Design for Collaborative Survival: An Inquiry into Human-Fungi Relationships

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ABSTRACT
In response to recent calls for HCI to address ongoing environmental crises and existential threats, this paper introduces the concept of *collaborative survival* and examines how it shapes the design of interactive artifacts. Collaborative survival describes how our (human) ability to persist as a species is deeply entangled with and dependent upon the health of a multitude of other species. We explore collaborative survival within the context of designing tools for mushroom foraging and reflect on how interactive products can open new pathways for noticing and joining-with these entanglements towards preferable futures. In addition to highlighting three tactics—*engagement*, *attunement* and *expansion*—that can guide designs towards multispecies flourishing, our prototypes illustrate the potential for wearable technology to extend the body into the environment.

Author Keywords
collaborative survival; wearable technology; sensing; post-anthropocentric design; fungi.

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

INTRODUCTION
"To use the world well, to be able to stop wasting it and our time in it, we need to relearn our being in it."
- *Ursula Le Guin [46]*

We are living on a damaged planet and in times where human impact on the earth has rendered species extinct, landscapes scoured, and resources strained. Researchers in HCI have responded to these crises by arguing that new interactions between humans and nonhumans (animals, plants, microbes) must be created to give rise to preferable futures (e.g. [29,42]). Moving towards these futures requires reorienting our understanding of the world from one where human needs are exceptional to those of other species (i.e. an anthropocentric worldview), to one that encapsulates and nurtures a multispecies perspective (i.e. a post-anthropocentric worldview) [10,11,17,42]. Yet, there are relatively few examples that translate post-anthropocentric theory into design practice and demonstrate the new design territories that could emerge from these approaches. Because technologies play a critical role in shaping how humans relate to their environments, investigating design strategies to support multispecies resilience are of critical importance.

In an effort to bolster post-anthropocentric design and reflect on its ability to alter the status quo, this paper presents the concept of "collaborative survival" and explores it through the design of three wearable tools for mushroom foraging. "Collaborative survival" is a guiding narrative for designing systems that prompt humans to notice and become compassionately concerned with the wellbeing of nonhuman species [52]. By integrating it into design practice, we tell stories of how technology can help humans forge and sustain livable collaborations.

In this paper we describe the concept of collaborative survival and how it can be taken up within the context of design by focusing on multisensory acts of noticing. Next, we describe how we translated this theory into practice in

Figure 1: The Hand-Substrate Interface creates a direct connection and engagement with environment by requiring the wearer to physically insert their hands in soil to obtain a digital moisture reading.

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the process of creating three provocations: Hand-Substrate Interface is a glove that requires the wearer to physically insert their fingers into a substrate to obtain a data reading; Data HarVest is a location-aware vest that uses vibration to alert the wearer to locations where mushrooms have been found in the past; Spore Stepper is a modified walking stick for collecting soil samples along a foray that will later be analyzed for spores.

Each design uses different materials and modalities to draw the body into the environment and bring different qualities of human-fungi relationships the attention of the wearer. Reflecting on these differences, we suggest that design tactics emphasizing *engagement* (shared physical experience of the environment), *attunement* (ability to sense the livelihoods of the nonhuman collaborator), and *expansion* (blurring of nature-culture divisions) can form a starting point for thinking about how design draws humans into the environment.

The primary contribution of this paper comes in the form of our "tools"—design provocations created with the intention of sparking the imagination of designers so that we can picture new roles and relationships for technology within a precarious present. These provocations offer a vision of wearables extending our human sensory capacities into the environment, thus, allowing us to notice, attend to, and become struck by nonhuman lives. Additionally, we contribute strategies to aid and catalyze other designers to consider post-anthropocentric approaches to design, specifically those that focus on multispecies relationships. More broadly, we illustrate how HCI can respond to calls across academia to reimagine, reevaluate and reconfigure our understanding of human-technology-environment relationships.

INTRODUCING COLLABORATIVE SURVIVAL

Anthropologist Anna Tsing develops her narrative of collaborative survival by tracing the stories of matsutake, a prized mushroom that is primarily foraged in forests that have sustained long-term damage from human impact. She writes:

Matsutake's willingness to emerge in blasted landscapes allows us to explore the ruins that have become our collective home. To follow matsutake guides us to possibilities of coexistence within environmental disturbance. This is not an excuse for further human damage. Still matsutake show one kind of collaborative survival. [8: 4]

In this quote, Tsing introduces collaborative survival to recognize processes where multiple species rely on each other to survive within damaged landscapes. What is notable about Tsing's narrative is that it is not one that looks backward longing for better times, or even one where humans are framed as protectors of the environment. Instead, it is a narrative that accepts the damaging forces of humans and environments, and sees a pathway towards preferable futures in recognizing and developing relationships with other species. Rather than sustainability for the benefit of humans, Tsing offers collaborative survival to motivate us to benefit all the other life forms.

Tsing asks us to examine the environment as a web of relations inevitably tied to one another to imagine an alternative future built on these relations. Design as a practice has sought to examine and intervene in these webbed systems in order to create new futures. Bringing this theory into HCI makes us ask how we can use technology to help foster relations between the human and other entities in this web. As humans, we are limited to our own experiences and knowledges as a species. Interactive technologies can play a role in allowing us to expand this understanding and imagine what collaborative survival may look like. Collaborative survival in design thus may be an opportunity to use the potential of new technologies to make humans aware of where they might situate themselves in these multispecies webs.

Tsing's descriptions of collaborative survival resonate with feminist technoscience scholar Donna Haraway's calls to "stay with the trouble" [21]—a call to look at, notice, and respond to the destructive processes we may prefer to ignore. For Haraway and Tsing alike, humans need to create the conditions for survival (or as Haraway says "ongoingness") by attending to the conditions of the present and the destructive forces that are continually unfolding. Humans can work towards recuperation by raising our "response-abilities," [21] our ability to notice, respond, and become-with the livelihoods of other species. Tsing uses similar language when she describes her ethnographic process as attending to the "arts of noticing" [52]. These "arts" consist of moments in which humans notice and gain insight into how systems function outside of our anthropocentric norm. Noticing is a first step towards our ability to be "response-able" and offers us, as designers, an entry point into seeing how interactive things might serve processes of collaborative survival.

This line of work motivates us in that it inspires us as humans to hold ethical obligations in our relationships with other animals and nonhumans. As HCI researchers, we feel that we can use this theory in considering technology as a force that can be leveraged to raise human response-abilities and build kinship.

SITUATING COLLABOARTIVE SURVIVAL IN HCI

Within HCI, issues of environmental concern typically fall under the banner of sustainable interaction design [5] and sustainable HCI. In 2010, DiSalvo et al. reviewed and organized this work, highlighting general themes of sustainable design that continue into the present [15]. Many of the themes focus on consumption, namely, research on how designers can use technology to prompt humans to reflect on their practices of consumption and the broader impacts of their choices upon the environment. In doing so, this work often frames technology as a means of persuasion and humans as choice-making actors (see also [6,16]) who, might make choices that are more "eco-friendly", focusing on individual action rather than systemic changes.

More recent work on sustainability, particularly work addressing repair [8,22,39,43], collapse [45] and foraging [14,28] has emerged to expand how HCI constructs and addresses environmental concerns. Much of this work draws directly from feminist technoscience to frame sustainability across timescales, space, and naturecultures [21,42]. Furthermore, it draws upon a broader set of speculative methods and "fabulations" that tells stories of multispecies flourishing and recuperation [21,30]. Collaborative survival joins with this work to emphasize beginnings rather than consequences—asking humans to form kinships with nonhuman species. The focus is on bringing humans to appreciate the livelihoods of the species who share our planet. Thus, the relationship between humans and nonhumans in collaborative survival is one of partnership rather than protector. One of the goals of design for collaborative survival, then, is to seek ways that humans become attentive and compassionately connected with other species such that issues of extinction, damage, and destructive affect us all.

Using the term collaborative survival also suggests a sense of urgency. Where sustainability tends to orient towards managing consumption of natural resources, collaborative survival orients towards the need to rethink overall relationships between humans and the environment, specifically in ways that encourage inter-species awareness. Consequently, this adds a post-anthropocentric bent to the research, moving the needs of nonhumans towards the center of design. In line with Tsing, we believe that this urgent tone of "survival," is a necessary call to action to prevent further damage in this precarious moment.

We draw additional inspiration from the following strands of research in HCI:

Design for Existential Crisis

Light et al.'s recent call for existential HCI outlines many new design challenges that emerge in the fact of socioeconomic and environmental precarity [29]. In questioning the role of design in a world where there is no more "business as usual," she seeks an alternative to prevailing models of "bovine design", technologies that seek to herd and control human behavior. In line with Tsing and Haraway, she argues that existential concerns necessitate the development of new sensitivities and vulnerabilities towards the nonhuman world. These new sensitivities can be cultivated through designed friction [27], decentering the user in the design process [7,10,11,17,19,42], and provoking enchantment though interaction [32]. As such, collaborative survival, and existential HCI more broadly, emphasizes the ethics inherent in aesthetic experience [3,4,12]. Designs for collaborative survival can focus on shifting the individual towards a greater sense of being, as opposed to acting, in the world. While issues of rational choice and collective action are still important, collaborative survival sees noticing, feeling, and co-productions [11] with other life forms as necessary pathways towards sustainable futures.

Multi-species interactions

Collaborative survival emphasizes multi-species relationships. Recent work in animal-computer interaction (ACI) offers perspectives on how we can bridge species to develop a deeper understanding of the relationships we have with other animals [31]. Human computer biosphere interaction (HCBI) [26] draws from Zen philosophy to explore how technology can facilitate appreciation and connection with nature. While often enacted through interfaces that allow people to connect with nature at distance, this work offers perspectives on the role beauty and meditation can play in fostering connections with ecosystems.

Post-Anthropocentrism in Design

Work focusing on cohabitation [42] and coproduction [11] share many of the theoretical roots and commitments of collaborative survival and highlights the productive role decentering users in design can play in creative production [10,11], education [7], urban planning [17,42], and everyday things more generally [47]. Each method, with its respective insights and approaches, builds a picture of what designing for collaborative survival could look like and accomplish when enacted in different contexts.

DESIGN PROCESS & METHODS

While we use the pronoun "we" to refer to the designers of the provocations in many places to improve readability, Liu led the design of all provocations (with ongoing feedback from Byrne) and all reflections are based on Liu's personal experiences wearing her designs. The insights in this paper about the provocations and contributions they offer to design research have emerged from ongoing discussion, reflection, and analysis by Liu and Devendorf.

Between June 2016 and May 2017, we explored the concept of collaborative survival in design by participating in a series of mushroom forays while creating interactive wearable tools to explore her relationships with fungi. The design process, then, was not a formal exercise of hypothesis testing or soliciting "user" feedback from mycologists on how tools ought to be designed. Instead, we conceptualize this practice as an active process of "sketching" [49,50] that interweaves inquiry into theories of collaborative survival, enculturation into mycological field practices, and physical prototyping to both understand the theory more deeply as well as the design implications it might hold for future human-environment (specifically human-fungi) interactions. As such, our process combines aspects of research through design (e.g. [18,51]), speculative design (e.g. [53]), critical making (e.g. [38]), autobiographical design (e.g. [34]), and embodied design ideation (e.g. [48]).

We see our tools of "speculative fabulations"—ways of telling stories about our worlds and future worlds that work towards collaborative survival [21]. As Haraway writes, "Each time a story helps me remember what I thought I knew, or introduces me to a new knowledge, a muscle critical for caring about flourishing gets some aerobic exercise" [21:29]. Stories are not idle tales; they actively construct our worlds. By designing tools for collaborative survival and presenting them as "stories" for HCI researchers to interpret within their practice, our aim is to sensitize and provoke researchers to imagine what collaborative survival could bring to practices beyond the ones we describe here.

While the design and development of the provocations emerged from our individual experiments and experiences, we make reference to the "users" of the system in the multiple senses of the term. Pierce et al. articulate the entangled notions of first-hand use (everyday/actual use of things) and conceptual use (what one would imagine everyday use of a could be) [37]. We draw on these notions to discuss how our tools might perform beyond Liu's personal experiences.

Additionally, we felt it was important to create working material artifacts to allow us to physically experience the systems as they were developed and understand how materials that are currently available could be used to create and inspire new interactions with fungi. One of the key benefits of the autobiographical nature of our design and study, is that it allowed for tight coupling between tool and body. In building wearables, a mannequin or model is frequently used to assist in determining placement of elements on the body. However, this method can often neglect issues regarding wearability by using an inanimate stand designed for a generic body. Specifically, by designing the tools to match her own specific body measurements, Liu could simultaneously design, use, and reflect back on the artifacts, discovering certain nuances through a close experience in wearing the tools.

While this commitment to building added particular constraints to the process, it also opened up new ways of feeling and thinking with the ideas while demonstrating that designing for collaborative survival could be accomplished using existing toolkits (microcontrollers, conductive materials, etc.) towards new effects. Prototyping for one body allowed us to quickly explore and experience design iterations while also reflecting on the theory that informed the design. Rather than providing a range of experiences and themes, we offer a more in depth account of one person's sensory experiences.

DESIGNING TOOLS FOR COLLABORATIVE SURVIVAL

As a first step towards integrating collaborative survival into design inquiry we focused our designs on fostering "arts of noticing," a term Anna Tsing uses to describe her process in understanding matsutake. We interpreted "arts of noticing" as the practice of observation across a wide variety of methods. Not limited to only the visual process of "seeing", this embraces an understanding of ecological-systems through multi-sensory examination.

Focusing on Human-Fungi Relationships

In designing our tools, we have narrowed to focus on building tools that help us understand human–fungi relationships. Using custom designed objects to examine our entangled livelihoods with this particular companion species allowed us to focus our designs on "living" things beyond the realm of animals and to relate more directly with the work of Anna Tsing that inspired the project.

Before we go on, it is important to clarify specific definitions relevant to fungi. *Fungi* can describe any member in the taxonomically classified kingdom of fungi which includes yeasts, molds, and mushrooms. *Mushrooms* describe the fruiting bodies of fungi. *Spores*, in the context of fungi, are the reproductive units that are dispersed by the mushroom bodies. *Mycelium* is the term used to describe the vegetative part of fungi that resides underground. *Mycology* describes the study of fungi and we use the term *mycological practice* to refer to the study of fungi by professionals and amateurs in both field and lab contexts. A *foray* is a field survey which can be conducted by amateurs or scientists in which a particular subject, in this case mushrooms, are collected, identified, and catalogued.

Fungi offer a rich field of inquiry. Mycelium networks, interlaced and entangled in the earth are an incredible architecture of information collection, storage, and distribution between and within other organisms. Through the exchange of nutrients between a forest of trees to being a deadly toxin to our human nervous system, fungi are at once pervasive, yet have found their own niches in which to flourish. Simultaneously decomposing and creating, destroying and rebuilding, fungi can serve not only a model of future technologies, but also as an important bridge for us as humans to understand the rest of the world. From fermenting in our bodies [33] to spanning across desolate landscapes, the ubiquity of fungi is undeniable. Fungi also function as bio-indicators in the sense that the health of fungi can tell us about the health of a multitude of other species. By designing tools to expand our human abilities to be able to notice these connections, we hope to gain deeper insight and perspective on how we affect and are affected by other organisms.

Currently, people come to form companionships with fungi through practices like mushroom hunting, which can be carried out for personal interests or as part of a mycological practice. In the latter, mycologist and citizen scientists alike conduct forays to collect samples and form species identifications lists to provide insight on the fungal presence in a community for both scientific research and information for the general public. Through observing and recording the conditions that mushrooms are found in during a particular foray, this information can be used to help understand not just the specific conditions for fungal growth, but how an environment may change over time and what actions to take to prevent damage.

THREE TOOLS FOR COLLABORATIVE SURVIVAL

Over the course of 2016 and 2017, the Liu attended multiple forays with a local mushroom club. Comprising of approximately 600 members local to the area, the club supports monthly meetings and weekly forays to collect and catalog mushroom specimens found in regional parks and nature preserves. A typical foray consists of meeting up at a location with other attendees and wandering around an area for about two hours before foragers regroup to share what they found. A club officer is designated as the main identifier will then verify the identifications. Attendees then gather, document, and log species into a database kept by the club. Some specimen also collected for DNA barcoding to document and compare to other found species.

In the sections that follow, we describe the design process of each tool and reflect on how the particular mode of "noticing" it employed created different opportunities for engaging, understanding, and working together with fungi.

Hand-Substrate Interface

Insights into the conditions of the substrate, the growing surfaces, in which fungi grow, can provide foragers with valuable information about how changes in the environment affect these organisms. The Hand–Substrate Interface (HSI) is a glove with embedded sensors that can be used to detect information about the substrate (soil, organic matter, etc.) that supports fungal growth.

This design is based off the concept of a deconstructed/reconstructed soil moisture sensor (see Fig. 1). A soil moisture sensor typically consists of two probes that function as a variable resistor. A forager will place these probes into the ground to measure the conductivity between the two points. The more moisture or water that is in the earth, the higher the conductivity will be between the probes, resulting in lower resistance. The HSI essentially replaces the typical metal probes of a moisture sensor with human fingers augmented with conductive materials. To take a reading, the fingers have to be directly inserted into the earth, which allowed for a simultaneous experience of collecting digital data through the sensor readings and physical data through feeling the soil on the hand.

Design Process

We chose to create a glove to explore an embodied form of sensing. A glove's ability to be (quite literally) ready at hand could encourage us to more frequently sample and make contact with substrates, producing a richer understanding of the environment through direct connection and sensory engagement.

This particular design emerged after several experiments. In the first iteration, we used a work glove as the base material onto which the sensors were placed. Although effective as a proof of concept, the thick glove was a barrier between the substrate and hand, which detracted from the felt experience of the soil. As a result, we experimented with a number of techniques and materials to alleviate this barrier. One experiment utilized temporary conductive tattoos based off the work of DuoSkin in order to create the sensor platform directly onto the surface of the skin [23]. This proved to be difficult due to the tearing of the gold leaf conductive traces when placed along the joints of the fingers. Furthermore, the conductive tattoo would degrade over time and would have to be reapplied with each use. While more time may have resolved these challenges, we saw benefits in constructing a prototype that could be easily removed and could be used multiple times.

We addressed issues of fit and feeling by creating a custom glove pattern that would allow the HSI to sit closely to the wearer's hand. We designed an LED interface to sit on neoprene on the back of the hand to communicate the state of the glove as well as approximate soil moisture readings. The LED interface as a radial indicator was selected as an output because of the legibility of the reading when paired with the task of inserting the fingers into the soil. A sound interface was considered but when tested in context, the audio was drowned out by ambient noise. We embedded the electronics within an attached wristband, also made of neoprene. We also used leather to create semi-detached caps that sit on the fingertips with exposed traces to take a reading, with mesh fabric for the underside of the finger cap so that as the wearer places her sensors in the soil, she is able to feel the ground through the mesh fabric. We connected the caps to the rest of the glove using traces made out of conductive spandex stitched to a knit material.

Liu tested this prototype by wearing it out into a forested area on multiple occasions over the course of building the iterations. The presence of wearing the HSI encouraged her to engage with different substrates on a hands-on level such as soil found along the path and under trees. With standard soil moisture sensors, the ends of the probes are pointed to allow for easy insertion into the earth. Liu realized her own fingers were not as pointed and thus had to engage in a wiggling and digging motion with her fingers to obtain a reading under leaf debris (See Fig. 2), a gesture that made her interactions with the environment feel strangely intimate. The HSI is calibrated for when the two fingers are pressed together lightly, side by side. Although the reading is not as accurate as a rigid soil moisture sensor, this conscious action to adjust and align the fingers to take readings contributes to this notion of engagement.

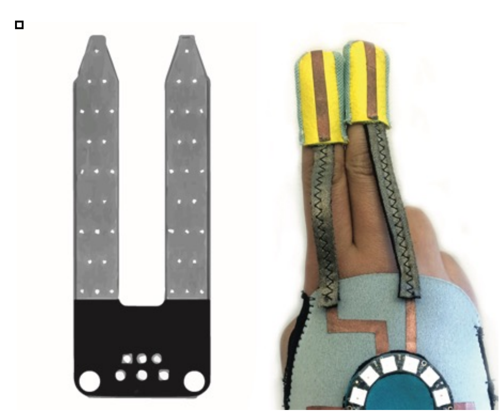

Figure 2 Comparison between standard soil moisture sensor (left) and HSI (right)

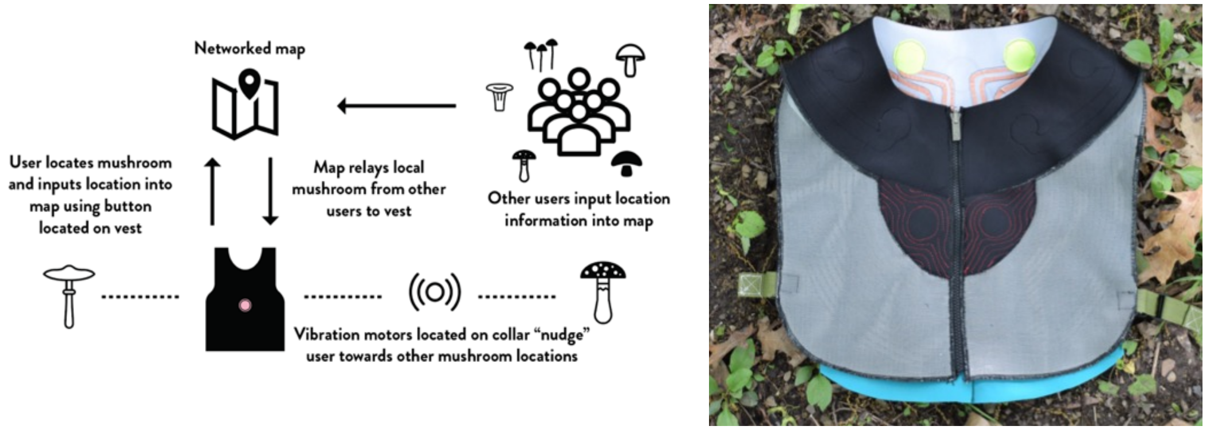

Figure 3: Data HarVest is a wearable tactile map that guides wearers to locations of community reported fungi growth.

Engagement
In this prototype, the focus on "arts of noticing" gave rise to an emphasis on a design that would foster a direction sensory connection and engagement with the organism of interest. While the human is not sensing the fungi per se, they are experiencing the substrate along with the fungi, laying the groundwork for shared experience and a basis for sensing ecological health. Prior work in environmental sensing describes how these practices of direct contact and engagement with the environment are common among those who work closely with organisms (like animals or plants) [28,36]. Kuznetsov describes how beekeepers may prefer to tip their beehives to determine weight instead of using digital scales, or how others tap plants to check for presence of pests, and farmers described the preference to use their finger to test for soil moisture. Such methods, as Kuznetsov describes, allowed the people they studied to create richer pictures of environmental health [28].

Through this lens, engaging collaborative survival in design created a vision where a human's sense-making capacities as a "natural" sensor pair with the capacities of digital data. Calibrating this natural/human sensor would require direct engagement in the environment and brings the wearers' attention to the conditions that communicate something about the specimen of interest, in this case fungi.

Data HarVest
In order to notice something, someone must be motivated to look. The idea for the Data HarVest comes from Liu's observation that novice mushroom hunter will become frustrated or discouraged in not being able to find mushrooms. Part of the challenge is that the occurrence of mushroom varies significantly based on the current environmental conditions—a mushroom spotted in one location may never appear there again. Thus, it is usually through practice and guidance by more experienced hunters that novices might learn the observational practices to spot where fungal growth may occur. Some of these practices include looking at the landscape and evaluating the topography of the local area since fungi tend to grow where rainfall can accumulate, along with looking at certain types of trees and substrates since some fungi have symbiotic relations with other organisms. Furthermore, knowing what to look for is key. Many novices may have a mental model of what a mushroom may look like, however the forms of mushrooms can take on many varied forms and shapes.

Data HarVest is a wearable tactile map that guides its wearer to locations where fungi growth has previously been found (see Fig. 3). The first author built the interaction of this prototype around a vest that can be worn on the body during a foray. When the wearer locates a mushroom, they are able to log the GPS location using a button on the vest. This button is linked to a logger connected to a networked map that can be accessed by other interested parties though their vests. As the wearer is in the foray location, vibration motors located around the collar "nudge" them in the direction of these shared mushroom locations.

This open sharing of the locations may seem contradictory to myths of mushroom hunters being secretive about their prized spots. However, in this context, the sharing of data allows the person to be *hinted* towards location, encouraging them to also infer from their surroundings with subtle guidance. Given the spontaneous nature of mushrooms, it is also not a guarantee that there will also be anything present at the final location. Thus the vest is designed to gives cues to look within a location, rather than give specific directions.

Design Process
While the ubiquity of smart phone based sensing applications offer convenient methods of input and tracking, the plethora of other functions, such as messaging and social media apps, may easily become distracting. To stay present in the foray, we designed it to offer an eyes-free method of tracking locations while allowing the wearer to remain perceptive to the environment.

We drew inspiration for physical design of Data HarVest from vests worn while fly-fishing. Vests in fly-fishing are designed to hold multiple tools and gears, along with design features that include adjustability and allows for full movement. With an attention to utility, durability, and flexibility, we chose to construct the vest from neoprene. In designing the collar, we constructed a circular yoke to allow for the vibration motors to be able to sit around the neckline without any interference of seams at the shoulders. The buzzing was designed to vibrate in pulses based on the relation to the designated location. As the wearer moves towards the area, the vibrations would increase in speed and intensity, coming to an almost continuous buzz when the wearer is within a close distance. On the front of the vest, we placed buttons for GPS input near the center of the chest, allowing for a central location for the logging function and marked their locations with decorative contrast stitching. On either side of the chest, we built mesh pockets that allow for storage of physical specimen found on the walk.

As Liu wore this prototype out in the field, she found the ability to capture location data readily available, allowing her to log GPS location while observing other aspects of the environment such as substrate conditions. Since this was the first vest that was created with this particular concept in mind, the notion of a shared sense of locations was not readily present. Reflecting on her experiences foraging, Liu imagined that as she accumulated more information over time, the vest may reach a state where it will be constantly buzzing. While she considered this becoming a nuisance for a wearer, she also began to think that constant buzzing could present an interesting insight regarding the ubiquity of fungi. Similarly, she began to see how the timescales of environmental change could an interesting design feature to play with, as she considered how one might be "buzzed" with notices of previous mushroom sightings in locations that may no longer be suitable for mushrooms—prompting the ability for new methods for mapping a changing environmental landscape over expanded timelines.

Attunement

With Data HarVest, design for collaborative survival and the arts of noticing led to a design focused on helping its wearer become attuned to both environmental conditions and practices of other foragers. In contrast to technologies that coach people how to see things in specific ways (e.g. [40,41]), this enactment of collaborative survival emphasized a move away from visuals, maps, and success and towards a more conceptual process of becoming attuned to the histories of mushrooms as well as the practices of mushroom foragers. As a platform of care for the novice hunter, it can be seen as lowering the barrier of entry into foraging such that more people might take an interest in these organisms. The buzzes may or may not be effective (since mushrooms can be illusive) but it could be the kind of action someone requires to remind them to keep looking and to stay open and engaged to the world outside of themselves.

Spore Stepper

Although mushrooms are usually seen as the main specimen for collection during a foray, a large amount of fungi occur in the form of mycelium and spores. Soil sampling is a way to gain a picture of the fungi that is in the environment, regardless of the mushroom, with estimates of 10^6spores per gram of soil [54]. Thus, through collecting and analyzing soil samples from a foray, one can build a portrait of the possible fungi species in an area even if the mushroom bodies are not present.

Spore Stepper is a walking stick that is used to collect soil samples for spores that have been distributed into the earth by mushrooms (See Fig. 4). After a foray, the sample can be germinated or DNA sequenced to determine what fungi species may be present. This seeks to expand and dissolve ideas of where the "field" lies through addressing where a person may find their mushroom specimen, whether during the foray itself or afterwards through germination.

Design Process

One form of soil collection that already occurs when out on a foray is collecting soil from the treads of the shoes. We used this action as a conceptual model in leveraging an action that takes place in foray (walking) with material data collection (soil collected for sampling). In the first iteration of Spore Stepper, we built hardware onto an existing shoe to allow soil sampling to occur. Although this prototype was able to a collect a small bit of soil using the step, issues of integration of the hardware into a shoe became apparent when assessing iterations for the prototype.

When we looked for an alternative, the walking stick presented itself as a viable option in that it makes contact with the ground through and can offers the physical potential for collecting samples. These tools also have a long history of being designed with multiples uses [13,44]. Walking sticks also share similar designs with existing soil sampling probes, which usually consist of a long hollow tube that can be inserted into the ground the extract soil. However, these probes do not actually store the sample and instead must be deposited into a bucket that is carried along by the person when performing soil samples. Thus for the next iteration, we created a walking stick that could function not only as a hiking aid, but could also store and

Figure 4: Spore Stepper is a walking stick that can also be used to collect soil samples.

collect samples. In addition, we built a GPS logger into the design as a way to provide additional contextual information about where individual soil samples take place.

This design of the Spore Stepper consists of advancing soil collection chamber at the bottom of the tool, with features of a walking stick on the top. At the bottom, we used an extruded acrylic square tube for this chamber and an acme threaded rod was added to advance and retreat a flat stopper that would increase or decrease the volume of the soil collection region. To collect soil, the stopper is advanced and the sample is collected. By twisting the handle, additional room is made in the tube to collect fairly uniform soil samples at each point. Because the soil is compressed during collection, it prevents the soil previously collected from falling out during subsequent probes. At the top of the Spore Stepper, we built a handle to allow the tool to be a comfortable height for use as a walking stick.

Through her experimentation with this collection process in the field, Liu became increasingly curious about what was contained in the soil and the possibility that it may hold bits of other life whether decaying or emerging. She became so fascinated in this process that the Spore Stepper became increasingly heavier with the addition of more and more soil samples. She noted that future iterations would need to address ergonomic issues such as weight, especially with the collection of additional soil.

Expansion

Engaging collaborative survival in the design of Spore Stepper suggests a different experience of noticing than the other two prototypes—one in which the person collects things in anticipation of discovering something unseen in the field. Through the process of walking and collecting samples, one can accumulate a fungal profile of an area based on the spores. These spores, invisible to humans along the foray, become perceptible though post-foray actions, like germination or DNA sequencing. Since some can stay alive multiple years after dispersal [35], these post-foray processes can activate histories of life latent in soil. Because the soil collected during the foray takes on new lives in labs or germination setups, we see this prop expanding the contexts for noticing and joining-with fungi. The "field" extends beyond the outdoor regions for foraging and into human controlled territories, crossing perceived natural and cultural boundaries.

DISCUSSION

While we began our design process by taking up collaborative survival in design by focusing attention on the "arts of noticing," the three prototypes that emerged from this inquiry illustrate multiple sensory and performative dimensions—*engagement*, *attunement*, and *expansion*—along which noticing took place. Each form of noticing offered different opportunities for Liu (and imagined future users) to form companionships with fungi. Through building these prototypes, we also see the potential for wearables to extend the human sensing capabilities to perform these "arts of noticing".

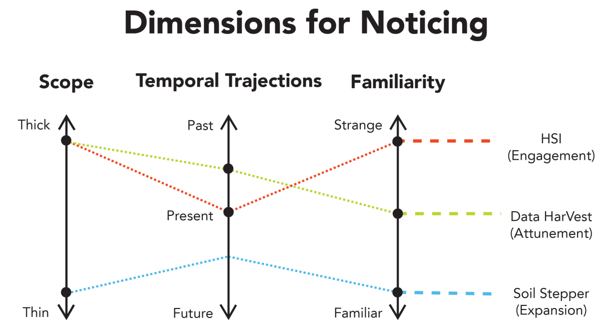

Figure 5: Visualization of our dimensions for noticing and the emergent themes.

Dimensions for Noticing

Specifically, because HSI required close physical proximity and direct sensory *engagement* to soil, it offered a shared experience of the substrate in which fungi grow and an opportunity for the human to form an embodied sense of the life and conditions required for fungi to flourish. With the Data HarVest, the wearer has an expanded field of view with the technology coming in to alert the wearer when extra attention could yield a mushroom spotting. This process *attuned* wearers not only to the environments for mushroom spotting, but the human practices and experiences of more seasoned foragers. The Spore Stepper uses more passive input method that shifted the focus of attention from the forage itself, to the lives of fungi in other life stages beyond the mushroom—*expanding* boundaries of how we might encounter fungi in our lives.

While HCI has a long history of using technology to provoke noticing we found through our analysis that we have a limited vocabulary for articulating the complexity of different mechanisms and outcomes of noticing. As we reflected on our designs and the way they shaped what and how fungi could be attended to on a foray we began to see differences along the following three dimensions: *scope*, *temporal trajections*, and *familiarity*.

Scope refers to the level of focus, human attention and sensory engagement and ranges from thick to thin focus. We see HSI and Data HarVest offering a thick experience in the sense that it fostered attention and engagement through action and multisensory experience. Thickly scoped technologies may be said to immersive or time deepening [20,28]. On the other end, Spore Stepper was relatively thin in terms of experience, as it required very little attention beyond functioning as a walking stick. Thinly scoped technologies could be said to be passive.

We see *temporal trajections* relating to time-space of fungi that become present through the tool. This encapsulates pasts, presents, and futures. Where HSI fostered a present connection, concurrently locating the experience with the fungi with the experience of the human, Data HarVest encompasses pasts of fungi and foragers by making information from the past visible in the interactions of the present. Since Spore Stepper collects objects of the past in the form of spores, we see its temporal trajectory extended from the past and into the future, in the sense that the soil collected allows the collector to join-with and appreciate fungi through germination after the moment of collection.

Finally, *familiarity* refers to the nature of the interaction itself and how habitual or naturally it occurs to a person. They may range from familiar to strange. Along this dimension, we see Spore Stepper as the most familiar, seamlessly integrating into habits and not requiring direct attention. Alternatively, HSI is strange, asking people to touch and feel soil in an unusual fashion (for most). Further, Data HarVest falls in the middle the spectrum: integrating the familiar buzzing notifications we have grown accustomed to through the use of smartphones to guide wearers in a potentially unfamiliar act of finding mushrooms.

What we see in these three dimensions is that the "arts of noticing" can take place in a variety of forms and can engage a wide variety of design methods. When noticing living things, which take on their own lives and histories, these acts span time as well as space. With noticing taking on increasing ethical importance though programs like existential HCI, a productive move for design research in the future could be to more formally describe and articulate the relationships between technology and human perceptions of the environments and nonhuman others.

Honoring Fungi in its Many Lives and Forms

What the variety of tools makes evident about collaborative survival is that it is well suited to attend to the multiplicity of human-fungi relationships. The metaphor allowed us to honor fungi in its multiple forms and expressions—a ubiquitous underground network, a barometer for eco-system health, a delicacy to eat, or a specimen to identify (to name a few). There is not one *true* or *correct* life for a human to attend to and thus, there are multiple ways of becoming entangled with fungi in both its physical and digital manifestations. For instance, Liu did not design the tools to enact particular narratives of protecting or conserving fungi. Instead, the concept suggested that we design only to make a particular relationship with fungi possible, and it is up to each human as to *what* that relationship can entail and what arrangements will be mutually beneficial.

At the same time, we see collaborative survival attending to the many ways in which the life of fungi becomes present to humans. What is decidedly missing from our narratives is an attention to understanding the singular life of fungi or being able, for example, to see as a mushroom sees. While these perspective switching techniques can have benefits in sensitizing people to certain phenomena and can be useful in particular contexts (e.g. [1,7,19]), collaborative survival suggests that we resist mapping aspects of human sensory apparatus upon a nonhuman other. Our tools suggest that technologies can bring humans to experience fungi, in its many forms, and acknowledge that these experiences can never speak to what a mushroom "feels" or "thinks." They are tools for beginnings, bringing people to the specimen and letting the relationship develop in open-ended ways.

Wearables as Extensions of Body into Environment

By engaging collaborative survival in design, we paint a picture of wearables extending the body into the environment. While several other wearable sensing projects exist, they often focus on the role of clothing as a kind of mobile or pervasive display of environmental data (e.g. [24].) In other examples, the wearable is an interactive surface upon which a person can trigger feedback based on environmental data (e.g. [25]). While both systems have unique benefits, we think the tools outlined here suggest that there is more to be explored when it comes to wearable technology and the environment.

When engaged in acts of sensing and data, collaborative survival shifts the focus from the data itself to the experience of collection. We found that using wearables (specifically HSI and Data HarVest) like costumes or props rather than clothing was a helpful tactic for setting the stage for certain kinds of experiences. For instance, the form of the HSI glove, its look and the placement of the sensor upon the fingers, is a prompt for the wearer to perform in their environment in ways they may not have previously. These performances and gestures color the experience. Specifically, in order for the HSI to work the wearer must physically insert and dig with two fingers into the earth. This gesture is strangely intimate as it connotes particular sexual or medical acts, though it is a common action by gardeners or others working directly with soil. The significance of this gesture is not a byproduct of the design, but something that we felt could bring notions of intimacy and the earth into perspective. Engaging the metaphor of collaborative survival adds attention to ways technologies can help humans looking beyond themselves and into the world to seek new forms of connection and companionship. Conceptualizing wearables as costumes, at once playful and productive, artful and suggestive, may be useful in prompting people to perform in particular ways within various material-semiotic contexts.

Tensions of Collaborative Survival in Design

As we reflected on our project and existing critiques of sustainable HCI, we began to wonder if technology and design is the most effective way to goals of collaborative survival.

On one hand, while theoretical literatures can inspire multiple interpretations and possible responses, implementing the metaphor into technology and design can run the risk forcing the theory to fit the more actionable aims of HCI (for which it may not have been intended). We are sensitive to critiques (like those outlined in [2]) that the practices and histories of HCI can form incompatibilities with the traditions from which those ideas emerged. At the same time, we look towards the theory for its generative capacity, seeing its value in what it inspires for HCI as opposed to a direct translation of how collaborative survival ought to be interpreted. This paper offers one specific interpretation and associated outcomes, and we would welcome others to draw their own.

On the other hand, we question if direct political action would be more effective as a strategy rather than technological tools. While our designs are certainly partial and may fall victim to criticisms to being overly focused on individual action [16], we see working with the language of tool design and technology as an initial step in questioning the way that collectives, beyond the individual can form new knowledges. In remarks regarding scientific observation, historian of science Lorraine Daston has pointed out that "individual observation is compiled as collective understanding", in such that our personal experiences, although individualized, can be accumulated and threaded together to create shared meaning [9].

In summary, collaborative survival, articulated in words or tools, is about considering alternative futures. We see design and technology as being part of what helps build those narratives. These tools also serve as objects that punctuate a critical moment in our technological and cultural landscapes, in which we possess the ability to start building and forming new environmental futures in the present. For instance, we see the potential for wearable technology to be designed to create outward looking tools that help people notice their environment to help build physical and emotional connections with those spaces. As Ann Light states, "The radical act of paying attention to things that we do not wish to see and that make us uncomfortable can be aided by design if it take up the challenge of resisting smoothness and self-centeredness" [29]. To ensure futures of flourishing and resilience, we as designers and developers need to take on tackling issues however challenging and existential they might be.

Finally, we want to reiterate that we think change should happen with multiple types of actions and approaches, and with this project, we are presenting one particular approach. The goal, then, is not to "solve" the future, but add a deepened set of methods and approaches that we can use to work towards that future.

NEXT STEPS

While our prototypes illustrate the potential for interactive technology to make humans present to the interconnections and dependencies of fungi within the broader environment, we see vital next steps in this work addressing (1) the formation of collaborations/coproductions with fungi after they are noticed and (2) building tools that move beyond the individual experience to explore collective forms of collaborative survival.

As we have acknowledged earlier, feminist technoscience constructs the world as a dynamic set of relations that interconnect and entangle humans, animals, things, and "critters" of various sorts. These relationships are dynamically changing, forming, and reforming though time. This work focused on a very small part of those vast arrangements, in particular, the interconnection between a human and fungi. We see future work in thinking about how design research might help expand the scope of what/who is accounted for in collaboration looking beyond human-nonhuman duals and towards larger arrangements of people/societies and things/infrastructures. These arrangements may also take the place of different temporalities, to better understand the trajectory of these collaborations. Similarly, we aim to study how the placement of a designed technological "thing" into these entanglements might cause them to unfold over time, allowing new forms of coproduction and cohabitation to emerge. This is especially important in considering the environmental impact of manufacturing and building new technologies, a comment that was raised by our reviewers. Prior to building more technological things, we see value in investigating new forms design inquiry and storytelling that help us traverse boundaries of the natural and artificial—whether that takes the form of studying fungi-built environment relations or relationships between mycelium and visions of ubiquitous computing. There is much more potential for collaborative survival to help designers explore territories that surpass people and things.

CONCLUSION

In this paper, we introduce the metaphor of collaborative survival to describe how human life is dependent and entangled upon the health of other species. We then situate the collaborative survival within existing HCI research as a way to address related work and also to see where it can contribute in the realm of design. We then describe prototypes (HSI, Data HarVest, and Spore Stepper) that seek to re-envision human-fungi relationships in the context of a mushroom foray as examples of how collaborative survival can be implemented in design. Three concepts emerged from these designs, *engagement*, *attunement* and *expansion* that provoke acts of noticing, an important tenet of collaborative survival. The process of building tools for collaborative survival shows potential as ways of how wearables can be used to reshape our perspectives of natural systems. In building these objects around the practice of forays used in mycology, the study of fungi, not just as contextual framing but as extended metaphor, these objects pose to become a step towards forming these alternative mutualistic relationships with humans and nonhuman others using technology. Speculative yet plausible, critical yet pragmatic, the tools suggest for a future that can already exist here and now.

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