Felt Experiences with Kombucha Scoby: Exploring First-person Perspectives with Living Matter

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Figure 1: Sensory engagement probes designed following felt experiences of growing and interacting with Kombucha Scoby—a microbial biofilm. From left to right: watching probe for following the biofilm growth, listening probe for hearing the Kombucha's fermentation, and touching probe for directly interacting with the Scoby.

ABSTRACT

Designing with living organisms can offer new perspectives to design research and practices in HCI. In this work, we explore first-person perspectives through design research with Kombucha Scoby, a microbial biofilm. We began with a material design exploration, producing digitally fabricated and crafted samples with Scoby. As we noticed our felt experiences while growing and working with Kombucha Scoby, we shifted towards a reflective autoethnographic study. Through reflective writings, we followed sensory experiences such as hearing the Kombucha fermentation, touching the Scoby while harvesting it, and watching the slow growth of layers over time. Subsequently, we designed "sensory engagement probes": designed experiments that bring forward new connections and communicate our process, motivations, and tensions that emerged while engaging with the organism. Lastly, we discuss how such design research can inform material design with living matter by creating space to contemplate "life as shared experience" and more-than-human design perspectives.

CCS CONCEPTS

• **Human-centered computing** → **Interaction design process and methods**.

KEYWORDS

felt experience; living matter; design research; sensory engagements; autoethnography; kombucha scoby

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1 INTRODUCTION

The Human-Computer Interaction (HCI) community has increasingly acknowledged the importance of the users' felt experience of interacting with technology [78, 83]. Given its sensory and emotional engagement, *felt experience* is thought as best captured

through users' first person perspective [47, 96], and in recent years, HCI researchers have incorporated their own first person perspective of related felt experiences throughout their design process. Capturing the account of the designer's first person perspective (i.e. autoethnography) not only supports the designer's empathetic understanding of users, but also enables novel design insights that wouldn't be reached otherwise [96]. Such research perspectives fall under the broader phenomenological research approach, which emphasizes the value of subjective accounts for interpreting the world [48, 96, 103, 104]; designers' observe their own emotional, sensory, and meaningful experiences, and utilize them for deriving insights and forming knowledge.

Notions of the body as a *tool-to-design-with*, and embodied experiences have also been used as subjective, emotional, and sensory accounts to derive insights upon which design decisions can be made [45, 47, 50, 78, 81]. Bodily experiences in particular, articulate the role of the body in making sense of the world, as reflected by soma concepts and somaesthetics [47], embodiment theories [60, 82], and Gendlin's experiential phenomenology and focusing method [35, 36]. Such experiences elicited during the design process are especially rich, multimodal, often ambiguous, and not simply captured through words [96]. Hence, articulating such tacit felt and sensed experiences requires a shift in our perception of design as a strictly cognitive effort, towards understanding design as a holistic mind-body practice, where *designers' bodies and not just their minds are present and key* [77, 88].

The reflective, experience-centered qualities of autoethnography and bodily experiences have the potential of offering new insights to works of BioHCI and "design with living matter" [59, 70, 84, 93]. Such biology-related emerging topics in HCI and interaction design, have offered novel bio-based materials, interactions, systems, and specifically discussions around sustainability [6, 40, 68, 84, 90, 93]. However, BioHCI researchers have yet to bring attention to the subjective, felt experiences a researcher holds when observing their own engagements with nonhuman bodies (i.e., living matter).

In this paper, we offer this novel perspective of design research in the context of BioHCI. We present an autoethnographic account of our *felt and sensed experience* noticed and captured throughout our long-term expanded experience when designing with Kombucha Scoby, a microbial biofilm grown in tea from bacteria and yeast. Using bodily sensing and action as a central modality of observation and experience, we set out to bring attention to the connections and communication we were building with the Kombucha Scoby. Specifically, when working with bio-based and living materials, sensations of touching and moving, smelling, and hearing, couple us closely with the material, organism, experience, design opportunities, and consequently - ourselves [84].

We were first drawn to working with Kombucha Scoby due to its accessibility (low cost, available in supermarkets, at-home grown), and its *materiality* that lends itself to physical crafting, making it suitable for "beginner biodesigners". Our initial motivation was to explore the Kombucha Scoby design space by experimenting with fabrication and crafting techniques and eventually to design an artifact or interface made out of Kombucha Scoby. However, this motivation shifted after 3-4 months within our exploration, as instances that exposed and brought our attention to the Kombucha's *livingness* [56] led us to *turn inwards* [49, 50] for reflecting on our felt experiences with the organism and on our own design practice. We followed our felt experiences through an autoethnographic account of reflective writings and creating "sensory engagement probes", a making practice of designerly objects that manifest the inner dialogue of the autoethnographic account. The first author (FA throughout the paper) conducted the autoethnography by following specific sensory experiences with the Kombucha Scoby (such as listening, watching, and touching), documenting events, thoughts, and emotional insights that arose, and further echoed and engaged with such tensions and points of connection in the design of the sensory engagement probes.

In this autoethnograpic study, we take a designer-researcher stance [89], and investigate our felt experiences with the organism during the design process. We contribute a novel perspective and account in the context of BioHCI, introducing a case study of decentering the narrow human-centered goals that exist in design processes, and incorporating the organism's livingness as valuable input and direction. We present our design journey including an initial material exploration of Kombucha Scoby, and the shift from "designing with living matter" to a "design-with" [111] inquiry. In this inquiry, we center our subjective, felt experiences, in order to elicit emotional responses and critical reflection on the process of designing with Kombucha Scoby. Finally, we draw from this felt, reflective practice or repertoire [111] and propose designing sensory engagement probes: a practice of designing objects for *being present* with nonhuman counterparts (in our case Kombucha Scoby) through sensory experiences that might surface during growing, caring for, and designing with organisms. The sensory engagement probes reveal the interconnectedness [91, 101, 111] present between us, the human-designer and the nonhuman, the organism-designer. We demonstrate this with three sensory engagement probes: a listening probe, watching probe, and touching probe; all which emerged from reflecting on our sensory experiences with Kombucha Scoby, and prompt us to further engage with unique felt sensations.

Our work can be read through the lens of Research-through-Design, and the broader range of works in HCI that value the creating of design artifacts as a means to uncover new knowledge that could not have been arrived at otherwise [4, 19, 29, 34, 61, 94, 115]. We were inspired by other works in HCI that have used Kombucha Scoby as a design material [69, 87, 92], and even more so by works that use design to address collaboration and communication between the human and the nonhuman other [10, 74]. In the remainder of the paper we: (1) situate our work amongst HCI and design research works, (2) present our methodology and research approach, (3) provide an overview on the nature of Kombucha Scoby, (4) report on the fabrication and craft practices we found to work with Kombucha Scoby, and (5) offer an autoethnographic account (including reflective writings and the design of sensory engagement probes) following our felt experiences with Kombucha Scoby.

2 RELATED WORK

2.1 Designing Interactions with Livingness

Initially powered by the DIYBio movement that opened access to complex laboratory experiments [62, 64], engaging with biology

has been an emergent trend within HCI research [63, 65, 66]. New opportunities for interaction design rise from the livingness of the organisms even when they are at microbial scale [56, 59, 84, 93]. For example, biotic games [15, 58, 112] such as Trap it! [71] and Pac Euglena [67] use the microalgae Euglena in a setup similar to digital games, however engaging the player with microscopes and light — controls that are specific to the organism. Moving towards direct interactions with the organisms, Ofer et al. explore the physical interactions with bioluminescent algae within three different environments designed for the organism [90]. They challenge human-centered design when designing with living matter; inspiring an organism-centered approach based on an increased awareness of the livingness qualities of the organisms [56, 84, 93]. Biological processes, such as fermentation of kombucha Scoby [100] or genetically engineering yeast [105] and bacteria [2], were shown to provide a platform for further recognizing the need to frame our relationality with nonhuman microbes. Finally, Lu and Lopes investigate designing care-based interactions by integrating living slime mold in the functionality of an interactive device [79]. They explore how physical care for a living organism embedded in a device can change user-device relationships.

In this work, we further engage with the livingness of Kombucha Scoby through an autoethnography study of our felt bodily experiences. Following HCI's interest in more-than-human perspectives [16, 31, 91, 101, 111], we turn inwards and reflect on experiences that elicit *noticing* the organisms' livingness, potentially re-situating the organism as an active entity in the design process (as opposed to being a manipulatable material), and reveal latent human-nonhuman relations.

2.2 Designing (for) Bodily Engagement

Soma design recognizes the significance of the human body as a whole ("soma") in the design process, encouraging a holistic engagement with the material and design process [47, 49, 50]. As a large body of work in HCI research, soma design acknowledges that a first person, felt engagement, allows us to touch the complexity and nuances of bodily experiences that are often lost when designing solely through a visual viewpoint [47]. For example, artist and researcher Thecla Schiphorst explores the concept of self-evidence through a wearable art installation that enabled self-to-self and self-to-other connections through movement improvisation, location discovery, and mirroring [97]. Schiphorst takes an embodied approach of accessing potential experiences through somatic sensibilities for evaluating technological interaction design. Inspired by and designed *for* soma design is Soma Bits, a collection of devices that enable felt interactions, overcoming language articulation barriers in evoking felt experiences [113]. Using heat, vibration, and shape-changing actuators, Soma Bits are designed based on feeling connected, embraced, and in correspondence as experiential qualities that facilitate soma design with interactive materials. Karey Helms further explores felt experiences from a maternal point of view [43]. Reflecting on physical and social discomforts and on designing with, for, and among more-than-human bodily materials, Helms uses creating as sense-making efforts to design clothing that transforms with the body, e.g., a knitted bra that accommodates the variation in the breast size, a nipple-shaped fiddling object for the baby made of maternal milk.

In another realm of bodily engagement, Boer et al. reframed self-tracking as cultivation of ones own microbes, through a mobile kit that enables daily collection and observation of gut bacteria [10]. Their work brings a physical and intimate dimension to self-tracking, a process usually implemented using digital data. However, in this form, monitoring data takes the form of nurturing, care, and wonder of self, building a longer-term relationship with the self. Framing the concept of multispecies as collaborative survival, Liu et al., designed wearables for mushroom foraging that allow for direct engagement with the environment, e.g., requiring the user to insert their fingers into the soil for a direct moisture sensing [74]. The tools were designed to extend the body to directly interact with the environment and provoke one to *notice and reflect* on the complexity of living things that imprint over time and space [22, 33, 72–74, 106].

Aligning with soma design that invites examining and iterating on sensation, feeling emotion, and subjective understanding [57], in this work, our bodies and minds are equally engaged in designing with and understanding the organism. Kombucha Scoby is not an inert material, it is alive; prompting us to physically engage with caring for it, harvesting it, crafting with it, and connecting with it. We formed a personal practice of *noticing*, contemplating about the organism's qualities and behaviors, and our own as well.

2.3 Sensory Experiences

Growing and interacting with the Kombucha Scoby brought forward unique sensory experiences. With HCI's shift towards recognizing the body as a site to design for and design with, a specific body of work focuses on addressing *rich sensory experiences*. For example, Klefeker et al. introduced Autonomous Sensory Meridian Response (ASMR) — a euphoric tingling sensation — as media that has the ability to inspire aesthetic experiences in HCI [61]. Since rich sensory experiences might be ignored or suppressed due to social norms, Dobson designed wearables that enable expression of deep emotions in public, such as a pillow that absorbs loud screams and gloves that cover physical expression of anger and aggression [25]. Dobson also developed Blendie, a blender transformed into an interactive device that interacts through sound, that works (or perhaps responds) according to people's growls encouraging them to perform uncovered gestures and sounds that may reveal hidden emotions and thoughts [24]. This interface and mode of interaction may also provoke discomfort in a foreign modality of communication, and discomfort in sensory overload. Discomfort itself has been proposed by Jones et al. to be used as a *material* in HCI research, as it may lead to increased personal development [55]. Other works emphasize the possibility of *leaning into* discomfort in a situation (specifically embodied ones) in order to evoke and support critical reflection [41], and even reach insights for designing affective technology [110].

When working with the Kombucha Scoby, we noticed that we relied on our own sensory experiences of the organism, which served as an implicit communication means. At times, we experienced discomfort - first stemming from interaction with a foreign living

organism that presents an unfamiliar and even irritating appearance (strong sour smells and a rubbery, flesh-like texture). Further in the interaction, the discomfort becomes more apparent when the *shared experience of life* [2, 56, 84, 90] evokes an inherent desire to communicate with the Kombucha Scoby—communication that is not possible through the usual means of humans (e.g., spoken language). Hence, in this work, in order to overcome and even further explore such deficiency, we turn to design. Research through designed forms, as opposed to verbose, explicit forms of media, has the reflexive potential "to bring forward new insights and to communicate experiences in a more abstract way" [19], offering a diversity of expressions and interpretations [3, 20, 99]. Through the case study of designing with Kombucha scoby, we draw from the complexity and discomfort of *felt experiences*, and design sensory engagement probes to create other, perhaps nonhuman-centered communication modalities.

2.4 Decentering the Human in Design and HCI

HCI and design researchers have voiced concern of the short-sided nature of human-centeredness in design, and have responded to this concern with calls for exploring human-nonhuman interconnectedness and decentering the human in design [9, 23, 31, 91, 111]. Ron Wakkary presents a perspective that positions human-centered thinking to be not the answer to the main problems of the Anthropocene (e.g., climate change, extinction of other species, etc.), but maybe part of the problem [111]. He points out that "design is exploitative in its relations to nonhuman species and materials that are mined for and reduced to human use", and questions what might a posthumanist understanding of design be? Drawing from the posthumanist thought of humans and nonhumans sharing the center [11], Wakkary proposes a more-than-human design practice of *design-with* [111]. He additionally calls for developing repertoires - actions or tools that designers could take to better represent the nonhumans involved.

Wakkary's account echos the challenge of decentering the human in design practices [9, 22, 23, 91, 101]. Several researchers have acknowledged the inherit limitation of being human and the human subjectivity when attempting to decenter the human in design. Thing-perspectives for example, have been developed as strategies to counter human perspectives, acknowledge the power of things, and invite the participation of nonhumans [7, 17, 37, 38, 51, 52]. Other perspectives have advocated, similarly to posthumanist views, that decentering the human should strive to "blur the boundaries between people and things, emphasizing the interconnectedness that is inherent in human/nonhuman assemblages" [101], as opposed to excluding the human perspective and place an animal or other perspective at the center of design thinking. Posthumanist philosopher Rosi Braidotti argues that it is not that human subjectivity disappears, but rather a posthuman subjectivity arises that is interdependent and interconnected with nonhumans [11]. Specific works in HCI have explored methods such as Anna Tsing's "arts of noticing" for stepping out of human perspectives [9, 74, 76, 95, 109], investigated nonhuman agency in the context of digital fabrication [21] by questioning "who or what should have agency or control in the making process", advocated for design to cultivate "a space to facilitate nature's participation than trying to exclude it from design" through theories of natureculture [75], and probe potential repertoires [91, 111] for increasing the participation of nonhumans in design research practice in the context of weaving and craft [91].

This work builds on the body of work addressing more-than-human design approaches and attempts of HCI to decenter the human. While autoethnography fundamentally focuses on events through the lens of the first-person, human experience, we direct our autoethnographic observations and reflections towards the relationship between ourselves and the Kombucha Scoby. Through our own human perspectives (e.g., somatic and felt experiences) we make room for the unspoken account of the organism, thus bringing forward the interconnectedness in human-nonhuman assemblages. Specifically, the sensory engagement probes are objects designed to viscerally emphasize the organism's livingness and agency, call attention to the human-organism relationship, and reveal our human-centered leanings and biases.

3 METHODOLOGY

In the following section, we set our motivation in this work, present an overview of autoethnography in HCI, and present our autoethnographic research method.

3.1 Motivation

This work began in fall 2020, during a graduate-level course the first author (FA) enrolled in. The course offered an experimental exploration of several fiber craft practices (e.g. spinning yarn, weaving, embroidery, etc.). FA chose to explore such craft practices with Kombucha Scoby as the base material since Kombucha Scoby has been utilized as a textile in the past [69]. However, in addition to applying fiber craft practices, FA was interested in experimenting with new techniques for crafting with Kombucha Scoby. Essentially, the initial motivation was to broaden the Kombucha textile design space by *exploring fiber craft practices on a growing textile.*

Since Kombucha Scoby takes several weeks to grow until its structure is robust enough to be handled (i.e., the biofilm formed isn't too fragile when removed from the medium), FA got frustrated when she didn't have enough "material" for completing class projects. Despite setting up several bioreactors (approx. 10 growing at a time), the yield still wasn't a consistent amount of robust, fast-growing Kombucha Scoby. Every microbial culture had a different growth rate and produced different Scobies: all of which led to a great amount of uncertainty in the process that FA was trying to replicate. A workaround would have been to buy already-grown Kombucha Scobies from local grocery stores or online. However by doing so, FA would have lost the opportunity to "tune" (as much as possible) the Scoby's properties (e.g., thickness, numbers of layers, color, texture) since these properties can be affected only during the growth of the organism. In addition, FA had recognized that being involved in the organism's growth was meaningful as it provided valuable insights about the organism itself. This in turn, drove FA to the realization that *making with a growing organism* might require a different process and practice than when making with traditional digital fabrication materials.

Through reflection and discussions with the research team, FA's design approach shifted. In reality, the Kombucha Scoby itself was

dictating not only what was feasible to fabricate and create, but also the progress and timeline of the project, which led the research team to "re-position" the Kombucha Scoby in conversations as a more active component in the design process. Considering the livingness qualities of Kombucha Scoby (e.g., the uncertainty of its growth: how fast the layer forms, how robust is, what color will the layer have), the research team agreed that an approach that positions the Scoby as a "material" reduces the organism in a way, restricting it from being perceived as living and active, and sets it to be seen and handled as inanimate, manipulatable matter. In other words, the research team agreed that there was nothing wrong with making and crafting with Kombucha Scoby, however, here was an opportunity to critically reflect on our goals and motivations (withstanding the sole goal of making something, but perhaps also developing a better understanding of the organism and a better practice). Essentially, this shifted the perspectives and project goals: from using Kombucha Scoby as a fabrication material for crafting, to perceiving Kombucha Scoby as a living organism to *design-with* [111]. FA's personal engagement with growing and caring for the Kombucha Scoby steered the search for an appropriate research method to document FA's engagement, process, insights, motivation, and experience, leading the research team to agree on first-person methods, specifically autoethnography.

3.2 Autoethnography

Autoethnography, a qualitative research method, aims to document and study the researcher's first-hand experience [26, 28, 102]. The researcher essentially becomes both the research *participant* and the *investigator*. The researcher brings forward descriptions of events and their own emotional account to illustrate a particular personal awareness and experience [26]. This first-person perspective affords sharing voices that might not have been heard, and insights that might have been too subtle to elicit with other research methods. As Margot Duncan emphasizes, the researcher must be fluent in "the art of self-reflection" [26], and such self-reflections must be documented in such a manner that corresponds to the research setting. For example, Ellis describes art-based autoethnography as a way of practicing embodied inquiry and experimenting with self-reflection [28].

3.3 Our Autoethnographic Approach

Autoethnography has been used in HCI as a method to document, understand, and refine a design when designing for oneself [86], it has been specifically used for somatic or embodied design [46], and also has served as a tool for prompting critical reflection on the design process [18]. We planned our autoethnographic approach with the motivation of: (1) being attentive to the sensory experiences present when growing and designing with Kombucha Scoby, (2) reflecting on our design process and motivations, and (3) notice other subtle insights that may emerge through noticing subjective and emotional events.

We conducted the research mostly in our HCI lab where FA grew most of the Kombucha cultures (with the exception of two cultures she was growing in her home), and spent time in daily. We drew inspiration from traditional biology lab documentation and kept a lab journal (similar to field notes [54]) to describe events and experiences. We used this writing as a reflective tool and engaged in making activities as part of the autoethnographic practice [9], which we specifically name sensory engagement probes. We also used digital tools (e.g. audio recording, video recording and photography) to capture and share the sensory experiences, which uncovered new sensory experiences that informed our reflections and designing the sensory engagement probes. Our sensory experiences served as the starting points that prompted observing the specific experience, attempting to capture it, sharing and reflecting on it with the research team, and designing sensory engagement probes for re-eliciting the felt experience in an iterative manner. We subsequently followed felt experiences that informed the design of the probes for further involving ourselves in, reflecting with, and re-eliciting the sensory experience.

In the following sections, we introduce the process of growing and caring for Kombucha Scoby, and then proceed to unfold our research in chronological order: first we describe our initial material exploration (i.e. fabrication explorations with Kombucha Scoby *as a material*) and follow with presenting our autoethnographic account with quotes of FA's reflective writings and creating sensory engagement probes.

4 GROWING KOMBUCHA SCOBY

In the biological sense, the term Scoby (symbiotic culture of bacteria and yeast) defines the whole Kombucha medium: the biofilm as well as the liquid culture present in the tea. However, we will use the term in this paper in its cultural meaning, i.e., referring to the biofilm it creates. The yeast in the medium metabolizes sucrose to ethanol and CO_2. The naturally occurring acetic acid bacteria further metabolize ethanol to acetic acid and excrete microbial cellulose, which forms the typical floating cellulose biofilm [8]. The microbial cellulose biofilm becomes visible within 3 days to 2 weeks, depending on the nutrient level and the environment temperature.

4.1 Microbial Cellulose

Cellulose, the main ingredient in paper, is the most abundant polymer on Earth, found primarily in wood, hemp and cotton [80]. While cellulose has been leveraged for papermaking for centuries, it was only in the nineteenth century that the advances in biochemistry enabled the identification of the polymer, and more recently, the discovery of *microbial* cellulose produced by bacteria [80]. One such microbe is Acetobacter, a type of acetic acid bacteria co-habitating within the homes of humans and being responsible for "spoiling" the good wine into vinegar. Acetobacter can be isolated from the nectar of flowers and it is brought into homes by fruit flies, where it ferments sugary liquids producing ethanol. Acetobacter can adapt to live in symbiosis with yeast (a fungus commonly found in human environments), and form a co-culture abbreviated Scoby (Symbiotic Culture Of Bacteria and Yeast). Originally a method of preservation [8], Kombucha has re-emerged since the 2000s with the rise of attention to probiotics in the western world and is cultured intentionally, fermenting sugary teas into a popular drink called Kombucha.

Professional biological equipment is not necessary for growing Kombucha, making it easy for designers that don't have access to a biological laboratory to grow it. We started our culture from

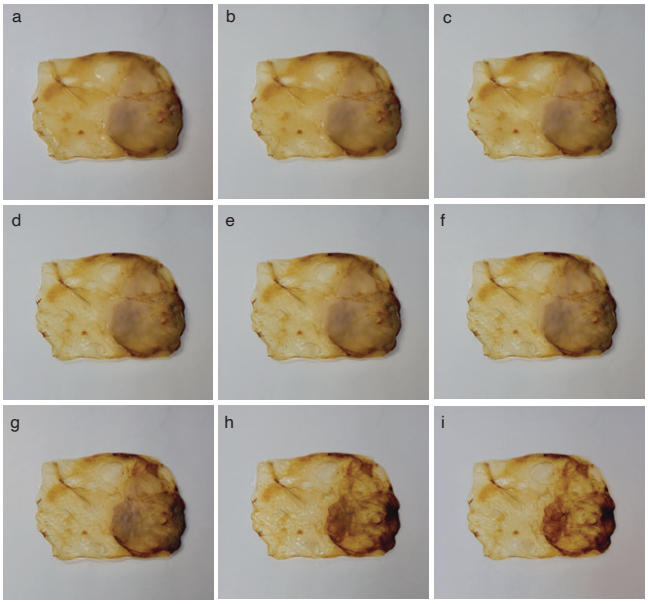

Figure 2: Kombucha Scoby harvested and dried over time. a) Taken immediately after Scoby was set to dry, b) taken after 4 hours, c) taken after 7 hours, d) taken after 10 hours, e) taken after 14 hours, f) taken after 18 hours, g) taken after 22 hours, h) taken after 24 hours, i) taken after 28 hours.

Figure 3: From left to right: the starter Scoby culture immediately after being fed with a black tea medium, the harvested Scoby biofilm after two weeks of growth, the biomaterial resulted after drying the Scoby over 4 days.

a living culture found in commercial Kombucha drink bought at the university's cafeteria (GT's Classic Raw Kombucha [30]) and used simple glass containers for culturing. As shown in Figure 4, we divided the starter culture between several containers and fed it weekly by doubling the culture volume with a sweet black tea medium (a solution of 10% sugar concentration, 1 black tea bag per 500 ml seeped for 40 minutes). Our bioreactor (Figure 4) uses a heating pad to provide the optimal growth temperature (30°C) and containers that allow gas exchange.

Handling the black tea medium at the right temperature plays a key role in feeding the culture, as the medium solution needs to be boiled to reduce contamination, but also cooled down to 30°C to avoid boiling (killing) the starter culture. After being fed, the culture grows a biofilm, commonly known as Scoby. While growing, the culture forms new Scoby layers at the top, thickening to a robust layer size within 1 to 2 weeks. During the following feeding cycles (on a weekly basis), we learned that the Scoby shape and thickness can be easily disturbed while pouring the medium. If poured too fast, the existing Scoby would sink down in the liquid culture, and the new layers that form do not connect in a strong mesh with the previous layers. We learned that feeding the Scoby requires handling it with care; by gently lifting a corner of the formed layer and gently pouring the medium under the Scoby biofilm. As shown in Figure 3, the bacterial cellulose transforms from the liquid culture, to a biofilm that can harvested, and eventually dried into a paper or leather-like biomaterial (see Figure 2). The biofilm is harvested by manually removing it from the liquid culture and left to dry.

Figure 4: Bioreactor for growing the Scoby. Optimal fermentation and Scoby growth occur at 30°C.

5 INITIAL MATERIAL EXPLORATION

In this section, we describe the fabrication lessons we learned while exploring crafting with Kombucha Scoby as a growing textile. Although an elaborate design space was not the ultimate goal of this work, this initial exploration initiated a relationship with the organism. The following initial material and design exploration served as the informal introduction to growing and and caring for Kombucha Scoby, in addition to crafting. All of our sensory and felt observations that stemmed from the physical handling of Kombucha Scoby led us to later on re-situate the organism not as a material, but rather as an *active entity* in the design process.

After harvesting the first layer of our grown Kombucha Scoby, we started to explore craft and digital fabrication techniques such as sewing and embroidering, layering, laser cutting and engraving, and molding. The nature of the exploration was *divergent*: the university course FA was participating in prompted testing some of the craft and fabrication techniques. The other craft and fabrication techniques we arrived at, emerged as opportunities the Scoby presented us with following previous tests. Aside from origami techniques with Kombucha Scoby [87], we were not aware of any works that provided a Kombucha Scoby design space exploration.

We used the Kombucha Scoby in two different forms: living and non-living (dried) as shown in Figure 3. The living Scoby was freshly harvested from the liquid, giving it a wet and and a rubber-like feeling. The non-living material was obtained after allowing the fresh Scoby to dry over several days until it reached a feel of thin paper or, if thicker, of leather (for example, the woven sample in Figure 8 is made with 2 different Scobies - the base (lighter) is thin like paper, and the individual strips (darker) are sturdier like leather).

We experimented with adding oil to result in a more flexible material. Not adding oil gave us a brittle material, that expressed fragility and needed to be handled with care. The concentration of the tea in the liquid medium, the homogeneity of the liquid solution, the thickness of the fresh Kombucha Scoby, the surface it was dried on: all of these conditions can play a role in the color and opacity of the dried material. We chose to not be intentional about any of these parameters, but instead allow the spontaneity of the dried material to come through. Throughout the paper we keep the variety in color and opacity of the samples as 'natural' and spontaneous as they came from the liquid medium.

5.0.1 Sewing and embroidering. As shown in Figure 5, we experimented with sewing and embroidering multiple layers of Kombucha Scoby. Wet Scobies are advantageous for sewing due to their flexible, soft properties that allow for an easy penetration of needles without breaking the Kombucha Scoby (as sometimes happens when penetrating through dry Scobies). In addition, the wet Kombucha Scoby can dry around and secure the thread in its place, essentially bonding to the thread and forming one uniform structure. When embroidering a relatively thick Kombucha Scoby (e.g. at least 7.5 mm thick), it is also possible to make use of the layers within the biofilm. A Kombucha Scoby that has been growing for several weeks (and even months) can show the generations of layers that form over time as they are slightly misaligned and can be easily be peeled off. With hand-embroidery, we can insert a foreign material (e.g. thread) into the Kombucha Scoby by needle and control in between which layers the thread is placed (see Figure 5). For example, if using multiple conductive threads, we can avoid different threads overlapping (causing a short) by inserting them over and under the layers, essentially using the layers to act as insulation and separate different threads. Similar to weaving with conductive materials and creating e-textiles, the Kombucha Scoby acts as a non-conductive substrate that we can strategically place several conductive materials in.

5.0.2 Layering. Through further experimentation, we learned that when placing multiple Scobies on top of one another, they bond when dried together into one piece (see Figure 6). The layering technique can be used for aesthetic purposes, e.g., to tinker with colors and opacity like in Figure 6, or for functional purposes, e.g., to obtain a thicker, sturdier material or to encapsulate a foreign material in between the Kombucha Scoby layers.

An example of the latter is the capacity sensor we created by layering graphite powder in between two Scobies (Figure 7). We used 0.1 grams of graphite powder and applied it on top of one Kombucha Scoby using a stencil to create the specific shape of the sensor. We then allowed the Kombucha Scoby to partially dry, and while still drying we layered it with another Kombucha Scoby on top. We wired the sensor using a conductive thread placed in between the Kombucha Scoby layers and in contact with the graphite powder as seen in Figure 7. As mentioned before, a similar capacitive sensor can be achieved using embroidering, with the difference being that layering allows for more refined control over the placement of the conductive and the insulator materials.

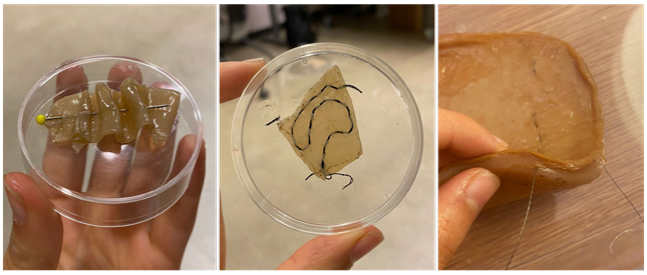

Figure 5: Experimenting with sewing and embroidering Kombucha Scoby layers. We found that living Kombucha Scoby is easier to penetrate with a needle than dry Kombucha Scoby. Two layers sewn together while wet tend to dry around the thread and secure it tightly. A Kombucha Scoby can be composed of multiple generations of layers that are connected strongly in the middle and loose at the margins. By using embroidery techniques, the layered affordance of Kombucha Scoby can be leveraged to embed different functions (e.g., conductivity or insulation).

Figure 6: Different Scobies are layered and dried together. We notice the interplay of colors, textures, and transparencies.

5.0.3 Laser cutting and engraving. We experimented with laser cutting as a technique that can help create new forms from the material. Since Scobies dry out to be thin layers of material, the laser cutting settings and properties are defined at low values, similar to the ones custom to set when laser cutting paper. One particularly successful laser cutting attempt was a woven sample made of 2 laser cut Scobies (see Figure 8). Vertical lines (1 cm apart) were laser cut along the "base" Kombucha Scoby (the lighter one), and the second Kombucha Scoby (the darker one) was laser cut into 0.9 cm wide strips. We wove the darker strips into the "base" Kombucha Scoby

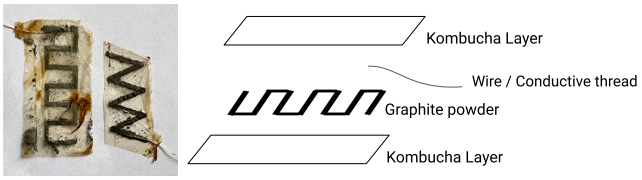

Figure 7: We used the layering technique to create a capacitive sensor. The first layer of Kombucha Scoby is uniformly coated with graphite powder using a stencil to define the zig-zag shape of the capacitor. While still drying, another Kombucha Scoby is layered on top, insulating the graphite and bonding the two Scobies into an electronic component. We used conductive thread to wire the Kombucha Scoby sensor and test its functionality via an Arduino microcontroller.

in a basic tabby pattern. The result was a woven structure that was sturdier than the thin base Kombucha Scoby, but more fragile than the Kombucha Scoby the darker strips were laser cut from.

Figure 8: Two layers of dried Kombucha Scoby, laser cut and woven together in a tabby pattern.

5.0.4 Molding. Kombucha Scoby lends itself to different molding techniques during the drying process. A wet Kombucha Scoby can be placed and dried on top of a 3D structure and it will take the structure's form while drying. Molding techniques can be used for giving Kombucha Scoby a different form, especially a tri-dimensional shape, since it loses volume when liquid evaporates during the drying process. In Figure 9, we covered a large mixing bowl with a very large Kombucha Scoby that had been growing for several weeks and allowed it to dry. The Kombucha Scoby dried in a dome-like form, embracing the curve of the bowl. Similarly, we placed a wet Kombucha Scoby on the grid-patterned board of a Blokus game. When it dried, the Kombucha Scoby received the grid-like texture, as the checkered lines imprinted on the material (Figure 9 right image).

Figure 9: On the left: Kombucha Scoby that was dried over a bowl and molded into a dome. On the right: Kombucha Scoby that was dried on a grid-textured surface.

We further experimented with molding through weaving foreign materials such as wires, threads and strings into the Kombucha Scoby. By manipulating those materials and allowing the Kombucha Scoby to dry in the woven structure, we were able to achieve other tri-dimensional forms (see Figure 10).

Figure 10: Nontraditional molding by weaving foreign materials such as wires and strings with the Kombucha Scoby. Here we present four woven-molded samples.

6 SENSORY ENGAGEMENT PROBES

The initial material and design exploration, detailed in the previous section (Section 5), served as an informal introduction for FA to growing and crafting with Kombucha Scoby. As FA engaged in hours of "troubleshooting" the Kombucha Scoby's growth and experimenting with crafting techniques, she became more familiar with the organism's growth process: how and when to feed it, what a healthy layer looks like, when a new layer should be expected, etc. All of these nuances in the Scoby's growth were difficult to predict reliably, as each microbial culture and each grown layer had different behavior and timeline. However, within that uncertainty,

during the research team's meetings, FA would describe the growth from her own *sensory point of view*: "the medium *looks* like it's starting to bubble", "I touched the Scoby and it doesn't *feel* like it's ready yet", "the surface *feels* smooth, almost rubbery", "the whole room *smells* like sour Kombucha".

The sensory descriptions became the language used when the research team discussed the work, and drove the investigation to focus on the bodily, sensed, and *felt* experiences. For example, FA would assess the health of the organism daily by *watching* and taking note of the amount of bubbles rising from the fermentation process, *touching* the biofilm layer to examine its texture and thickness, and bringing attention to the intensity of the sweet-sour *scent* of the Scoby to know when it is time to feed it again. During and after her engagements with the Scoby, FA shared the sensory experiences (i.e., what the culture looked like today, how the biofilm felt when touching it, how intense the sweetness or sourness of the smell was, etc.) with the research team. FA would recreate her own sensory experiences for the other researchers to experience, e.g., inviting them to see, touch, and smell the Scoby. These sensory engagements with the Kombucha Scoby became somatic ways of knowing and prompted us to design designing sensory engagement probes for furthering our own sensory explorations and experiences with the Scoby (see Figure 11).

We propose sensory engagement probes, designed experiments and forms to bring forward new connections (within our selves and with the organism) and to communicate experiences in a more abstract, but *felt* way. These objects act as metaphorical *extensions* of ourselves towards the organism, thus perhaps amplifying our sensed experiences when interacting with the organism. These objects are physically and conceptually situated between us (the human-designers) and the organism.

When designing the probes, we were guided by the unique sensed experiences that we became familiar with during direct interaction with the organism. We were more interested in personal outcomes of methods such as autobiographical design [86] in our research practice, rather than perhaps generalizable findings from a user study testing aspects of the interaction with the organism via designed objects. Thus, the probes were not designed for "users", but for our own experience and process, as we were interested in exploring our own connection and relationship with the organism via designed experiences with our senses. The question we held in mind was "how might we experience the organism in unfamiliar, sensory, and elaborate ways, possibly prompting connection and self-reflection?". Our goal was for the probes to prompt such experiences that would capture our senses and attention, and possibly lead us to new connections, attachments, and ways of noticing [13, 76]. The sensory engagement probes are not elaborate design applications per se, but rather resonate with notions of designerly prototypes: "things that give form or curate access to that which is difficult to speak about" [19] and speculative props [27]. Although we do not position the sensory engagement probes as speculative design proposals and as part of other worlds as speculative props do [27], the sensory engagement probes are subtle objects that help facilitate imagining and nudge towards alternative possibilities of design with living matter (see Figure 11).

We take a Reflective Design [99] approach when engaging in the sensory engagement probes design process. Our design considerations value *reflecting* on our process, our relationship with the organism, our motivations as a core design outcome. The designs also aim to bring "unconscious aspects of experience to conscious awareness, thereby making them available for conscious choice" [99]. In addition, we engage in such reflection through not solely a cognitive activity, but it is "folded into all our ways of seeing and experiencing" [99] through our designed probes. The reflection we aim for, follows the concept of Reflection-in-Action as outlined by Donald Schön [98]. Throughout the process of designing the probes, we were attuned to the Kombucha Scoby and its responses. Further, while using the designed probes themselves our attention was drawn to reflection as an active, in the moment, visceral process that imposes constant changes as experiences unfold.

In the next paragraphs, we present FA's autoethnographic account and process of following three main sensory experiences with the Scoby: watching, listening, and touching. Through writings, we describe the felt and sensed experiences that emerged, and the design of the sensory engagement probes.

6.1 Watching

The appearance of the Kombucha Scoby changes significantly both while growing a layer and while drying outside of the Kombucha medium. Growing cultures change from a translucent tea to a opaque, non-homogeneous liquid containing bubbles, a floating biofilm at the surface, and fine strips of older Scoby generations floating in the medium. Similarly, while drying, the Scoby biofilm changes its appearance from wet and rubbery to thin and paper-like (see Figure 2 for a time-lapse of drying Scoby over time). FA came into the lab everyday and looked at all the Kombucha cultures to see if maybe any of them had changed from the day before.

> *"I started a new culture on Monday, I combined living cultures from 2 "mature" cultures to grow a strong new one. It's been 3 days and there still isn't a visible layer growing. I know it can happen even just within a day at this point, so I'm waiting. "*

The growth of the biofilm is a slow process, occurring over several days, which makes it impossible to perceive while it is happening. For the first days of the culture growing a layer, FA found herself just *waiting*, which was also something to learn (or unlearn).

> *"I'm being very impatient, every 2 days I open the jars to check on growth and I [accidentally] disturb whatever layer has started to form at the surface with my movement. For some reason its difficult to keep a distance and I just want to see and feel a new layer. But of course me disturbing the growth won't help a layer form. It's interesting that these days are so ambiguous and I feel helpless because I just want to know if it [new growth] is working or not."*

On days that FA had come into the lab and seen some sign of a new layer, she felt as if the Kombucha had finally decided to give some visual feedback that it was doing well. Once the culture had passed those first few days and started showing a layer, FA was able

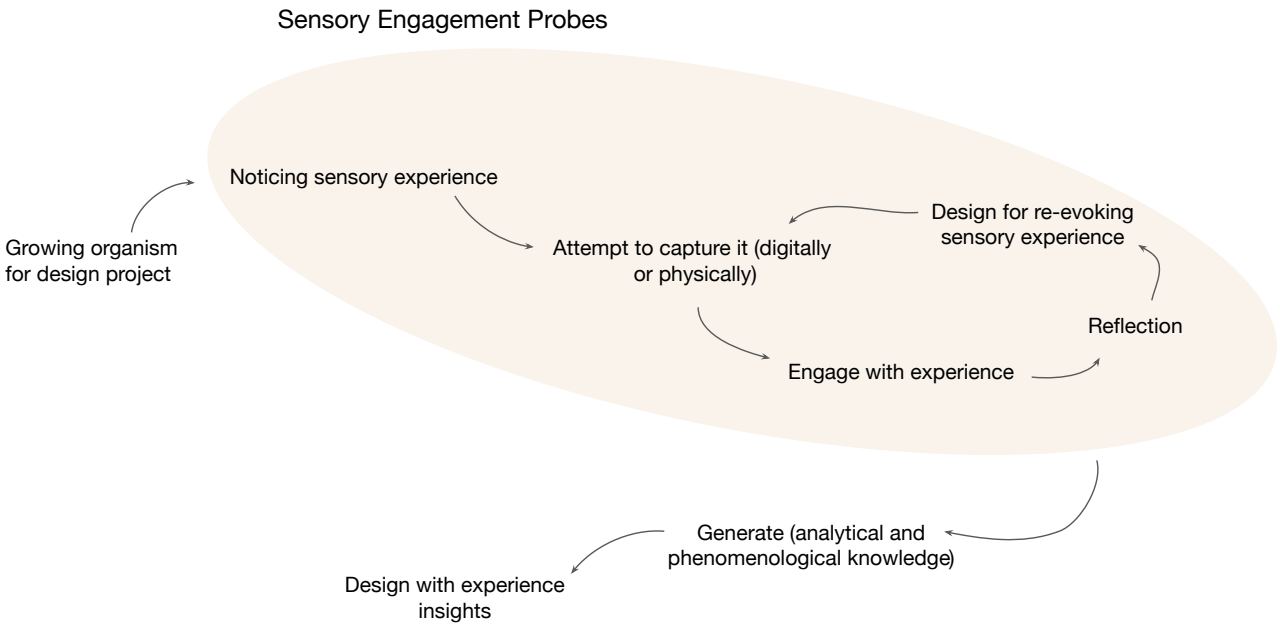

Figure 11: We offer the sensory engagement probes as a design practice to engage in as part of a broader design project or on its own. The designer should start with noticing their own sensory experiences, then attempt to capture and document the experience, leading to re-eliciting and reflecting on the experience and sharing it. The designer holds these experiences and insights as they design probes that evoke new but familiar sensory experiences. This process is circular, as the designed probes are meant to trigger another iteration and thus deepen the engagement and reflection of the designer. Eventually, the designer can move forward in the broader design project with the experienced insights.

to visually assess when the Scoby was robust enough and ready for harvesting and drying.

In order to further engage with the challenging feeling of waiting, FA attempted to capture the Scoby layer growth with time-lapse. FA knew that in order to capture a successful time-lapse, the captured object must stay in place, with minimal disruptions. This helped "discipline" FA to be patient and kept her from interacting with the organism for about a week. In addition, the waiting FA was struggling with suddenly became rewarding - after waiting days, FA had access to both a mature Scoby and an interesting documentation of the Kombucha's life FA hadn't had access to before.

> *"I set the Kombucha in a time-lapse setup and left it there for 5 days. I was very excited to come back and see the result and prayed that the camera didn't run out of battery or fall. When I set it up, I couldn't even imagine what I would get, but when looking at the time-lapse, I could see that the Kombucha changes so much! I never saw before how much of the culture evaporates and reduces volume, and I also never saw the subtle movement of the liquid over time. "*

FA became more and more interested in those days where nothing can be seen and all of a sudden - something changes. Those few days held the "hidden life" of the Kombucha, as FA knew something was happening, yet was not a part of "the secret". In many cases in biology, the human cannot clearly perceive the stage or quantity of the bacterial growth just by looking at the culture. In these cases, biologists use spectral sensors (spectrophotometers) - measuring how much light passes through a liquid culture which demonstrates the change in optical density produced by a higher concentration of bacteria to estimate bacterial growth over time [39]. FA was inspired by this use of light, as it (physically and metaphorically) illuminates what cannot be seen. Light as an interaction modality specifically, has been used in real-time displays and objects [44, 49, 85, 114], or as a slow agent that transcends the design over time [5].

Following this sentiment of *seeing the unseen*, we designed a watching probe (see Figure 12) - a back-lit surface to place Kombucha cultures on and watch the Scoby's biofilm slow formation and transition from translucent to opaque. Similar to spectral sensors, the probe shines light from underneath the culture. The light travels through the thickening Scoby layer and over time aids in illustrating the growth of the biofilm with its increased light absorbance properties. The probe was placed in the corner of the room, and served as a subtle, ambient reminder of the slowly-changing, living Kombucha Scoby.

FA used the watching probe (see Figure 12) to watch the subtle change in light diffusion over time as Scoby layers form at the surface and thicken over time. The probe was constructed from a $28cm \times 28cm$ light-emitting diode (LED) panel, an acrylic sheet, and 3d printed spacers for suspending the acrylic sheet on top of the LED panel. The LED panel coincidentally also functioned as a heating element that helped accelerate the Scoby's growth. As

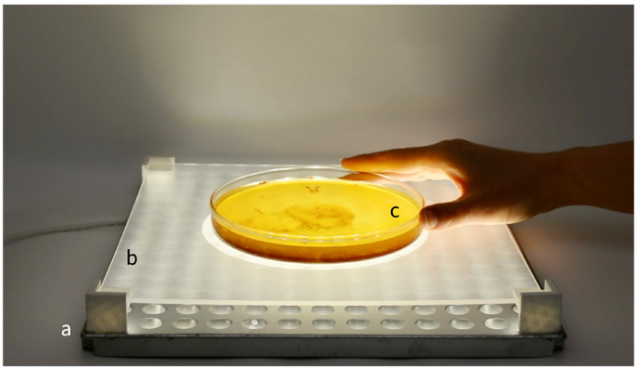

Figure 12: The watching probe is a back-lit surface for watching the slow change as Scoby layers grow over time. The probe consists of: a) a $28cm \times 28cm$ light-emitting diode (LED) panel, b) a slightly frosted acrylic sheet and 3d printed spacers for suspending the acrylic sheet on top of the LED panel, and c) the growing Kombucha medium placed on top of the surface.

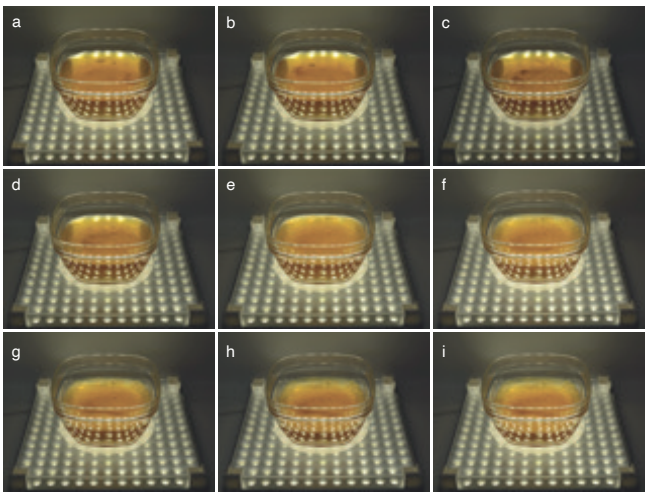

Figure 13: Change of the Kombucha Scoby growth over time on the watching probe. a) Taken immediately after the medium was poured, b) taken after 5 hours, c) taken after 24 hours, d) taken after 30 hours, e) taken after 40 hours, f) taken after 46 hours, g) taken after 52 hours, h) taken after 60 hours, i) taken after 70 hours.

the biofilm forms over the course of several days, the light shined from the probe fades; it becomes diffused when seen through the growing Scoby "filter". FA also used the watching probe as a time-lapse setup - Figure 13 captures the time-lapse over three days: light from the back row of LEDs permeates through the Scoby in shot 13 a, but becomes less and less visible in shots 13 e-i (see Figure 13).

Time and uncertainty are often seen as challenges and potential issues as organic processes operate on slower and often less predictable timescales than hardware and electronic materials for example [66]. However, this probe holds and embraces the notion of *slowness* [42, 89] as we continuously interact with it over time as the biological culture grows and changes, specifically over the course of at least 7 days. This probe honors the organism's time and process, contrasting the immediate visual feedback we are used to receiving from digital interfacing. Hence, prompting awareness to subtle changes and a slow unfolding as ambient displays [53].

6.2 Listening

The first instance of FA *hearing* the Scoby was a confusing event. FA arrived at the research lab early in the morning in order to attend a video call meeting; it was quiet all around, but there was a slight, continuous, unfamiliar noise. Doors opening and closing, footsteps, the air conditioning and other appliances produce noises that one gets used to in their regular environments. However, the slight hissing-like noise held FA's attention:

> *"It is so quiet in the morning that I could hear the tiniest noise. It sounded like someone is hissing very quietly but I am the only one here. I got up and moved around and could no longer hear it, but I heard it again when I came back to my desk. I realized that among the many jars and bottles of Kombucha brewing in our lab, one of the jars closest to me was making the noise... a glass jar with a metal clasp was releasing pressure. I know it isn't completely sealed since I once spilled Kombucha medium from a similar jar by accidentally tilting it to much. I forgot and remember now that I had "fed" this jar a few days ago, so I am guessing that the jar is releasing gas build-up from the fermentation bubbles. I quickly tried recording the sound on my phone, but it [the fermentation fizz] was too quiet to really capture."*

This specific Scoby jar was not airtight thus allowing for fermentation byproduct gas to be released. Although the jar mechanics strongly influenced the production of the sound, the event reminded FA that there was a living organism present. This encounter between FA and the Kombucha somehow made it seem more *real* to FA. Although audible, Scoby's sound was not loud enough to be captured by the phone. As the hissing continued, FA released the metal clasp and opened the jar, hopefully providing the culture with "fresh air":

> *"I am happy that the Kombucha decided to make contact with me. I know that's not exactly the case, but still the hissing jar is a reminder that the Kombucha is constantly changing, and LIVING. I wonder when and if I can catch it again in time. This makes me anxious to try to catch the next time this happens, and also catch the tiny fermentation bubbles."*

This sensory experience led FA to further search for sound experiences and imagine "what would it feel like to *listen* to the Kombucha"? After this first sound experience, FA was highly motivated to go from *hearing* to *listening* to the sounds of the Kombucha Scoby:

> *"Hearing sounds from the Kombucha culture was the most lively and "interactive" experience I have had with it. It is so satisfying that a part of me wants to feed the cultures every time the culture stops fermenting... but feeding every 3-4 days seems like too much, and I'm*

not sure it'll benefit the Kombucha's health. I feel like preserving a constant fermentation will be an act of entertaining myself, and might not be a kind motivation."

With this reflection, FA encountered a motivation that felt uncomfortable. FA tried to resist the desire to make the Kombucha "perform" unwillingly, like a puppet. After a few weeks, when it was time to feed the culture again, FA came back to the attempt of recording the sound of the fermentation bubbles. FA chose one of the "strongest" cultures (i.e. cultures that had been growing most consistently), fed it, and waited a day to see the fermentation bubbles (see Figure 14). Although the focus was to capture sound, the size (i.e. visibility) of the bubbles was a visual cue that helped FA assess if the fermentation audio could be captured. FA relied on this visual cue in order to avoid constantly opening the jar and disturbing the fermentation process.

"I made the kombucha food with more sugar than usual... about 1/2 a cup of more sugar, hoping that the culture would have a strong, visible fermentation. I borrowed some sound equipment from friends, and tried recording, but the air conditioning in the building made too much noise. My home might be quieter so I'm bringing everything home with me. "

FA used a Behringer UMC204HD audio interface and a RØDE M5 Condenser Microphone, all recommended by audio engineering colleagues. The setup was as follows: FA set an open jar (padded the jar so as to avoid extra noise cause by conduction through glass) of the fermenting Kombucha on the floor of the bedroom, and placed the microphone above it. The cables from the microphone ran to the room outside, were the audio interface was connected to a computer.

"Recording the fermentation fizz was nerve-racking. Everyplace I went, there was noise - I felt like I couldn't be alone with the Kombucha. My lab has other people in it and blasting AC, and my apartment has neighbors. I tried recording the fizz late at night but still every 30 seconds or so, there was some noise. I never noticed how much noise lives around me / I live in. I also felt like I was making so much disturbing noise, even when I was trying to be so quiet, I even held my breath. "

The delicate fermentation fizz was audible with FA's ears alone, but the recording sounded different. Adobe Audition [107] and Ableton Live 11 [1] were used for recording and audio editing (sound files are available for listening as supplementary materials). The sound of the fermentation had different qualities in the recording and could also be slightly altered and tweaked with the mixing software. The software's ability of bringing different captured sounds to the forefront of the recording once again emphasized that FA wasn't purely capturing the Kombucha's fermentation, but was also capturing dripping condensation liquid, echos of noises in the jar and from outside the jar; essentially, the Kombucha Scoby's whole environment.

"This process is really helping me practice acceptance and patience. The sound recording picked up a lot of other noise and I tried filtering so much of it out in Adobe Audition. But I also loved that I could sift through the layers of the sounds in the recording, and hear different things. I still like the one that emphasizes the bubbles the most, but I think I stopped thinking of the background layers as noises, and started understanding that they are part of the sound."

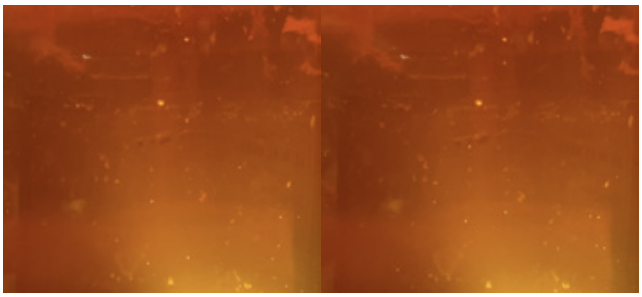

Figure 14: Two images of the fermenting Kombucha culture, taken one second apart. The small, bright specks are the bubbles from the fermentation. The sound files are available for listening as supplementary materials.

The attempt of the recording prompted FA into bodily modes that were at times difficult to hold (e.g. holding still, breath holding), however contributed to the overall experience of "trying to be ("alone") with the organism".

"Holding my breath to listen to the Kombucha made me feel uncomfortable, but I think it was somehow good and made me appreciate the delicate sound. I like that I had to 'work' for the sound... that it wasn't available at all times or at a comfortable volume. Now, even when I am not recording, I still try myself to get closer to the Kombucha jar, is if it were glued to the table... hopefully this causes less movement in the jar, and less disturbance to the culture."

We drew inspiration from the intimate ways we engaged our bodies when listening to the Kombucha, and set out to manifest this experience in a physical object. Since the jar acoustics were so influential in the sound production, we decided to keep the Kombucha in the jar, and try to *extend* ourselves towards it. In order to test the intimate situating of the body close to the Kombucha Scoby, we designed paper-based low-fidelity prototypes (see Figure 15). These prototypes lightly echoed the fizzing sound of the fermentation bubbles, but more importantly, they served as experience prototypes [12] for us to feel the positioning of our bodies in relation to the fizzing medium. The paper horn-shaped prototypes required us to physically bend down towards the Kombucha medium; engaging our *soma*, and patiently wait still and quietly to hear the fizz.

Following the prototype, we designed the listening probe (see Figure 16). The listening probe is a 3d printed horn-like object that follows the interaction elicited by the prototype, aiming to create an opportunity for us to physically come closer and tune into the sounds of the Kombucha Scoby. We found inspiration in the Pinard horn, a type of stethoscope used to listen to the heart rate of a fetus during pregnancy. The Pinard horn is a handheld object that asks the human to directly place their ear onto it and adjust their

Figure 15: Low fidelity prototype of horn. Recording of the fermentation can be found in the supplementary materials.

body in order to hear through it with every use. There is physical engagement of the body in proximity to the object and what is being listened to, leaning towards it, and moving with it with every adjustment.

The listening probe is situated directly between the listener and the organism, creating closeness and intimacy between us and the Kombucha Scoby. We chose 3d printed plastic as the horn probe's material considering it might come in contact with the liquid medium and 3d printed plastic would withstand it. The flat end of the horn invites the human to place their ear on it, and the second end, cone-shaped, is to be placed on and cover the Kombucha Scoby medium's jar. For best acoustic quality, it is best to keep the distance between the two ends relatively small. In addition, the cone-shaped end does not adhere to the Kombucha Scoby jar, asking us to hold and support it in its place and requiring us to stay close and still while using it.

Figure 16: The listening probe can be used to hear the Kombucha Scoby's fermentation. Recording of the fermentation can be found in the supplementary materials.

6.3 Touching

Touch can be a meaningful, emotional modality of interaction. In the context of designing with living matter, it is not common to come in direct contact with the organism, as it may harm the organism and contaminate it, and it may even be dangerous to us. However, unlike many other microorganisms, Kombucha Scoby *affords* direct contact and touching: it is food-grade and safe to consume by humans, and it has a low potential of hydrogen (pH) that prevents contamination when touched as the human microbiome does not thrive in acidic environments. Thus, in order to harvest Kombucha Scoby layers, we use our hands or tools such as tongs to reach into the culture and lift out the Kombucha Scoby layer. As mentioned, directly touching it does not pose any danger to the human, and it can also serve as a tool for assessing growth and the state of the Kombucha Scoby after it forms a layer. Hence, touch is constantly present between the human and the Kombucha Scoby, allowing for physical interaction and perhaps even a sensation of connection. In fact, many of the interactions with the Kombucha Scoby are physical and sensory acts of labor; from pouring a new culture and feeding it, feeling the liquid swish around in the container, to harvesting the grown Kombucha Scoby from the medium.

Such physically felt experiences stayed with us as we could easily recall the specific felt sensation. FA shared new felt sensations (e.g. an unusual texture of the Kombucha Scoby) with the research team, and learned that the sensation of touching the Kombucha Scoby isn't pleasant to everyone. FA recalled a time when a lab mate was appalled watching her harvest a large layer of Kombucha Scoby:

> *"I have become very comfortable with touching the Scoby. [Lab mate] watched me harvest a 15x22 inch layer and was absolutely disgusted. I asked him if he wanted to try touching it and he nervously laughed. I told him that I also used to be a bit repelled by its smell and slimy texture, but not anymore. Today it is almost essential that I touch it... I can feel if it is healthy by just running my finger across the Scoby."*

FA did not document and reflect on the first time she touched or harvested a Kombucha Scoby layer. However, some notable "touch" experiences stayed with FA in a very felt way. For example, the sewing and embroidering attempts with Kombucha Scoby during the initial material exploration (see Figure 5 in Section 5) introduced the *haptic*-like sensation of applying force to the Kombucha Scoby and receiving a very physical, springback feedback. Since the resistance from applying pressure to the Kombucha Scoby was physically felt, FA needed to apply a high amount of pressure when trying to penetrate a thick, robust layer with an external tool such as a needle or X-ACTO knife. Furthermore, penetrating or cutting through of the Scoby was such a distinct sensation, that FA was able to sense the tearing of the *individual* layers that make up the Scoby. In spite of Scoby's rubbery appearance, the sensation is not similar to slicing a smooth, jelly-life texture, but rather similar to cutting a fibrous material where the hand can feel the texture while cutting down the vertical cross section.

> *"It's interesting that I love sewing and cutting the Scoby. The feeling of cutting it is so satisfying. It reminds me of popping bubble wrap - so satisfying and it's hard to stop. The act is wet and messy, but since first trying it, my fingers can still feel it."*

Not all touch experiences that stayed with FA were as satisfying. In fact, there were instances when FA was anxious to handle the Kombucha Scoby or even feed it. During one memorable feeding, FA clumsily poured the food medium she had prepared into the container and accidentally drowned the already-grown layer (instead of carefully lifting the corner of the layer and pouring the liquid underneath it). Like in this instance, during some of these touch

interactions, FA felt that her actions were more harmful rather than helpful:

> *"I took the Scoby that was growing in the big container out for drying and it fell apart in my hands. It totally disintegrated. It might have been unhealthy and therefore didn't form a robust layer, or it just wasn't strong enough yet. My impatience disturbed it and I feel a discomfort, almost sadness. "*
>
> *"Trying to feed the Kombucha is tricky... sometimes I accidentally pour the food liquid on top of the Scoby layer, causing it to sink, and I disrupt the layer growth. I am always very frustrated when this happens. I disrupted one of the Scobies I've been growing for a month... I feel like sometimes my touch is harmful, and I am anxious every time it is time to feed. "*

Through similar reflections, FA gathered that touch experiences were the most emotional ones for her. Touch was the most "full" and direct sensory experience (as opposed to limited *seeing* of the layers grow and limited *hearing* of the fermentation fizz), however, many of the touch interactions did not turn out the way FA had planned. The frustration with FA's own touch actions prompted a design exercise of challenging the direct touch, but still preserving some intimacy between FA and the Kombucha Scoby.

When designing the touching probe, we drew from the notion of *being in touch*; connection and contact; but challenging the extent of touch. We prototyped a minimal glove (see Figure 17) made from nylon stocking fabric and a needle positioned at the tip of the wearer's index finger. The needle hinted at a delicate, minimal action the wearer could take when interacting with the Kombucha Scoby (e.g. gently running the needle tip across the Scoby surface), rather than a larger, possibly aggressive gesture of touching the Kombucha Scoby with one's whole hand. Although made mainly from stretchy nylon, the glove was sewn to fixate the fingers one to another, limiting range of movement and freedom. By this design, the glove afforded a more limited touching interaction (as opposed to the whole hand touching the Kombucha Scoby).

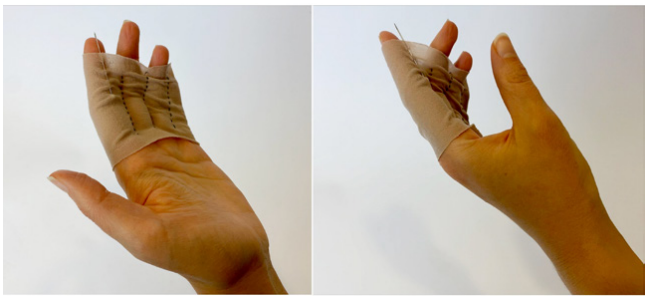

Figure 17: Low fidelity prototype of glove with needle.

Following the glove probe, we designed a less limiting wearable object, however kept the needle for challenging and minimizing the direct touching interaction, and the nylon fabric was replaced with 3d printed plastic, a liquid-resistant material (see Figure 18). The finger-cap sits on the wearer's finger, with a needle attached, adjacent to the finger tip, and can be used to physically feel (e.g. stroking, poking, moving the Kombucha Scoby in the medium) the biofilm's texture and thickness when still in the growing medium and when harvested for drying. Designing the touching probe to challenge physical interaction reflects the shift of perspective to see and incorporate Kombucha Scoby as an living and active counterpart in design processes. Specifically, when reflecting on offering her lab mate to touch the Scoby, FA started to reflect on what would be the Scoby's own level of comfort around being touched. Thus, the touching probe holds the longing of *being in touch*, however keeps the human at a distance in order to create a metaphorical boundary in favor of the Kombucha Scoby. This led to preserving a minimal point of connection by using a needle (which does not harm the Scoby), and avoiding the potentially harmful weight of a human's whole hand that could entirely disrupt the Scoby's growth.

Figure 18: Touching probe model and in use; in contact with a grown Scoby biofilm.

The needle's origin was from the sewing and embroidering experiments described in the initial material exploration (see Section 5 - Initial Material Exploration). Although in those experiments the needle served as a sewing tool function, in the touch sensory probe, the needle served as a mediator between the human and the Kombucha Scoby; connecting for physical interaction but still preserving some distance.

7 DISCUSSION

> "I must walk more with free senses. It is as bad to study stars and clouds as flowers and stones. I must let my senses wander as my thoughts, my eyes see without looking. [...] What I need is not to look at all, but a true sauntering of the eye."
>
> -Henry Thoreau, p. 351 [108].

In this section, we switch back to the research team's collective voice as we discuss our research practice. This work originally set out to explore the opportunities of designing with Kombucha Scoby in the context of BioHCI, however shifted towards an autoethnography of exploring the felt experiences in the designer-organism relationship. While crafting with the Kombucha Scoby, we began to contemplate our approach, as we became more and more aware of the organism's livingness [56]. We recognized an opportunity to engage in a deep, inwards observing design research, hence we pivoted from focusing on designing with Kombucha Scoby as the material, to reflecting-through-design on Kombucha Scoby as an active, living entity in the process.

7.1 Alternative Narratives of Designing with Living Matter

Designing sensory engagement probes engage us in an embodied and self-observation practice, allowing us to form connections between noticing our felt experiences and designing with living matter. This practice enabled us to better tune to ourselves and the nonhuman entities at play, resulting in new possibilities of engaging with our own *sensing* to guide design decisions [78]. Additionally, we unfolded alternative narratives for designing with living matter by bringing attention to the designer-organism relationship, rather than a utilitarian purpose of designing with the organism as strictly a material or as an attempt of controlling it for an engaging user experience. We offer these discussions as insights to the BioHCI and design research communities, and as a kind call for more intimate, experience-driven design with living matter and with ourselves.

7.1.1 Our Body, Other Bodies. Noticing the felt experiences of our bodies brought forward the presence of the other bodies, i.e., the Kombucha Scoby. By being present in our bodies [49, 78, 113], through autoethnography, we found ourselves connecting, tending, and better understanding the foreign body next to us, and essentially forming a relationship. Our bodies were also a site for generating and observing emotions that emerged, which in turn inspired design concepts and qualities [78]. The excitement of *hearing* the Kombucha fermentation and the frustration of accidentally disturbing the growing layer by *touching* it too early, both prompted points of connection and tension that seemed crucial to "stay with" [19]. Hence we were prompted to design sensory engagement probes, situated between and bridging our bodies and the more-than-human bodies [45].

Not just by proximity, the sensory engagement probes closely couple us and the living organism, perhaps demonstrating ways in which bodies, human and nonhuman, are intertwined [31, 32]. Moving towards more-than-human perspectives, the sensory engagement probes facilitate us "turning inwards" [49, 50], confronting us with our own motivation, practice, and reflection [18], but ultimately decenter us [9, 74, 101] and bring our focus to the other [50]. For example, a sensory engagement probe for when touching the Kombucha Scoby might invite the human to touch the organism, however might also set boundaries and confine the human to consider organism-centered [90] needs in their action. Although designed for human use, the intent with the sensory engagement probes was to reorient us for connection with other (nonhuman) bodies, perhaps creating space for kinship [14] and an orientation of designing for togetherness and care.

This *inwards as a mean to outwards* orientation may traditionally seem unusual in its functionality, however, it may redirect us towards not only the other bodies and beings involved in a design process, but towards a shared focus on the human-nonhuman interconnectedness [101], corresponding with the posthumanist thought [11]. Essentially, we consider the body as a tool-to-design-with for bringing forward the mesh of bodies, human and nonhuman, and through which can extend the human designer's perspective and awareness of constituencies [111]. We encourage BioHCI and design researchers to further turn to the body, their own felt experiences, and to designing sensory engagement probes specifically when designing with organisms that have characteristics and reactions that are within the human sensory spectrum.

7.1.2 Challenging the Roles of the Designer and Organism. In this work, we challenge the prevalent orientation of human-centered design [31] and the prevailing biodesign approach of making artifacts and systems out of living *materials*, as we moved away from *using* the Kombucha Scoby just like we would use other, nonliving design materials. We abandoned the approach of perceiving and using Kombucha Scoby merely as another manipulable material, as we noticed and acknowledged the *agency* of the Kombucha Scoby; how its health, growth, and own living timeline influenced us and the process. We ultimately brought attention to redefining the entities participating and critically reflected on our practices by observing our own thoughts and actions throughout the process.

In the context of more-than-human approaches, the designed sensory engagement probes can be understood as potential *repertoires* [91, 111], stemming out of our explicit effort for finding "ways for nonhumans to be more present, more participatory, more cared-with and lively within constituencies" [111]. The circular process of (1) noticing the sensory experience with the organism, (2) recreating or capturing it for reflection, and (3) prototyping designed forms for further enhancing and engaging with specific sensory experiences(see Figure 11), forms a practice that not only involves the living organism in the design process or broader constituency [111], but it becomes *seen* and *heard*.

Considering we stepped away from an anthropocentric approach, we also consider discussions on material agency and thing power [7], challenging the extent of our control and emphasizing the "power" of inanimate things. However, this work brings attention to a *living* thing that influences decisions and practices, which might hold rich connections of our interconnected, entangled existence in the world [32]. Saying this doesn't mean to assume a hierarchy of living versus nonliving entities, but to further illustrate that our process was explicitly informed by a noticeably active organism.

Understanding the active role of Kombucha Scoby as a living organism to design with further aligns with *morphogenesis* - the view that materials (all, not just the living) take an active role in determining the form that emerges [17, 52]. DeLanda describes morphogenesis to be a bottom-up view - as opposed to "a hierarchical command from above as in an assembly line", form and structure can come from within the materials [17]. The human, tools, and material form a "correspondence" according to Ingold; a relationship in which the materials "speak" through their physical properties, pushing towards and pulling against the maker's actions [51].

The sensory engagement probes and their process of becoming speak to Ron Wakkary's (2021) argument for generosity and adopting a horizontal orientation in design; "This speaks to positioning oneself alongside other humans and nonhumans to literally expand the points of contact and increase the multiplicity of relations through greater proximity..." [111]. A horizontal orientation, as opposed to a vertical one, welcomes humility and an opportunity to shed our human privilege, and the act of *designing-with*. As HCI and design researchers work towards a horizontal orientation, designing with living organisms as *materials to manipulate* might

preserve a more vertical orientation, whereas designing opportunities for *contact and connection* with living organisms (through the form of sensory engagement probes, for example) may afford bringing forward awareness of their agency and livingness, and hence a closer human-designer / organism-designer relationship.

In the case of designing with Kombucha Scoby, while not directed specifically to us, the organism demonstrated information about its state, needs, and limitations through its physical properties. This inspired an attentive practice, where we continuously encountered the dissonance between out desired outcomes and what the organism actually made possible, urging further decentering of the human and integrating perspectives of the other [16]. The notion of moving away from *acting on* the Kombucha Scoby to *acting with*, unfolded a different dynamic of the entities involved, and ultimately new design orientations. We follow and extend Ingold's call for the need to dissolve the "category of the social, so as to re-embed [human] relationships within the continuum of organic life" [51] and call for work in biodesign, BioHCI, interaction design, and design research to observe the entanglement of the human in and as part of the organic world, along with other non-human entities that take action on the world. We encourage designers to bring forward *other* perspectives that will reveal to us the existing landscape of constituencies, especially those who cannot be voiced.

8 CONCLUSION

Designing with living matter is pushing the boundaries of design and interaction in HCI, however it is still conforming to the specific orientations of human-centered design. Through first-person perspectives when designing with Kombucha scoby, we reflect on what and how the organism invites and prompts us to create. Being attentive to our own lived and sensed experiences, we were inspired to further engage with the organism, and perhaps through designed forms, create new opportunities for such engagements and reflections. Experiences of crafting and using the sensory engagement probes gave rise to understandings and new meanings between us as the designers and the organism. The design sensory engagement probes also prompted being present with the organism and with ourselves, creating a space for communication and the human-organism relation to come forward. We hope this work will spark further works and discussions that will bring these values and practices forward.

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REFERENCES

[1] Ableton. 2022. Ableton Live. Retrieved January 29, 2022 from https://www.ableton.com/en/live/
[2] Mirela Alistar and Margherita Pevere. 2020. Semina Aeternitatis: Using Bacteria for Tangible Interaction with Data. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.
[3] Kristina Andersen and Ron Wakkary. 2019. The magic machine workshops: Making personal design knowledge. In *Proceedings of the 2019 CHI conference on human factors in computing systems*. 1–13.
[4] Jeffrey Bardzell, Shaowen Bardzell, Peter Dalsgaard, Shad Gross, and Kim Halskov. 2016. Documenting the research through design process. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. 96–107.
[5] Fiona Bell, Alice Hong, Andreea Danielescu, Aditi Maheshwari, Ben Greenspan, Hiroshi Ishii, Laura Devendorf, and Mirela Alistar. 2021. Self-deStaining Textiles: Designing Interactive Systems with Fabric, Stains and Light. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–12.
[6] Fiona Bell, Ella McQuaid, and Mirela Alistar. 2022. ALGANYL: Cooking Sustainable Clothing. *Diseña* 20 (2022), 1–1.
[7] Jane Bennett. 2004. The force of things: Steps toward an ecology of matter. *Political theory* 32, 3 (2004), 347–372.
[8] Pascal Bertsch, Danai Etter, and Peter Fischer. 2021. Transient in situ measurement of kombucha biofilm growth and mechanical properties. *Food & Function* 12, 9 (2021), 4015–4020.
[9] Heidi R Biggs, Jeffrey Bardzell, and Shaowen Bardzell. 2021. Watching myself watching birds: Abjection, ecological thinking, and posthuman design. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–16.
[10] Laurens Boer, Harvey Bewley, Tom Jenkins, Sarah Homewood, Teresa Almeida, and Anna Vallgårda. 2020. Gut-Tracking as Cultivation. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference*. 561–574.
[11] Rosi Braidotti. 2019. *Posthuman knowledge*. Vol. 2. Polity Press Cambridge.
[12] Marion Buchenau and Jane Fulton Suri. 2000. Experience prototyping. In *Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques*. 424–433.
[13] Janghee Cho, Laura Devendorf, and Stephen Voida. 2021. From The Art of Reflection to The Art of Noticing: A Shifting View of Self-Tracking Technologies' Role in Supporting Sustainable Food Practices. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–7.
[14] Patricia Ciobanu. 2019. Designing for and with Care in Multispecies Kinship: Exploring Methods of Decentering the Human in Design.
[15] Nate J Cira, Alice M Chung, Aleksandra K Denisin, Stefano Rensi, Gabriel N Sanchez, Stephen R Quake, and Ingmar H Riedel-Kruse. 2015. A biotic game design project for integrated life science and engineering education. *PLoS Biol* 13, 3 (2015), e1002110.
[16] Aykut Coskun, Nazli Cila, Iohanna Nicenboim, Christopher Frauenberger, Ron Wakkary, Marc Hassenzahl, Clara Mancini, Elisa Giaccardi, and Laura Forlano. 2022. More-than-human Concepts, Methodologies, and Practices in HCI. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. 1–5.
[17] Manuel DeLanda. 2004. Material complexity. *Digital tectonics* 14 (2004), 21.
[18] Audrey Desjardins and Ron Wakkary. 2016. Living in a prototype: A reconfigured space. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 5274–5285.
[19] Laura Devendorf, Kristina Andersen, and Aisling Kelliher. 2020. Making design memoirs: Understanding and honoring difficult experiences. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–12.
[20] Laura Devendorf, Kristina Andersen, Daniela K Rosner, Ron Wakkary, and James Pierce. 2019. From HCI to HCI-amusement: Strategies for engaging what new technology makes old. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–12.
[21] Laura Devendorf and Kimiko Ryokai. 2015. Being the machine: Reconfiguring agency and control in hybrid fabrication. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 2477–2486.
[22] Kristin N Dew and Daniela K Rosner. 2018. Lessons from the woodshop: Cultivating design with living materials. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–12.
[23] Carl DiSalvo and Jonathan Lukens. 2011. Nonanthropocentrism and the nonhuman in design: possibilities for designing new forms of engagement with and through technology. *From social butterfly to engaged citizen: urban informatics, social media, ubiquitous computing, and mobile technology to support citizen engagement* 421 (2011).
[24] Kelly Dobson. 2004. Blendie. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques*. 309–309.
[25] Kelly Dobson. 2005. Wearable body organs: Critical cognition becomes (again) somatic. In *Proceedings of the 5th conference on Creativity & cognition*. 259–262.
[26] Margot Duncan. 2004. Autoethnography: Critical appreciation of an emerging art. *International journal of qualitative methods* 3, 4 (2004), 28–39.
[27] Anthony Dunne and Fiona Raby. 2013. *Speculative everything: design, fiction, and social dreaming*. MIT press.
[28] Carolyn Ellis. 2004. *The ethnographic I: A methodological novel about autoethnography*. Vol. 13. Rowman Altamira.
[29] Daniel Fallman. 2003. Design-oriented human-computer interaction. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. 225–232.
[30] GT's Living Foods. 2022. GT's Classic Kombucha. Retrieved January 12, 2022 from https://gtslivingfoods.com/
[31] Laura Forlano. 2017. Posthumanism and design. *She Ji: The Journal of Design, Economics, and Innovation* 3, 1 (2017), 16–29.

[32] Christopher Frauenberger. 2019. Entanglement HCI the next wave? *ACM Transactions on Computer-Human Interaction (TOCHI)* 27, 1 (2019), 1–27.

[33] Jon E Froehlich. 2011. *Sensing and feedback of everyday activities to promote environmental behaviors*. University of Washington.

[34] William Gaver. 2012. What should we expect from research through design?. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 937–946.

[35] Eugene T Gendlin. 1984. The politics of giving therapy away: Listening and focusing. *Teaching psychological skills: models for giving psychology away* (1984), 287–305.

[36] Eugene T Gendlin. 2004. The new phenomenology of carrying forward. *Continental Philosophy Review* 37, 1 (2004), 127–151.

[37] Elisa Giaccardi, Nazli Cila, Chris Speed, and Melissa Caldwell. 2016. Thing ethnography: Doing design research with non-humans. In *Proceedings of the 2016 ACM conference on designing interactive systems*. 377–387.

[38] Elisa Giaccardi, Chris Speed, Nazli Cila, and Melissa L Caldwell. 2020. Things as co-ethnographers: Implications of a thing perspective for design and anthropology. In *Design anthropological futures*. Routledge, 235–248.

[39] Gilad Gome, Yuval Fein, Julian Waksberg, Yuval Maayan, Andrey Grishko, Iddo Yehoshua Wald, and Oren Zuckerman. 2019. My First Biolab: a System for Hands-On Biology Experiments. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–6.

[40] Phillip Gough, Larissa Pschetz, Naseem Ahmadpour, Leigh-Anne Hepburn, Clare Cooper, Carolina Ramirez-Figueroa, and Oron Catts. 2020. The Nature of biodesigned systems: Directions for HCI. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference*. 389–392.

[41] Helen Halbert and Lisa P Nathan. 2015. Designing for discomfort: Supporting critical reflection through interactive tools. In *Proceedings of the 18th ACM conference on computer supported cooperative work & social computing*. 349–360.

[42] Lars Hallnäs and Johan Redström. 2001. Slow technology–designing for reflection. *Personal and ubiquitous computing* 5, 3 (2001), 201–212.

[43] Karey Helms. 2021. Entangled Reflections on Designing with Leaky Breastfeeding Bodies. In *Designing Interactive Systems Conference 2021*. 1998–2012.

[44] Tom Hitron, Idan David, Netta Ofer, Andrey Grishko, Iddo Yehoshua Wald, Hadas Erel, and Oren Zuckerman. 2018. Digital Outdoor play: Benefits and risks from an interaction design perspective. In *Proceedings of the 2018 CHI conference on Human Factors in Computing Systems*. 1–13.

[45] Sarah Homewood, Marika Hedemyr, Maja Fagerberg Ranten, and Susan Kozel. 2021. Tracing Conceptions of the Body in HCI: From User to More-Than-Human. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–12.

[46] Kristina Höök. 2010. Transferring qualities from horseback riding to design. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*. 226–235.

[47] Kristina Hook. 2018. *Designing with the body: Somaesthetic interaction design*. MIT Press.

[48] Kristina Höök, Baptiste Caramiaux, Cumhur Erkut, Jodi Forlizzi, Nassrin Hajinejad, Michael Haller, Caroline Hummels, Katherine Isbister, Martin Jonsson, George Khut, et al. 2018. Embracing first-person perspectives in soma-based design. In *Informatics*, Vol. 5. Multidisciplinary Digital Publishing Institute, 8.

[49] Kristina Höök, Martin P Jonsson, Anna Ståhl, and Johanna Mercurio. 2016. Somaesthetic appreciation design. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 3131–3142.

[50] Kristina Höök, Anna Ståhl, Martin Jonsson, Johanna Mercurio, Anna Karlsson, and Eva-Carin Banka Johnson. 2015. Cover story somaesthetic design. *interactions* 22, 4 (2015), 26–33.

[51] Tim Ingold. 1997. Life beyond the edge of nature? Or, the mirage of society. *The mark of the social* (1997), 231–252.

[52] Tim Ingold. 2013. *Making: Anthropology, archaeology, art and architecture*. Routledge.

[53] Hiroshi Ishii, Craig Wisneski, Scott Brave, Andrew Dahley, Matt Gorbet, Brygg Ullmer, and Paul Yarin. 1998. ambientROOM: integrating ambient media with architectural space. In *CHI 98 conference summary on Human factors in computing systems*. 173–174.

[54] Dhruv Jain, Audrey Desjardins, Leah Findlater, and Jon E Froehlich. 2019. Autoethnography of a hard of hearing traveler. In *The 21st International ACM SIGACCESS Conference on Computers and Accessibility*. 236–248.

[55] Michael Jones et al. 2021. Discomfort: a New Material for Interaction Design. *arXiv preprint arXiv:2105.04015* (2021).

[56] Elvin Karana, Bahareh Barati, and Elisa Giaccardi. 2020. Living Artefacts: Conceptualizing Livingness as a Material Quality in Everyday Artefacts. *International Journal of Design* 14, 3 (2020).

[57] George Khut. 2016. Designing biofeedback artworks for relaxation. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 3859–3862.

[58] Honesty Kim, Lukas Cyrill Gerber, Daniel Chiu, Seung Ah Lee, Nate J Cira, Sherwin Yuyang Xia, and Ingmar H Riedel-Kruse. 2016. LudusScope: accessible interactive smartphone microscopy for life-science education. *PloS one* 11, 10 (2016), e0162602.

[59] Raphael Kim, Pat Pataranutaporn, Jack Forman, Seung Ah Lee, Ingmar H Riedel-Kruse, Mirela Alistar, Eldy S Lazaro Vasquez, Katia Vega, Roland Van Dierendonck, Gilad Gome, et al. 2021. Microbe-HCI: Introduction and Directions for Growth. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–4.

[60] David Kirsh. 2013. Embodied cognition and the magical future of interaction design. *ACM Transactions on Computer-Human Interaction (TOCHI)* 20, 1 (2013), 1–30.

[61] Josephine Klefeker, Libi Striegl, and Laura Devendorf. 2020. What HCI Can Learn from ASMR: Becoming Enchanted with the Mundane. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–12.

[62] Stacey Kuznetsov, Cassandra Barrett, Piyum Fernando, and Kat Fowler. 2018. Antibiotic-responsive bioart: Exploring DIYbio as a design studio practice. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–14.

[63] Stacey Kuznetsov, Carrie Doonan, Nathan Wilson, Swarna Mohan, Scott E Hudson, and Eric Paulos. 2015. DIYbio things: open source biology tools as platforms for hybrid knowledge production and scientific participation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 4065–4068.

[64] Stacey Kuznetsov and Eric Paulos. 2010. Rise of the expert amateur: DIY projects, communities, and cultures. In *Proceedings of the 6th Nordic conference on human-computer interaction: extending boundaries*. 295–304.

[65] Stacey Kuznetsov, Alex S Taylor, Eric Paulos, Carl DiSalvo, and Tad Hirsch. 2012. (DIY) biology and opportunities for HCI. In *Proceedings of the Designing Interactive Systems Conference*. 809–810.

[66] Stacey Kuznetsov, Alex S Taylor, Tim Regan, Nicolas Villar, and Eric Paulos. 2012. At the seams: DIYbio and opportunities for HCI. In *Proceedings of the Designing Interactive Systems Conference*. 258–267.

[67] Amy T Lam, Jonathan Griffin, Matthew Austin Loeun, Nate J Cira, Seung Ah Lee, and Ingmar H Riedel-Kruse. 2020. Pac-Euglena: A Living Cellular Pac-Man Meets Virtual Ghosts. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[68] Eldy S Lazaro Vasquez, Netta Ofer, Shanel Wu, Mary Etta West, Mirela Alistar, and Laura Devendorf. 2022. Exploring Biofoam as a Material for Tangible Interaction. In *Designing Interactive Systems Conference*. 1525–1539.

[69] Suzanne Lee. 2012. Biocouture. In *The textile reader (2012)*. 391–395.

[70] SA Lee and IH Riedel-Kruse. 2022. Micro-HBI: Human-Biology Interaction With Living Cells, Viruses, and Molecules. *Front. Comput. Sci. 4: 849887. doi: 10.3389/fcomp* (2022).

[71] Seung Ah Lee, Engin Bumbacher, Alice M Chung, Nate Cira, Byron Walker, Ji Young Park, Barry Starr, Paulo Blikstein, and Ingmar H Riedel-Kruse. 2015. Trap it! A playful human-biology interaction for a museum installation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 2593–2602.

[72] Ann Light, Alison Powell, and Irina Shklovski. 2017. Design for existential crisis in the anthropocene age. In *Proceedings of the 8th International Conference on Communities and Technologies*. 270–279.

[73] Silvia Lindtner, Shaowen Bardzell, and Jeffrey Bardzell. 2018. Design and Intervention in the Age of" No Alternative". *Proceedings of the ACM on Human-Computer Interaction* 2, CSCW (2018), 1–21.

[74] Jen Liu, Daragh Byrne, and Laura Devendorf. 2018. Design for collaborative survival: An inquiry into human-fungi relationships. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13.

[75] Szu-Yu Liu, Jeffrey Bardzell, and Shaowen Bardzell. 2019. Decomposition as design: co-creating (with) natureculture. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction*. 605–614.

[76] Szu-Yu Liu, Jen Liu, Kristin Dew, Patrycja Zdziarska, Maya Livio, and Shaowen Bardzell. 2019. Exploring noticing as method in design research. In *Companion Publication of the 2019 on Designing Interactive Systems Conference 2019 Companion*. 377–380.

[77] Lian Loke and Claudia Núñez-Pacheco. 2018. Developing somatic sensibilities for practices of discernment in interaction design. *The Senses and Society* 13, 2 (2018), 219–231.

[78] Lian Loke and Thecla Schiphorst. 2018. The somatic turn in human-computer interaction. *Interactions* 25, 5 (2018), 54–5863.

[79] Jasmine Lu and Pedro Lopes. 2022. Integrating Living Organisms in Devices to Implement Care-based Interactions. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology*. 1–13.

[80] Lee R Lynd, Paul J Weimer, Willem H Van Zyl, and Isak S Pretorius. 2002. Microbial cellulose utilization: fundamentals and biotechnology. *Microbiology and molecular biology reviews* 66, 3 (2002), 506–577.

[81] Laura Malinverni, Edith Ackermann, and Narcis Pares. 2016. Experience as an object to think with: From sensing-in-action to making-sense of action in full-body interaction learning environments. In *Proceedings of the TEI'16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*. 332–339.

[82] Paul Marshall and Eva Hornecker. 2013. Theories of Embodiment in HCI. *The SAGE handbook of digital technology research* 1 (2013), 144–158.

[83] John McCarthy and Peter Wright. 2005. Putting 'felt-life'at the centre of human–computer interaction (HCI). *Cognition, technology & work* 7, 4 (2005), 262–271.

[84] Timothy Merritt, Foad Hamidi, Mirela Alistar, and Marta DeMenezes. 2020. Living media interfaces: a multi-perspective analysis of biological materials for interaction. *Digital Creativity* 31, 1 (2020), 1–21.

[85] Timothy Merritt, Christine Linding Nielsen, Frederik Lund Jakobsen, and Jens Emil Grønbæk. 2017. GlowPhones: Designing for Proxemics Play with Low-Resolution Displays in Location-based Games.. In *CHI PLAY*. 69–81.

[86] Carman Neustaedter and Phoebe Sengers. 2012. Autobiographical design in HCI research: designing and learning through use-it-yourself. In *Proceedings of the Designing Interactive Systems Conference*. 514–523.

[87] Audrey Ng. 2017. Grown microbial 3D fiber art, Ava: fusion of traditional art with technology. In *Proceedings of the 2017 ACM International Symposium on Wearable Computers*. 209–214.

[88] Claudia Núñez Pacheco and Lian Loke. 2017. Tacit narratives: Surfacing aesthetic meaning by using wearable props and focusing. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*. 233–242.

[89] William Odom, Ron Wakkary, Ishac Bertran, Matthew Harkness, Garnet Hertz, Jeroen Hol, Henry Lin, Bram Naus, Perry Tan, and Pepijn Verburg. 2018. Attending to slowness and temporality with olly and slow game: A design inquiry into supporting longer-term relations with everyday computational objects. In *Proceedings of the 2018 CHI conference on human factors in computing systems*. 1–13.

[90] Netta Ofer, Fiona Bell, and Mirela Alistar. 2021. Designing Direct Interactions with Bioluminescent Algae. In *Designing Interactive Systems Conference 2021*. 1230–1241.

[91] Doenja Oogjes and Ron Wakkary. 2022. Weaving Stories: Toward Repertoires for Designing Things. In *CHI Conference on Human Factors in Computing Systems*. 1–21.

[92] Pat Pataranutaporn, Jaime Sanchez De La Vega, Abhik Chowdhury, Audrey Ng, and Galina Mihaleva. 2018. Toward growable robot: Exploring and integrating flexible–Biological matter with electronics. In *2018 International Flexible Electronics Technology Conference (IFETC)*. IEEE, 1–4.

[93] Pat Pataranutaporn, Angela Vujic, David S Kong, Pattie Maes, and Misha Sra. 2020. Living bits: Opportunities and challenges for integrating living microorganisms in human-computer interaction. In *Proceedings of the Augmented Humans International Conference*. 1–12.

[94] James Pierce and Eric Paulos. 2015. Making multiple uses of the obscura 1C digital camera: reflecting on the design, production, packaging and distribution of a counterfunctional device. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 2103–2112.

[95] Anton Poikolainen Rosén, Maria Normark, and Mikael Wiberg. 2022. Noticing the Environment–A Design Ethnography of Urban Farming. In *Nordic Human-Computer Interaction Conference*. 1–13.

[96] Corina Sas. 2019. First person HCI research: Tapping into designers' tacit experiences. (2019).

[97] Thecla Schiphorst. 2011. Self-evidence: applying somatic connoisseurship to experience design. In *CHI'11 extended abstracts on human factors in computing systems*. 145–160.

[98] DA Schön. 1983. The Reflective Practitioner: How Professionals Think in Action Basic Books Inc. *New York, NY* (1983).

[99] Phoebe Sengers, Kirsten Boehner, Shay David, and Joseph'Jofish' Kaye. 2005. Reflective design. In *Proceedings of the 4th decennial conference on Critical computing: between sense and sensibility*. 49–58.

[100] Aybars Şenyıldız and Emilija Veselova. 2022. Why would I ever fry and eat my SCOBY? It would be like murder!: Attuning to nonhumans through kombucha fermentation practices. In *Design Research Society International Conference*. Design Research Society.

[101] Nancy Smith, Shaowen Bardzell, and Jeffrey Bardzell. 2017. Designing for cohabitation: Naturecultures, hybrids, and decentering the human in design. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. 1714–1725.

[102] Tami Spry. 2001. Performing autoethnography: An embodied methodological praxis. *Qualitative inquiry* 7, 6 (2001), 706–732.

[103] Dag Svanæs. 2013. Interaction design for and with the lived body: Some implications of merleau-ponty's phenomenology. *ACM Transactions on Computer-Human Interaction (TOCHI)* 20, 1 (2013), 1–30.

[104] Dag Svanaes and Martin Solheim. 2016. Wag your tail and flap your ears: The kinesthetic user experience of extending your body. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 3778–3779.

[105] Erika Szymanski and Jane Calvert. 2018. Designing with living systems in the synthetic yeast project. *Nature Communications* 9, 1 (2018), 1–6.

[106] Alex Taylor and Daniela Rosner. 2017. Alex S. Taylor and Daniela K. Rosner. *Interactions* 24, 6 (2017), 12–13.

[107] Adobe Creative Team. 2013. *Adobe Audition CC Classroom in a Book*. Adobe Press.

[108] Henry David Thoreau and Ray Angelo. 1906. *The Journal of Henry David Thoreau*. Vol. 3. Peregrine Smith Books.

[109] Anna Lowenhaupt Tsing. 2015. The Mushroom at the End of the World. In *The Mushroom at the End of the World*. Princeton University Press.

[110] Muhammad Umair, Miquel Alfaras, Hugo Gamboa, and Corina Sas. 2019. Experiencing discomfort: designing for affect from first-person perspective. In *Adjunct Proceedings of the 2019 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2019 ACM International Symposium on Wearable Computers*. 1093–1096.

[111] Ron Wakkary. 2021. *Things we could design: For more than human-centered worlds*. MIT press.

[112] Peter Washington, Karina G Samuel-Gama, Shirish Goyal, Ashwin Ramaswami, and Ingmar H Riedel-Kruse. 2018. Prototyping biotic games and interactive experiments with javaScript. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–4.

[113] Charles Windlin, Anna Ståhl, Pedro Sanches, Vasiliki Tsaknaki, Pavel Karpashevich, Madeline Balaam, and Kristina Höök. 2019. Soma Bits-mediating technology to orchestrate bodily experiences. In *RTD 2019-Research through Design Conference 2019, the Science Centre, Delft, on 19th to 22nd March 2019.*

[114] Bin Yu, Jun Hu, Mathias Funk, and Loe Feijs. 2018. DeLight: biofeedback through ambient light for stress intervention and relaxation assistance. *Personal and Ubiquitous Computing* 22, 4 (2018), 787–805.

[115] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. 493–502.