object, but it is important to note that the ESwatchBook itself was insufficient and drawing methods were also needed to bridge this gap between disciplines.

One substantial characteristic of boundary objects, which we believe make them effective tools in collaborative interdisciplinary design of artistic creative outcomes, is their plasticity in nature. Just as Benford et al. explained that the ambiguity and discomfort between HCI researchers and artists can act as a proving ground and springboard for innovation [4] . The plastic and flexibility in shared meaning of boundary objects used in bridging knowledge between artists/designers and HCI/engineers can create wonderfully opportunistic misunderstandings. When designing a product in terms of an aircraft component, this type of misunderstanding could be disastrous. When designing fashion, performance, or other artistic leaning endeavors this could lead to truly unique and innovative solutions, which neither individual discipline or expert would have developed while working within their isolated standard working process. The EswatchBook we used was designed with this plasticity of meaning in mind [18]. The interface was purposefully designed without direct use cases foregrounded, meaning that when a user interacts with an e-textile swatch the computer screen shows a square which changes colors depending on types of interaction (Figure 2). Gilliland, Komor, Starner, and Zeagler designed the device in this way as to not point to specific use cases, hoping to inspire designers while leaving them free to come up with their own uses for e-textile technology. The original ESwatchBook contains somewhat aesthetically sterile e-textile swatches mimicking standard GUI gestures. We would argue that the ESwatchBook could use an overhaul and include some swatches with more influence form designers and trend forecasters. This could make the ESwatchBook more effective as a boundary object, pushing the balance of shared meaning closer to design and closer to the fulcrum between the disciplines it wishes to connect.

Formalizing and labeling artifacts and materials as boundary objects within the creative design process can have a number of beneficial outcomes. As a prescriptive measure, in planning to work with boundary objects, prepares a creative interdisciplinary team (researchers, technologists, and designers) to know that they speak different languages and have different processes before they even start working. By using or creating boundary objects the team also accepts up front the flexible nature of the terminology, which surrounds these objects, aiding in opportunistic misunderstandings. Star notes in her later writing on boundary objects that they "became almost synonymous with interpretive flexibility" [26].

Star used her description of a boundary object as a framework for explaining collaborative work around which consensus of meaning was seldom reached, but work was effectively completed. This descriptive use of the boundary object can help frame collaborative work process after the work is completed. If at the start of collaborative group work, we set out to use boundary objects, the framework of boundary objects can also help build a design process which is inclusive and participatory. When we consider boundary objects by Star's definition we should also consider the scale and scope of the object [26], which in turn would reflect on the scale and scope of the project.

By starting the 'Hood' project with an understanding that the ESwatchBook and drawing were to act as boundary objects, we also appropriately scaled the work to be accomplished. If we had considered language a boundary object, the scale of our project could have been too grand, or too broad [26]. By having a clear set of technology and a boundary object starting point that was flexible in use and understanding, we were able to scale our work to the appropriate time frame. Thus we arrived at a functional, aesthetically, and socially appropriate prototype.

Usefulness of Boundary Objects in Time Constrained Collaborative Work.

In our work here on the 'Hood' and in other work described by Gandy [15] and Zeagler [42] tools such as DART and The ESwatchBook have acted as boundary objects between disciplines. The usefulness of these boundary objects is highlighted in case studies like the 'Hood' and the E-textile interface workshops, where the time frame of the project is constrained and expedited. Forced timeframes and pressure to complete a prototype can lead to solutions without compromise, weakening at least one discipline's participation. Boundary objects allow for quicker translation of information through the shared meaning within the object. This stress of process translation echoes back to Gandy's work with Duran Duran, and how it helps when all team members have a solid grasp of the affordances and constraints of the task at hand early in the process [15]. The time constraint of one day within the e-textile interface workshops along with the pressure to perform by showing final ideation prototypes parallels the one-week time frame and musical performance of the 'Hood'. Both the time constraint and pressure of performance necessitate a timely understanding between parties so creativity and ideation can take hold. In the future it might be possible to use time constraints and qualitative methods to tease out the effectiveness and scale considerations embedded in the shared meanings created through boundary objects such as DART and the ESwatchBook.

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