POSTHUMAN INTERACTION DESIGN:
DESIGNING WITH, THROUGH, AND FOR HUMAN-NATURE INTERACTION

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For my furry companions
Bagel and HeiHei

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Szu-Yu Liu

Posthuman Interaction Design:
Designing with, through, and for Human-Nature Interaction

Responding to climate change, environmental crisis, and the global pandemic, human-computer interaction (HCI) researchers are moving from a human-centered design paradigm to one that supports participation and care towards nonhuman stakeholders, such as animals, plants, and microorganisms. Posthumanism, with its critique of anthropocentrism, offers sophisticated theoretical vocabularies on decentering humans—yet it is unclear how to mobilize posthuman concepts in HCI research and design practice.

This dissertation contributes to the development of HCI theories and methods that pursue more sustainable, inclusive, and resilient futures, specifically by accounting for a wider range of species as stakeholders. Through ethnographic and design fieldwork, I identify strategies to pursue posthuman concepts within design practice by tracing encounters of human and nonhuman stakeholders. The three examples of human-nature encounter I include in this dissertation include collaborating and co-creating with nature in design studios, growing foods and cultivating symbiosis with weeds and pests in rural farms, as well as sensing and cohabitating with air pollution in urban spaces.

This work contributes to the development of an alternative design paradigm—posthuman interaction design (PID)—in which technological intervention takes into account the needs of different stakeholders, regardless of whether they are human or nonhuman. PID contributes theories and methods to support HCI researchers and designers in three key areas: practicing attentiveness towards supporting participation for nontraditional users, including but not limited to nonhuman stakeholders; strengthening bonds of intimacy and care to help sustain equitable food cultures; and facilitating public engagement with data to increase algorithmic accountability and to support environmental justice.

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Chapter 1.

Posthuman Interaction Design: An Introduction

> We are all in the gutter, but some of us are looking at the stars.
>
> – Oscar Wilde[1]

> Industrial transformation turned out to be a bubble of promise followed by lost livelihoods and damaged landscapes. And yet: such documents are not enough. If we end the story with decay, we abandon all hope—or turn our attention to other sites of promise and ruin, promise and ruin.
>
> – Anna Tsing[2]

We are living in the "blasted landscapes", meaning areas where human activities lead to climate change, resource exhaustion, species extinction, soil depletion, and food crisis, just to name a few (Tsing 2014). Crutzen (2002) coined the term Anthropocene to render the current geological epoch when human activities have more environmental impacts than other forces combined. The term Anthropocene puts humans at the center of planetary transformations, suggesting that our actions have big consequences to different life forms, including other human beings and nonhuman others (Brondizio et al. 2016; Tsing et al. 2017; Bai et al. 2016; Purdy 2015; Haraway 2016; Vogel 2015; Braidotti 2016; Harrison 2015). Industrial agriculture is a notable example: to

[1] Originally come from Oscar Wilde's play *Lady Windermere's Fan* (1892), Lord Darlington, Act III.

[2] Tsing, Anna. Blasted Landscapes (and the Gentle Arts of Mushroom Picking). The Multispecies Salon, Kirksey, Eben (ed.). Duke University Press, 2014.

boost labor efficiency, increase yields, and maximize profits, industrial farming has developed high dependency on fertilizers and pesticides. Without adequately taking the capacity and adaptability of the environment into consideration, industrial farming and its analogous practices have resulted in the production of drug-resistant pests, virulent diseases, industrial runoffs, and large-scale pollution which has drastically altered our landscape.

Following anthropologist Anna Tsing (2015), I believe that it is not enough to mourn for what we have lost in the Anthropocene; instead, it is our responsibility to find promise and hope in this blasted landscape. Living in the blasted landscape with neither a simple pathway to return to a less hazardous past, nor a flourishing future; this work explores ways to design in the Anthropocene. The conversation on whether the Anthropocene is the right term (or does it further intensify human superiority and species isolation?) is still on-going (Grusin 2017; Kimmerer 2014), but without going deep into a linguistic debate, I do use the term often in this dissertation, mainly because I find its usefulness in offering "an invitation to understand how knowledge is produced and also how infrastructure is or could be produced differently" (Hannah and Jeremijenko 2017). This work is, in essence, an invitation to pause, reflect, and re-examine the entanglement between design, sociotechnical infrastructures, and our relationships with other species on Earth.

This dissertation is both critical and speculative. The criticality of this work lies in my resistance to falling into the trap of human-centered thinking. Instead, I will argue throughout this work that *human-centered design narrows our perspectives and is to blame for issues of environmental crisis and social injustice*. Following this thread, this work is inherently speculative. Specifically, if we were to counter human-centeredness, we need to simultaneously explore alternative forms of knowledge production as well as develop new ways to engage in technological interventions. In other words, the speculative dimension of this work is about finding alternative futures, "seeing

what is and what can be" (Blevis 2018), and expanding "the space of what can be pursued, endorsed, and so on" (Shotwell 2016, 154). In this chapter, I outline the motivation of my research, introduce posthuman thinking as a way to resist human-centered design thinking, articulate the research questions and goals encompassing this work, illustrate briefly how I position this work within the field of HCI, disclose the positionality of myself, as well as provide a brief description of the structure and intended contributions of this work.

1.1 What is Posthuman Interaction Design?

In writing a dissertation titling "Posthuman Interaction Design" (PID), it seems necessary to define the term. As a reader of posthumanism, I am fully aware of that a single definition would most likely fail to capture the complexity and richness that comprises posthumanism (and thus also falls short in illustrating posthuman interaction design as a whole), including its diverse origins, perspectives, methods, and possible applications. However, to better guide the readers for reading this work and to open up discussions for members in the HCI/interaction community regarding what constitute PID, I offer a working definition to make explicit the thread and criteria that unify the studies I include in this dissertation.

> Posthuman Interaction Design (PID) refers to any interaction design theory, agenda, method, practice, and application that employ posthuman epistemologies to account for the needs of all stakeholders, regardless of whether they are human or nonhumans.

Without claiming to offer a definite and final definition, this working definition is sufficient in setting apart PID from conventional human-centered design (HCD) practices. Specifically, PID differs from HCD for it avoids privileging human perspectives; instead, PID involves adapting existing strategies and developing new ones to seek to amplify the agency of all stakeholders,

including those of whom are traditionally marginalized, oppressed, or ignored in sociotechnical interventions. The emergence of PID is a response to the increasing concern on climate change, environmental crisis, and species extinction; as a fledgling topic of research, it is also constantly shaped by emerging and existing areas of focus, such as environmental sustainability, community participation, and social justice.

Before going into details about what comprises PID, it is necessary to offer a short description on posthumanism, the theoretical roots of PID. Briefly, posthumanism is not a single theory but a constellation of intellectual propositions and sensibilities which aim to reflect and reconstruct what it means to be human beyond human bodies. In reflecting the current relationship humans have with nature, environmental biologist Robin Kimmerer writes, “we have enabled a state of nameless anonymity, bringing human people to a condition of isolation and disconnection, that philosophers have called ‘species loneliness.’ Species loneliness—this deep, unnamed sadness—is the cost of estrangement from the rest of creation, from the loss of relationship.” (2014, 21). Alongside with her, posthuman scholars problematize human-centered thinking and illustrate through contemporary forms of collaborative being—including cyborg (a hybrid of machine and organism), companion species (the process of becoming a joint life), and the many identities of an individual—to challenge the taken-for-granted ontological divide between human, nonhuman, technology, mind, and body (Haraway 1991; 2006; 2008; Wolfe 2010; C. Adams and Thompson 2016; Bennett 2011; Barad 2007; Hayles 1999).

Drawing from posthuman theories and concepts, PID explores and surfaces how our modes of being are entangled with other life forms on the planet. Key to PID is the practice of recognizing oneself not as a singular, static existence, but a mode of being who is always in the process of “becoming” another. In doing so, posthumanism decenters individual human agency, cultivates

the ability to fluently understand the world from heterogeneous perspectives by reorienting our attention to considers the social "as a tissue of associations between humans, non humans, and objects working in the realization of new relational formations" (Puig de la Bellacasa 2010, 7). The posthuman foundation in PID "dis-objectifies" nonhumans by mobilizing, rendering visible, and augmenting their agency to provide more possibilities of technological development and design research. Smith (2019, 27) argues that "we cannot predict the future, and we cannot prevent all unintended consequences in design, but we can improve ecological outcomes by thinking beyond humans." Following her, acknowledging interspecies relationality is necessary to attend to the increasing uncertainties and conflicts in the Anthropocene.

I am aware that the term posthuman can be quite confusing, so it seems necessary to provide some clarifications. Although the prefix "post-" means after and subsequent, posthuman does not suggest the end of humanism; rather, it signals the attempt to resist a specific form misconception of what it means to be human (Hayles 1999). More specifically, posthuman challenges human superiority, exceptionalism, and isolation by putting into question whether humans should be at the center of design consideration or whether a center of focus should exist at all (McShane 2007). The humanism in PID does not disappear or neglected; it simply suggests "shifting away from a centering, and thus privileging, of human activities and desires" (DiSalvo and Lukens 2011). On other words, PID is highly compliable with human-centered design but broadens its considerations to incorporate all stakeholders, regardless of their lifeforms; by doing so, PID provides the opportunity to better understand, describe, sustain, represent, reflect, critique, and intervene a given design scenario (see Figure 1).

Incorporating different species in design is nothing new; in fact, mediating human-nature relationship has always been one of the goals in design and intervention. Back during the Stone

Age, humans have created sophisticated tools for hunting, fishing, and foraging (National Museum Wales 2007). More recently in HCI, interactive toys for pets, trackers and sensors for wild animals, and autonomous technologies for agricultural practices have become commonplace. However, as others have argued (Mancini and Lehtonen 2018; D. J. Metcalfe 2015; N. Smith 2019), previous explorations remain largely human-centered, as design intervention is nothing but a means to an end: all it does is asserting human dominance. Among these studies, researchers have proposed terms like “multispecies interaction design” (Mancini and Lehtonen 2018; D. J. Metcalfe 2015; Gatto and McCardle 2019), “animal-computer interaction” (Mancini 2011), or “plant-computer interaction” (Aspling, Wang, and Juhlin 2016; Steiner et al. 2017). In this dissertation, I coin the term “posthuman interaction design” in part to honor the intellectual legacy of posthumanism, and in part to avoid the loaded meanings (e.g., previous work has a heavy focus on domestic animals and plants, such as pets and crops) already inscribed in other terms.

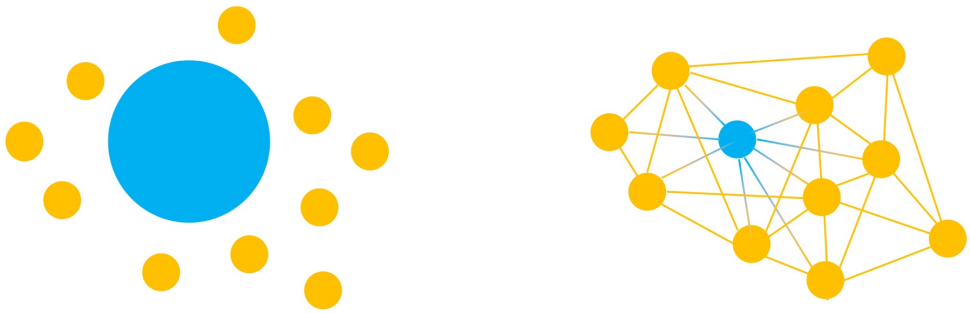

Figure 1: From human-centered thinking to posthuman thinking. If we use the blue dot to represent human actors and yellow dot to represent nonhuman species, the goal of posthuman thinking is to move away from human-centeredness and isolation (illustration on the left) towards species interdependency (illustration on the right). Posthuman interaction design (PID) broadens considerations of design to include nonhuman stakeholders and multispecies relations.

It is also worth mentioning that although in my home field the terms Human-Computer Interaction (HCI) and interaction design are often used interchangeably (Sharp, Preece, and Rogers 2019), in this work, I intentionally choose the term posthuman interaction design to avoid blindly following the anthropocentric viewpoint embedded at the very term HCI itself. Another reason that I shy away from using posthuman HCI is to prevent describing all human beings—with different genders, races, ages, cultural backgrounds, sextual orientations, social classes, wants, needs, and desires—as homogeneous individuals. Again, this is not to suggest nonhumans as the right term nor to claim that there are no similarities or overlaps between designing for different species of stakeholders.

The term "nonhuman" will appear repeatedly throughout this dissertation. By nonhuman, I refer to all the other living entities—animals, plants, fungi, microorganisms and so on—that are not humans. The term nonhuman is not unproblematic, as it seems to oversimplify and violently homogenize everything that is not human and thus further intensifies human superiority. However, for the lack of a better word, when I must, I will use the term nonhumans to provide a distinction between humans and other species—as I acknowledge that it is even more absurd to claim that humans and everything else are all the same.[3] However, whenever possible, I will try to be precise about who exactly I am referring to, and I invite my readers to practice the same.

Finally, I acknowledge that it is indeed paradoxical to be writing about PID as a human. On the one hand, the intension of PID is to make sure that different species of stakeholders all have a say in the design process; on the other hand, I am not actually co-authoring this dissertation with plants, animals, or bacteria, I am also aware that myself and the readers—as humans, limited to

[3] For a more detailed argument supporting the use of "nonhuman", see Nathan Schneider's blogpost http://www.candidhominid.com/2011/10/animals-who-arent-human.html

human languages, capabilities, and epistemologies—are able to imagine. In fact, this dissertation itself is written in English, a human language with a strong Western philosophical legacy. To solve this paradox, I consider PID as a horizon to work towards to, rather than a laundry list that eventually leads to an (unrealistic) ideological world. In other words, what matters the most in PID is the practice and progress we made in trying to view the world from a different perspective.

1.2 How I Came to Posthuman Interaction Design?

In writing about practicing design, design philosopher Donald Schön suggests that the exercise of storytelling provides a way to see the world in a new light. Quoted in length, he writes, "students are often surprised at the stories they tell, and even more surprised at how useful their stories turn out to be. Where do their stories come from? And why is storytelling so often accompanied by a sense of discovery? On one view, the storytelling context leaves us relatively unconstrained by fear of criticism, allows us to 'speak before we have anything to say,' and thereby enables us to tap into our store of tacit knowledge—things we have known about this situation and its relations to other situations but had not made explicit to ourselves. Or perhaps storytelling enables us to piece together bits of knowledge we already possessed but had never assembled." (Schön 1990, 134). The dissertation, too, starts from a personal story, a story about my own struggles concerning the current design practices. Drawing from literary critic Katherine Hayles's book, "How We Became Posthuman" (1999), this section outlines the motivation of my dissertation research. This section is not meant to be read like standard academic writing but as a personal anecdote, as it is my intention to resist the impulse of constructing an argument from the outset. Instead, I aim to remain genuine and reflective to my personal values and make it visible to the readers; here is a short story of how I come to question the dominating paradigm of human-centered design.

Before embarking on my doctoral study, I was a product designer by training who strived to create user experiences that turn mundane or unpleasant moments into joyful and enjoyable experiences in life. In an older version of my personal website, I wrote that my goal is to "transform prose into poetry." By poetry, I mean designs that reflect the value, belief, experience, culture, quality, taste, and aesthetics of the user[4]. On one hand, as a seasoned designer, I am familiar with classical user-centered design theories, methods, and processes, which include ensuring product usability and user satisfaction, developing empathy to champion the users, thinking beyond individual users but involve all stakeholders, and engaging in the iterative product development cycle popularized as "design thinking" (T. Brown and Katz 2011; Stickdorn 2012; Norman 2005; Buchanan 1992; Hassenzahl and Tractinsky 2006; Wright and McCarthy 2008; T. Brown and Wyatt 2010). On the other hand, my design inspiration and process are not always so human-centered. Oftentimes, I find myself both unconsciously and intentionally drawing inspiration from nature—the softness of feathers, the hardness of marble, the warmth of wood, and coolness of metal, the patterns of bacteria colonies, the texture of honeycombs, the rhythm of rain, the colors of the summer fields—to search for the quality, aesthetic, and the uniqueness that I wish to capture in nature through form, material, and other tactics of materialization. Even though there seemed to be a tension between what I was taught to do and how I actually practice my craft as a designer, I was fulfilled then, knowing that I have the right set of tools and skills to turn prose into poetry. However, while working at an international personal computer design firm back in Taiwan, I found my passion in presenting the beauty of nature at odds with the waste and pollution generated during such a pursuit.

[4] Full disclosure: I changed this motto only very recently, not only because it seems too abstract for the majority of my readers but also because it no longer captures the ethical and political dimension I aim to address in my work, which is not always so poetic or pleasant to the viewer.

A typical product development process looked more or less like this: the project manager kicks off a project by offering a design brief, the designer moves forward to do some quick research on the use scenario and potential competitors, propose design ideas using sketch, 3D modeling, 3D rendering, and physical prototyping. In the product development phase, there are several runs of prototyping involved before it moves towards mass production: sample run (SR) focuses on proof of concept, which require a making mock up samples for design and mechanical validation; engineering run (ER) or engineering prototype aims at producing a small batch of engineering samples (e.g., 10 pieces) to be used for tooling design and iteration, as well as tech and process validation; and finally, product run (PR) or production verification test (PVT) requires a larger test batch of product samples produced (e.g., 100 pieces) for production system stability evaluation and tooling final refinement. During these various verification phases, hundreds of samples were shipped from the production factory in China to our design studio in Taiwan for inspection. Our office space was always crowded with shipping boxes and samples that yearly cleaning has become not only a routine and but also a requirement.

Every year around spring, the trucks came to pick up the product samples that were no longer needed, sending them to landfills. I have never visited a landfill, but I imagine it as a place filled with wastes that do not decompose even after hundreds and thousands of years. The wastes and debris that do not make it to landfills might end up in a remote island out of human sight but continue to harm, poison, or suffocate birds and marine animals[5]. In my mind, the landfill is a "death zone" where it remains silent and lifeless even in spring (Carson 2002). As a designer, I

[5] See Photographer Chris Jordan's on-going artistic photograph collection "Midway: Message from the Gyre". http://www.chrisjordan.com/gallery/midway/

felt that I am responsible for turning a once beautiful planet into a blasted landscape— in the name of pursuing design rigor and servicing user experience.

American architect R. Buckminster Fuller once said, “you have to make up your mind either to make sense or to make money, if you want to be a designer.” (Papanek 1972, 86). I have made my choice back then, but I had little clue how do create designs that make sense in a corporate setting. I was lost then as a young designer. My training had taught me that a designer has more to do than creating a sleek, shimmering shell to fit all necessary electronic components, and the teachers had held us accountable in creating positive changes we wished to see in the world. I was taught that design goes far beyond boosting consumerism and profit (although it is often part of it); design is also about promoting inclusivity, diversity, participation, creativity, and sustainability. However, as a young designer, I did not know how to maintain all these seemingly far-fetched goals while making sure that my designs meet the sales expectations. I took on the path to become a designer with the passion of turning prose into poetry and showcasing the beauty of nature, but I ended up producing wastes so gigantic and toxic that the Earth can no longer digest.

In writing about my own struggle in creating design that really matters, my intention is not to criticize the product development cycle at my previous workplace as intrinsically unsustainable or unethical. In fact, such a process is commonly practiced in design firms and manufacturing facilities across the globe; it might be fair to argue that a rigorous process is necessary in creating products of high quality and endurance to reduce disposal and wastes. Rather than focusing on finding an alternative design process, I believe it might be more effective if we start from reflecting on the design *orientation*. Back then, I had no solid clue how to achieve so in a large corporate setting, so I left to search for possible answers. Realizing that an innocent or virtuous

intention of showcasing the beauty of nature can end up producing harmful substances that murder its liveness was indeed a traumatized experience, but it has also led me to commit to forging together a stronger connection between design practices and environmental sustainability.

This dissertation tells my journey working toward finding what alternatives design practices might be. Presented in a series of empirical, methodological, and theoretical experiments I conducted during my doctoral research. This work focuses on finding alternatives to human-centered design, resists the trap of the progress narratives, and explores ways of cultivating attentiveness and sensitivities towards the diverse actors that reside with us in the biosphere.

1.3 Reorienting Attention to The World

Although my personal attachment to nature and concern of climate change plays a major role in motivating this research, the call to reorient our attention away from designing exclusively for humans towards including nonhumans can be useful to anyone interested in design and design research. In this session, I offer a few reasons as to why PID complement HCI and interaction design. The goal is not about offering a comprehensive laundry list but to better articulate the shared values, goals, orientations, and approaches between PID and HCI.

Elevating user experience for all. HCI has a long-standing commitment in creating products, interfaces, and services that offers not only usability but also positive user experiences—name it efficiency, effectiveness, ease of use, joy, fulfillment, satisfaction, or fun—to users with different needs, abilities, and constrains (McCarthy and Wright 2004; Hassenzahl and Tractinsky 2006; Rusu et al. 2015; Bødker 2006; Wright and McCarthy 2008; Sharp, Preece, and Rogers 2019). To achieve this goal, design for accessibility and inclusiveness has been one of the major

research areas in interaction design (Holmes 2018). Companies like Google[6], Microsoft[7], and Apple[8] all have deliciated design guidelines and developer tools to promote accessibility and inclusion, because when the voice of one user is not being heard, it ends up discounting or jeopardizing the experience for all stakeholders involved (Holmes 2018). For example, wild species are often neglected in urban planning initiatives, and the loss of their natural habitat have caused many conflicts between urban dwellers and wildlife (David E. Williams 2006; D. J. Metcalfe 2015). In short, underlying PID is the idea that overlooking the needs of nonhuman stakeholders (e.g., wild animals in urban spaces) undermines the quality of the entire user experience we aim to provide through design. In other word, I argue that if HCI were to design better user experiences, we need to reorient our attention from the user as a surface level to the product ecology in order to avoid oversimplifying the problems. For the same reason, in most places in this dissertation, I intentionally replace the term "user" with "stakeholder" to describe the heterogeneous entities (whether they are humans or nonhumans) who are involved in the design process or are affected by the design outcome. However, there are also exceptions. Considering the long-standing tradition of the term "user" and subsequently "user experience," a typical "user," or an extreme "user" in HCI, I do use these terms often to help better communicate with my readers—drawing from the concept of "boundary objects" (Star 1989).

Attending to and challenging power. More recently, researchers in HCI has shown an increasing interest in attending to the large-scale social challenges such as environmental sustainability, economic development, global labor, participatory and responsible AI, and urban planning. The topics of issues the HCI community are tackling are increasingly complex and

[6] https://www.google.com/accessibility/
[7] https://www.microsoft.com/design/inclusive/
[8] https://www.apple.com/accessibility/

wicked. When providing a single clear solution becomes impossible or inappropriate, interventions often "raise questions of privileging some values and stakeholders over others" (Dombrowski, Harmon, and Fox 2016). Similarly, the Anthropocene not only surfaces but also aggravates issues of injustice and oppression among marginalized populations (e.g., climate refugees, endangered species). In a time when doing intervention is not business as usual, a posthuman design orientation offers us sensibilities to recognize unequal power structures and to work toward mitigating injustice and discrimination. It is worth mentioning that with the goal to engage with the knowledge and experiences of the "other," this work challenges "scientific oppression" and thus is inherently critical (Halpin 1989)—later in this dissertation, I will introduce related work that has significantly shaped my understanding of PID.

Designing for the real world. Although the topics and orientations in HCI research are diverse and myriad, their shared, pragmatic commitment is to tackle real world problems. When challenges raised and intensified by climate change (e.g., food insecurity, global pandemic, species extinction, refugees and homelessness, etc.) become the new norm, it is time for HCI researchers to attend to the new challenges and work toward a collective solution. As Victor Papanek (1972) has long argue, "we must stop defiling the earth itself with poorly-designed objects and structures," it is necessary to reorient our attention away servicing short-term industry profit goals. Many business owners are now paying attention to their corporate social responsibility (CSR); overtime, we might see more activist practices among private sectors. To be clear, I am not asking everyone to become posthumanist or environmentalists; rather, inspired by previous activist works (Harding 2008; S. Bardzell 2018; Grusin 2017), I suggest critically reflecting on our own agenda and politics, as well as being mindful of the possible consequences our technoscientific interventions might bring.

Making other worlds possible. Design is always future-oriented and is inherently about change. As Dunne and Raby mention, design is about "changing reality rather than simply describing it or maintaining it" (Dunne and Raby 2013, 3), it is safe to say that to design is to make statements about the future. To Dombrowski, Harmon, and Fox (2016), the practice of interaction design goes far beyond creating new material artifacts; it also concerns ways in which "new technological objects afford new practices, social habits, and ways of living and interacting." The orientation towards change and transformation remains in PID. On top of an orientation towards change, PID also offers to HCI is a highlighted sensitivity and tool of inquiry into better understand what constitutes the alternative futures we are creating. Following Taylor (2020), living in the precarious time of the Anthropocene surfaces the entanglement between sociotechnical intentions and multispecies relationships; I argue that PID provide a useful lens to imagine ways of making other worlds possible.

As I will illustrate throughout this dissertation, although PID challenges some of HCI's taken-for-granted assumptions and long-standing design paradigms, it is compatible and complementary to HCI. An interaction design project may be posthuman in its *epistemology*, in that it draws from posthuman concepts or theories; in *orientation*, in that it takes actions to decenter the privileges and empower the margins; in *intended users*, in that it attends to or services the needs of non-traditional or marginalized users, especially nonhumans (e.g., animals and plants); in *process*, in that it encourages a constant and fluid change in perspectives and identities; and/or in *form*, in that it challenges dominate forms of representation by experimenting novel ways of communications and unconventional emotional and sensory encounters. Joining HCI's recent scholarly activist move in addressing power, oppression, and participation (N. Smith, Bardzell, and Bardzell 2017; Forlano 2016; Jen Liu, Byrne, and Devendorf 2018; Light, Powell, and Shklovski 2017; Dombrowski, Harmon, and Fox 2016; Blevis 2018; S. Bardzell 2018), my work

in PID argues decentering the human in design, overcoming the shadow of the anthro-, and working towards a more ethical and responsible way of engaging with technological intervention.

1.4 Positionality

Speaking of the necessity of reflecting, acknowledging, and writing about positionality, critical anthropologist Soyini Madison argues, “when we turn back on ourselves, we examine our intentions, our methods, and our possible effects. We are accountable for our research paradigms, our authority, and our moral responsibility relative to representation and interpretation.” (2020, 23). Similarly, to indigenous researcher Linda Tuhiwai Smith, “reading and interpretation present problems when we do not see ourselves in the text. There are problems, too, when we do see ourselves but can barely recognize ourselves through the representation.” (2012, 37). Finally, to Dooren, Kirksey, and Münster (2016), a reflection on individual positionality is crucial as we reorient our attention away from human centeredness towards a multispecies worldview. They write, “multiplying perspectives is not simply about assembling diversity, nor is it about the adoption of an easy relativism; rather, it is about ‘staying with the trouble’ in an effort to meaningfully navigate one’s way through the complexity of worlds in process. This navigation is fundamentally a question of ethics and politics.” (2016, 11–12). I was lucky enough to have encountered these feminist scholars early in my doctoral study to acknowledge that my personal ethics and politics play a critical role in my engagement with PID. I provide a short description on my positionality to make visible my personal privilege, power, and biases in this section as well as throughout the dissertation.

Reflecting back on how I began to question human-centered design, I recall feeling confused and powerless in my own voice and actions. In fact, a large part of this research started with my first-hand experience of oppression; I do not like it and I want to change it. To being with, as a

junior designer in a multinational corporation, I did not know how to "challenge industrial agendas" (Dunne and Raby 2001) or creating designs that benefit the ecosystem; as a doctoral student in computing and engineering, I feel marginalized for not coming from a STEM background or trained to do "good science" (which oftentimes involves a shallow perspective associating science rigor with positivism, quantification, and generality, rather than constructivism and subjectivity); as a female in computing, I find myself trying hard to live in harmony with the masculinity in my workspace, which often includes adapting my personal preferences to cater the likings of my male colleagues; as an immigrant in a Western institution, I often lack the linguistic or cultural background to effectively communicate my thoughts or voice my concerns. As D'Ignazio and Klein (2020, 167) described, "white people […] have a hard time naming and talking about racism. Men have a hard time naming and talking about sexism and patriarchy. Straight people have a hard time seeing and talking about homophobia and heteronormativity", my commitment to challenge the dominating human-centered design paradigm, too, was driven by my personal encounters on the "structural forces of oppression." (D'Ignazio and Klein 2020).

Interestingly, and perhaps counter intuitively, the other side of my encounter on oppression is a sense of empowerment. Specifically, having a solid training in product design, I possess proficient visual and crafting skills which are powerful tools for both research and intervention; as a design practitioner, I have the skillsets in actively participating in creating the future I prefer; as an immigrant, I am capable of understanding different cultural values, traditions, implicit norms, and communicative actions. Together, my multi-cultural and interdisciplinary background have shaped my way of knowing and thus guide the direction of this dissertation.

And finally, as I began to write this dissertation, it has become increasing clear to me that my way of viewing, knowing, and reasoning is heavily shaped by Western philosophical traditions. I suspect that the whole realm of posthuman thinking, for example, however deeply connected with modern technologies and their implications, is neither novel nor alien to other non-Western cultures. For example, rather than considering humans and animals as entities that are separated in two distinct realms, Mi'kmaq cosmologies always "portray animals as siblings to humanity" (Robinson 2013). For this reason, it is worth emphasizing that the intended audience for this dissertation is technology and design researchers who are, similar to me, trained by Western philosophies. Meanwhile, I believe that this work might still be of interest to those who are familiar with indigenous and postcolonial epistemologies as it explores how these modes of thinking might be applied to contemporary technologies to create more resilient futures.

1.5 Research Questions and Goals

To attend to the ever-raising concerns on environmental crisis, community welling, and social injustice, I conducted a series of field studies to investigate how human-nature interaction might be otherwise when we reorient our attention from designing for human stakeholders to also incorporate the perspectives and voices of different species. While each study in this doctoral work held its own research questions and motivations at the time of investigation and analysis, this dissertation focuses on addressing the following high-level question:

> How might technological intervention amplify the agency of different species to support more sustainable, inclusive, and aesthetic forms of human-nature interaction?

Made explicit here is my confrontation with classical human-centered design principles and design approaches that privilege the dominant narrative. In its essence, the questions involve in

this doctoral work concern exploring alternative theories, practices, and applications for PID. There are three subsequent questions that emerge from this inquiry, each of which builds on the preceding questions. It is perhaps worth mentioning that the research questions included in this dissertation all stand in the intersection of human activities, computing, and the biosphere. For the following of this work, I will address one of each question through different chapters in my dissertation work—one per study:

1. How might interaction designers incorporate natural phenomenon and nonhuman stakeholders into their creative processes? This inquiry focuses on the design process to explore both high-level theories and actionable strategies regarding designing *with* human-nature interaction.

2. How might collaborative and responsible forms of human-nature interaction inform alternative design processes and technological systems to achieve sustainability? This question explores ways *through* which interaction designers might draw from existing symbiotic relationships between different species to develop new process and systems that attend to the needs of both human and nonhuman stakeholders.

3. How might we better engage with the environment to promote environmental justice, resilience, and sustainability through interaction design? This inquiry investigated both the technological limitations and possibilities concerning interaction design paradigms, methodologies, and applications to design *for* more socially just and sustainable forms of human-nature interaction.

1.6 Dissertation Organization and Contributions

In this section, I outline the scope and structure of this dissertation as well as the intended contributions. As I have argued in the previous section, I believe that this work will not only be of interest to HCI researchers and interaction designers who work on topics closely related to environmental sustainability and, but also for those who want to address issues of social justice, creating better user experiences, and designing for the real world in general.

1.6.1 Dissertation Outline

The dissertation is divided into three parts. Part I introduces key concepts, HCI literature, and research methodologies central to PID. Specifically, Chapter 1 provides a general sketch of this work, including the motivation of PID research, the scope of my work, the research questions, goals, as well as contributions. The stories will be told with a combined style of personal narratives and scholarly arguments. In Chapter 2, I review and synthesize literature in HCI and design that has contributed review to the foundation and understanding of PID; encompassing works in sustainable interaction design, posthumanism and the nonhuman turn in technological design, as well as works that attend to and draw from the margins for innovation (e.g., commitment to social justice design, rural computing, design for animals and plants). The work included in this chapter play a significant role in informing my research trajectory and analysis. Chapter 3 outlines the methodological foundation of my research and the research methods that I employ in my study, combining together arts-and-design based methodologies (e.g., visual thinking, research through design, and artifact analysis), social science and ethnographic approaches (e.g., virtual ethnography, multispecies ethnography, critical qualitative inquiry), and approaches originated from the humanities (e.g., close reading, interaction criticism).

Part II of this work includes chapter 4 to chapter 6 which offers three empirical studies to investigate ways of amplifying nonhuman agency with, through, and for human-nature interaction. To explore the landscape of PID, I intentionally chose field sites that are very distinct from one another, including one in a more controlled environment ("the lab"), one in the rural farming villages ("the rural"), and another in the cityscape ("the urban"). Each setting provided distinct affordances, embodiments, arrangements, manifestations, and constrains concerning the interrelation among human-nature interaction. Part II is comprised and adapted from a collection of studies previously published in top-tier HCI venues, illustrated in below.

In HCI and many other fields, "the lab" is a controlled environment where ideas initiated and tested before deploying to "the wild." In Chapter 4, I use the lab as an analogy to illustrate a series of art studio practices, which involve activities such as visual thinking, design critiques, sketching, crafting, making, and design reflection. This chapter investigates strategies of designing *with* human-nature interaction to provide answers to the question, "how might interaction designers incorporate natural phenomenon and nonhuman actors into their creative processes?" I began this work from curating and critiquing hundreds of exemplars in design and its analogous fields to unpack the posthuman concept of decomposition. Through design curation, analysis, and experiment, I propose "scaffolding" and as an interaction design theory accompanied by its actionable tactics (namely fragmenting, aging, liberating, and tracing) for those who are interested in experimenting natureculture co-creation. Through this study, the abstract concept of decomposition is materialized using ceramics as a medium. Drawing from posthuman theories, the study illustrates an alternative pathway to innovation by considering design activities not as a pure cultural practice but as a creative space where humans "can be both actively involved and passively fascinated" (Hitchings 2006, 376). By incorporating more-than-human agencies in the creative process, the theoretical concept of natureculture is

translated into actionable design tactics to add value, character, function, aesthetics, and sustainability to design.

Building on my previous study on natureculture collaboration and co-creation, I became interested in understanding how the collaborative relationship between human and nature might be applied to a different context, such as from making things together to growing foods together. Chapter 5 presents my three-year ethnographic fieldwork with small-scale farmers in rural Taiwan to answer the question, “how might collaborative and responsible forms of human-nature interaction inform alternative design processes and objects?” For those farmers who I engaged with, the farm is not so much a system, but an assemblage characterized by multiple systems or rationalities always evolving and changing. Through working alongside with eco-friendly farmers, I gradually learned to see weeds and pests not as something to be eradicated but as inhabitants with whom we share the land. Through embodied understanding of the earth, I then moved on to create a compost sensor that tracks different attributes of soil (e.g., temperature, humidity, biometric movements) and translate the digital reads into acoustic representations. On the one hand, the soil sensor physically manifests the embodied, intimate, and aesthetic relationship that farmers shared with the soil. On the other hand, the design contributes to HCI research by exploring novel and alternative algorithms, data processing, and data representation models considering how interactive technologies might support human-nature engagement.

Following previous chapters on exploring ways of cultivating intimacy with the biosphere through technology, Chapter 6 focuses on narrating environmental data to support public awareness, civic engagement, and sustainable behaviors. Over the past decade, the emergence of low-cost sensors, proliferation of personal devices, and expansion of wireless networks have made it possible to collect air pollution data at an increasing granular level. However, there is still a gap

between generating fine-grained environmental measurements and turning data into actionable representations to protect citizen health and inform policy. Data does not speak for itself; it must be interpreted to have meaning (Dourish and Cruz 2018; D'Ignazio and Klein 2020). Different data visualization models such as graphs, scales, and dashboards have proven to increase environmental awareness and support decision-making; however, they can be abstracted away from the embodied experiences people have with the environment, risking over-simplifying data as prescriptive devices rather than tools support open-ended reflection to inform sociocultural practices. Grounded on a two-phase design fieldwork with urban residents, this chapter provides a critical reimagination of environmental representation and outlines design strategies couple air quality data with the embodied experience of individuals to increase awareness, support sense-making, and inform practices.

Finally, Part III provides a synthesis of the works involved in this dissertation and outlines the implications and contributions PID offers to HCI research and design. In particular, Chapter 7 explores the proposition of PID in depth by analyzing works in the preceding chapters with a layer of abstraction to explore the theoretical, methodological, and sociotechnical contributions my dissertation may offer to the broader HCI and interaction design community. In sum, I argue that if HCI is to better connect human and nature through technological intervention, it should cultivate the sensibility to recognize that culture and nature are never separated, regardless of the settings and activities. I illustrate through design examples to provide concrete strategies.

Throughout this work, there are three different voices speaking—this is a conscious decision that intends to truthfully illustrate what actually happened in the inquiry and to render visible the intellectual contributions offered by my collaborators. Specifically, in Part I and Part III of this work, I use the term "I" to refer to either my old self who conducted the original studies or the

newer me who does the analysis and synthesis after completing all three studies. In comparison, in Part II, I use the term “we” almost exclusively to capture the collaborative nature of the studies. The only exceptions are in the introductory paragraphs where I use the term “I” to describe the newer me who conduct the synthesis while putting together this dissertation. Additionally, to better guide the readers, I include a footnote at the beginning of Chapter 4-6 to describe in more details where my collaborators participated in the inquiry and contributed to this work. Finally, related to the topic of intellectual and creative property, I note that all images and photos included in this dissertation are made by and belong to myself, unless otherwise noted.

1.6.2 Intended Contributions

With the focus on amplifying the agency of nonhumans through design, there are three main pillars in my research. First, coming from the field of HCI, much of the emphasis is on exploring the applications and implications of emerging technologies (e.g., Internet of Things, Artificial Intelligence, precision agriculture.) In addition, I bring in literature on sustainable interaction design as the second pillar of research in order to attend to my concern on environmental crisis and think about the broader environmental impacts of technology. Lastly, I draw from posthuman theories to shift the attention from a human-centered perspective in HCI to one that also incorporate nonhumans as stakeholders. By positioning this work at the intersection of emerging technologies, sustainable interaction design, and posthumanism, this work has the potential to provide the following three contributions.

First, on an *empirical* level, this dissertation illustrates three different encounters with nonhumans to explore how interspecies relationships might add value to design. In particular, I leverage the natural phenomenon of decomposition as a creative process (chapter 4), learn to see weeds and pests in eco-friendly farms as companion species (chapter 5), and trace perceptions of air

pollution in urban spaces to increase environmental awareness (chapter 6). By investigating and analyzing these human-nature encounters from a posthuman lens, the stories foreground interspecies dependency and entanglement that may have been latent.

Second, on a *theoretical* level, this work translates high-level posthuman concepts into trackable interaction design theories and design tactics. Specifically, I propose concepts such as scaffolding (chapter 4) and working with nature (chapter 5) as well as their accompanying design strategies to mobilize posthuman thinking. Collectively, these concepts lay the foundation of posthuman interaction design (PID), which not only problematizes human-centered thinking but also providing an alternative paradigm that incorporates and amplifies different species in design.

Finally, this work also offers a *methodological* contribution. Specifically, while there are previous explorations on multispecies ethnography and multispecies interaction design (Kirksey and Helmreich 2010; Forlano 2016; Liu, Byrne, and Devendorf 2018), it is still an underexplored area in interaction design and HCI. In this work, I combine methods from social science, arts-and-design, and the humanities to orientate attention away from the human and to cultivate a sensitivity towards noticing, listening, and responding to nonhuman stakeholders.

Chapter 2.

Interaction Design in The Era of Conflicts and Crisis: A Review

> We stand now where two roads diverge. But unlike the roads in Robert Frost's familiar poem, they are not equally fair. The road we have long been traveling is deceptively easy, a smooth superhighway on which we progress with great speed, but at it end lies disaster. The other fork of the road—the one "less traveled by" —offers us last, our only chance to reach a destination that assures the preservation of our earth. The choice, after all, is ours to make.
>
> – Rachel Carson[9]

> Every ant knows the formula of its ant-hill, every bee knows the formula of its beehive. They know it in their own way, not in our way. Only humankind does not know its own formula.
>
> – Fyodor Dostoevsky[10]

The environment has always played a critical role in human activities. With an increasing pressure on climate change, ecological disaster, and economic decline, designing in the Anthropocene is no longer business as usual. Instead, we are facing unprecedented sociotechnical challenges and questions when it comes to technological intervention. For example, how may we develop

[9] Rachel Carson. *Silent Spring*. Houghton Mifflin Harcourt, 2002. (First published in 1962).
[10] Quote from philosopher Fyodor Dostoevsky. Original source unknown.

sociotechnical systems to help us address issues of uneven resource distributions and adapt to the future of resource scarcity? How may we design to mitigate food crisis when the global food system is disrupted by natural disasters, pest plagues, and intensified by socioeconomic turbulence such as economic recession and political conflicts? How may we build communities that stays resilient to climate change? How may we protect the inhabitants from different forms of pollutions to ensure community health? How may HCI researchers and interaction designers play a part in environmental planning initiatives and public health decisions? Indeed, these are wicked problems without any simple solution; while one can easily feel discouraged in trying to address these complicated challenges, we are not entirely clueless.

This chapter introduces the main literature I engage with in exploring ways to design in the Anthropocene. Specifically, I review works that lay the foundation of Posthuman Interaction Design (PID), including previous research on sustainability interaction design, posthuman theories and its implication to the nonhuman turn in HCI, as well as works that focus on technology for marginalized or underserved populations. In particular, the discourse of sustainability interaction design offers me useful frameworks, critiques, and focuses that scaffolded my dissertation, posthuman concepts provide me theoretical foundation and analytical strategies to attend to the diverse and dynamic entanglements between human and nonhuman actors, further expanding considerations of sustainability to also incorporate different species in the ecosystem. Lastly, following the thread of decentering humans in design, I draw from literature that challenges scientific oppression and advocate concepts such as participation, emancipation, pluralism, and social justice; related works that share similar commitments include feminist HCI, ICT4D, HCI4D, rural computing, postcolonial computing and transnational HCI, intersectional HCI, critical race theory in HCI and so forth. Although it is out of the scope of this

dissertation to include a comprehensive review for all related works, I will introduce the key concepts in the literature that helped shaped my work in PID.

2.1 Sustainable Interaction Design

The term sustainable HCI (SHCI) and sustainable interaction design (SID) first appeared in the ACM CHI 2007 conference in response to the increasing concern on climate change, consumerism, and environmental pollution (Blevis 2007; Mankoff et al. 2007). Since then, the community of SHCI and SID have received enormous interests and attention. In CHI 2021, Critical and Sustainable Computing[11] first appeared as a new subcommittee to welcome research that focuses specifically on global sustainability and social justice; the formation of a new subcommittee exemplifies that SID/SHCI has entered a stage of maturity. A similar thread of research is computational sustainability, which aims to utilizing computations techniques and models (e.g., optimization and stimulation, data and machine learning, crowd-sourcing and citizen science) to help address societal and environmental challenges (Gomes et al. 2019).

To date, there are multiple threads of research that focus on different aspects of sustainability in HCI and interaction design; the topics include but not limited to sustainable agriculture and food systems, energy efficiency and maximization, collaborative environmental sensing, resource consumption and restoration, pollution monitoring and mitigation, waste reduction and management, infrastructure planning and maintaining, as well as pro-environmental behavior change and policy reform. Previous attempts were made in trying to arrive at a single definition of sustainability (Pargman and Raghavan 2014); however, considering the heterogeneity in

[11] The goal of this subcommittee is to promote diversity, inclusion, and justice to work toward a flourishing future. See more descriptions of the Critical and Sustainable Computing on https://chi2021.acm.org/for-authors/presenting/papers/selecting-a-subcommittee#Critical-and-Sustainable-Computing

research focuses and processes, I believe that it is not only impossible but also inappropriate (Silberman et al. 2014; Knowles, Bates, and Håkansson 2018). However, to work toward developing a workable research plan and providing more solid contributions to the community, in the context of this dissertation, I focus on three identical threads in sustainable interaction design, including theories and applications on persuasive sustainability, as well as frameworks on environmental justice that call attention to the politics regarding sustainability. In this section, I give an overview on the three threads of research on sustainable interaction design and describe how these areas of work contribute to my dissertation.

Despite the differences between definition, focuses, and approaches, works in sustainable interaction design share a same *orientation*—putting sustainability at the center of focus (Blevis 2007; J. H. Choi and Blevis 2010; Tomlinson et al. 2013; Nardi 2016; Raghavan et al. 2016; Fogg 2009; Knowles and Håkansson 2016; Disalvo, Boehner, and Knouf 2009; Remy et al. 2018; Liu, Bardzell, and Bardzell 2019b; Pargman and Raghavan 2014). Specifically, Blevis (2007) draws from product design and critical design to propose five guiding principles in regard to sustainable interaction design practices. His focus was on reducing the material impacts of technological interventions both directly (i.e., "linking invention and disposal" and "promoting renewal and reuse" through material selection) and indirectly (i.e., "promoting quality and equality" by allowing products to achieve heirloom quality, "de-coupling ownership and identity" to maximize product use, and "using natural models and reflection" that draws from natural processes and materials). Similarly, Mankoff et al. (2007) propose considering both sustainability *in* (reducing the material impacts of products) and *through* design (encouraging sustainable behaviors and decisions) to address issues of sustainability through interactive technologies. Remy et al. (2017) further define sustainability through design as the attempt "to develop technology that has an impact on sustainability through people's lifestyle" while considering sustainability in design as

"developing technology that is sustainable regardless of use"—the differences have to do with whether the technology is sustainable by itself or if it facilitates sustainable behaviors and practices; regardless of the approaches, works in SID/SHCI aim to contribute to sustainability through technological interventions.

One SID/SHCI framework I find particular useful in thinking about addressing issues of sustainability through design is a conceptual framework that considers building resilient future as "an iterative and evolutionary process involving interactions amongst people, place, and technology." (J. H. Choi and Blevis 2010). In particular, the helpfulness of this framework is that it breaks down the loaded and intricate term of sustainability into three major aspects to make it more workable. In my dissertation, Choi and Blevis's framework not only lays the foundation of my empirical studies but also guides me to reflect SID/SHCI's overemphasis on human-centered design thinking (people) and technology exploration (technology) while defining the dimension of place in a narrow sense that focuses on location-tracking and tagging. In chapter 2.2, I will go back to describe how SID/SHCI research has heavily focused on the cultural, material, and technological constructions regarding the concept of place but overlooked the natural environment and nonhuman stakeholders—insects, wild animals, bacteria, and microorganisms—who are part of the landscape.

Finally, it is perhaps worth mentioning that SID/SHCI are often used interchangeably within the community. In this work, I favor the term SID because it focuses on issues of sustainability without unconsciously putting human agents at the center—a similar reason that I choose the term PID as opposed to posthuman HCI (or nonanthropocentric HCI, which I will introduce later in this chapter). In this dissertation, I engage extensively with SID/SHCI literature to forge together a stronger connection between environmental sustainability and design practices.

2.1.1 Persuasive Sustainability

Within the discourse of SID/SHCI, one major focuses of research is to create systems that "convince users to behave in a more sustainable way." (DiSalvo, Sengers, and Brynjarsdóttir 2010). Notice the word "convince"—a large portion of SID/SHCI literature has to do with persuading the users to behave a certain way, which often involves correcting the current behavior of an individual or the common practices of a community. Indeed, SID/SHCI designers and researchers often rely on the metaphor of control (e.g., resource consumption) and correction (e.g., unsustainable user behavior) to achieve sustainability. Among the thread of persuasive sustainability, Woodruff and Mankoff (2009) emphasized on the actions of tracking and regulation. In their words, "environmental sustainability involves efforts such as monitoring the state of the physical world; managing the direct and indirect impacts of large-scale human enterprises such as agriculture, transport, and manufacturing; and informing individuals' personal choices in consumption and behavior." Building on this, predicting and monitoring energy consumption comprises a large portion of research (Costanza, Ramchurn, and Jennings 2012; Comber and Thieme 2013; Mauriello et al. 2017; Schwartz et al. 2013; Petkov et al. 2011). In most cases, the ultimate goal of behavior tracking is to provide feedback to either increase the awareness of undesirable behaviors, encourage sustainable behavior change, or assist pro-environmental decision making and social practices (Hasselqvist, Bogdan, and Kis 2016; Kjeldskov et al. 2015; Meurer et al. 2016; Lockton et al. 2014; Nkwo and Orji 2018; Brynjarsdottir et al. 2012).

Works in persuasive sustainability tend to frame sustainability as an awareness and persuasion problem; common narratives regarding persuasion include: "rais[ing] awareness of sustainable travel opportunities" (Meurer et al. 2016), "support[ing] people's sustainable intentions" (Rasmussen et al. 2017), and "stimulate[ing] cooperatives [to] reduce […] collective energy use"

(Hasselqvist, Bogdan, and Kis 2016)—all these strategies can be traced back to the goal of persuasive technology originally proposed by Fogg (2009)—"to create an intervention that succeeds in helping the target audience to adopt a very simple target behavior that can be measured." In short, the design strategies that have been most widely adopted focused either on "controlling" resource consumption to reduce waste or "correcting" unsustainable user behaviors to pro-environmental ones.

More recently, researchers have begun to reveal limitations regarding the model of control and correction; the concerns have to do with what to measure and consequently how to measure. Specifically, many have argued that building resilient futures requires a broader shift of attention rather than monitoring environmental conditions, regulating personal behaviors, and correcting individual behaviors (Dourish 2010; Petkov et al. 2011; Liu, Bardzell, and Bardzell 2018b; DiSalvo, Sengers, and Brynjarsdóttir 2010; Brynjarsdottir et al. 2012; Pierce and Paulos 2012; Møllenbach and Hoff 2012; Ringenson et al. 2017; Knowles et al. 2014). Within this thread, the concern is whether measuring individual behavior or behavior change is the right approach. For instance, Brynjarsdóttir et al. (2012) argue that persuasive sustainability over emphasizes resource conservation and optimization; its heavy reliance on the predictability of individual user behaviors has made it conceptually detached from complex reality of everyday life. Similarly, Møllenbach et al. (2012) demonstrate that persuasive sustainability tends to neglect societal norms and macrostructure while overemphasizes facilitating individual behavior change, making sustainability an unrealistic pursuit. Considering ways of measuring sustainability to evaluate whether a proposed approach is indeed sustainable, Remy et al. (2017) suggest treating evaluation as a case-by-case scenario to reflect the different goals. Specifically, they argued that sustainability may have to do with the design idea, the prototype, the system, the process, the user, or the outcome of an implementation; as a result, it is inappropriate to create a one-size-

fits all evaluation matrix. In short, recent works in SID/SHCI foreground the risk of oversimplifying issues of sustainability for considering tracking technologies and behavior data as prescriptive devices; instead, they suggest attending to the cultural, political, economic, and technical dimensions of sustainability as well as their implications to behavioral and social change.

2.1.2 Environmental Justice and Politics

As the community of SID/SHCI continues to grow throughout the years, the control and correction paradigm in persuasive sustainability is further problematized. For instance, a decade after the initial appearance of SID/SHCI, Blevis's (2018) expands conditions of sustainability to incorporate not only behavioral, material, and technical considerations but also the cultural and political dimensions in design; he writes, "I propose as a hypothesis that designers can influence even global policy by designing for respect, as a matter of sustainability." In this note, the focus of SID/SHCI research has expanded to policy reform; such an approach is also shared by many others (Thomas, Remy, and Bates 2017; Dombrowski, Harmon, and Fox 2016; Milano 2013). Other iterations on the SID framework of included adding digital infrastructure to the rubric (Preist, Schien, and Blevis 2016), as well as reorienting attention to the scarcity of global resource and the possibility of large-scale environmental breakdown when designing for environmental sustainability (Tomlinson et al. 2013; 2012; Nardi 2016). Collectively, recent works in SID/SHCI have foreground dimensions such as technical development, information accessibility, sociopolitical structure, and environmental constraints. The importance of critically reflecting technological interventions in their use contexts has become evident in designing and evaluating sustainable interactive technologies (Dourish 2010; Petkov et al. 2011; Liu, Bardzell, and Bardzell 2018b; DiSalvo, Sengers, and Brynjarsdóttir 2010; Brynjarsdottir et al. 2012; Pierce and Paulos 2012; Møllenbach and Hoff 2012; Håkansson and Sengers 2013; DiSalvo et al. 2010).

Following recent developments in SID/SHCI scholarship, we see that pursuing sustainability goes far beyond exploring novel technologies; instead, SID/SHCI considers a series of design challenges in with each intervention yields complex social and infrastructural implications. Concerning the multiplicity and complexity of sustainability, I explore in my dissertation opportunities for building sociotechnical systems that goes beyond the paradigm of control, correction, and persuasion. My intention is not to criticize the control and correction model as intrinsically bad, but to look beyond it, and to identify alternative and complimentary design paradigms for SID/SHCI. For example, reflecting on the dominating control model in persuasive sustainability, My co-authors and I (Liu, Bardzell, and Bardzell 2019b; 2018b) observe how small-scale experimental farmers manage their lands with a focus of cultivating symbiotic relationships between crops and wild species; to the end, we suggest moving away from the notion of working against individual behaviors towards working with the conditions in the given context.

To shift the focus from persuading individual behavior change towards addressing issues of sustainability by taking into account the broader sociocultural context, I am inspired by work that foreground politics of collective sustainability. For example, Dourish (2010) criticizes SID/SHCI's overemphasis on technology determinism and progress. To reorient our attention to focus on transforming collective social practices, he suggests "connecting people through their actions and their consequences" rather than "connecting people to their actions and their consequences." Through the notion of scale-making through technologies, his intention is to facilitate environmental movement by connecting people who share similar values, commitments, and interests (Dourish 2010). In the context of my dissertation, what is particular useful in the concept of scale is that it shifts the unit of investigation and analysis towards a collective unit.

To Dombrowski, Harmon, and Fox (2016), sustainability as a wicked problem that "is never about one person's resource consumption, but is always rooted in a multiplicity of stakeholders, power relations, and the already-existing unevenness of social life." In this perspective, a shift in the unit of analysis necessary as it provides an opportunity to explicitly account for "an undercurrent of class, gender, and race/ethnicity-based conflict around socio-ecological relations." (Goodling and Herrington 2015, 184). By treating SID/SHCI as a research area that requires direct engagement with the unevenness of social systems, their work brings to the forefront questions such as who is served by design and who is neglected in the process. To re-politicize sustainability, they encourage researchers to critically and systematically practice three kinds of commitments, including "a commitment to conflict, a commitment to reflexivity, and a commitment to personal ethics and politics." (Dombrowski, Harmon, and Fox 2016). Specifically, when involving stakeholders with a multiplicity of values, perspectives, and goals, disagreements and conflicts are mostly likely to arise. In chapter 4-6, I will illustrate through three examples how different species of social actors negotiate through courses of conflicts to reach a common ground. Prior to that, it is necessary to introduce to the readers those social actors who are traditionally marginalized, underserved, oppressed, or excluded in design and technology—those whom we call nonhumans—including animals, plants, microorganisms, and many different lifeforms who share the planet with us human beings.

2.2 The Nonhuman Turn in HCI

Fictional novelist Ursula Kroeber Le Guin writes about how human-centeredness leads to tragedies; she says, "the fractal world of endless repetition is appallingly fragile. There is no illusion, even, of safety in it; an entirely human construct, it can be entirely destroyed at any moment by human agency. It is the world of the neutron bomb, the terrorist, and the next plague.

It is Man studying Man alone. It is the reality trap. Is it any wonder that people want to look somewhere else? But there is no somewhere else, except in what is not human, and in our imagination." (2009, 41). To her, looking around other world-making subjects and their ways of living is one of the ways to resist falling into the trap of human-centeredness. In reviewing literature, I noticed that HCI and interaction design research, too, have been "all too human." When design researchers and practitioners talk about users, we often picture them using demographic metrixes such as gender, age, and ethnicity; for those whom we consider as underserved populations, we usually refer to people with physical, social, financial, or intellectual challenges or disabilities. Except a few initiatives that focus on conservation and restoration, very rarely would we turn to understand and service users who are not humans.

Such is the case even in SID/SHCI research when the goal is to mitigate climate change and ecological disasters through technology. Going back to Choi and Blevis's framework (2010) that describes people, place, and technology as the three pillars of research towards building resilient futures, people and technology are often at the center of focus in previous works. Instead, when it comes to the notion place, the descriptions are often centered around hardware and software infrastructure as well as the cultural values and norms that situate human activities; oftentimes, there is no mention about the animals, plants, bacteria, and critters who are not only part of the landscape but also stakeholders of our technological systems. While previous work in SID/SHCI offers me useful theories and frameworks to engage with issues of sustainability, I was left with the question on how to account for and design with different lifeforms of stakeholders such as birds, insects, weeds, and soil. In trying to answer this question, I turned to posthumanism, a mode of thinking that challenges human-centeredness and the dichotomy of nature and culture. In the following sections, I will offer a short introduction to posthumanism, introduce the

concepts that lay the foundation of my dissertation, and describe how posthuman thinking has been taken up in HCI and interaction design research.

2.2.1 Posthumanism: A Lens and Two Concepts[12]

Earlier in this dissertation, I have argued that the concept of human exceptionality does not lead to building a resilient and prosperous future but the a "blasted landscape" (Tsing 2014). With the goal to design for a more sustainable and resilient future, part of my work is about finding an alternative model to guide design process that replaces human-centered thinking, a dominating paradigm of design that we have been taken for granted. In exploring ways of moving humans away from the center to cultivate a more inclusive and multispecies worldview, posthumanism is particularly useful as it provides a theoretical foundation to support the pluralization of perspectives. Following STS scholar Puig de la Bellacasa (2010), posthumanism is not about relinquishing humanity, nor does it aim to neglect humans in design; rather posthuman thinking is to "promote a mode of attention that resists falling automatically into the 'human' perspective. […] They enrich our perception of the complex articulations of agency, decentering individual human agency and considering the social as a tissue of associations between humans, nonhumans, and objects working in the realization of new relational formations." It is important to note that posthuman "does not really mean the end of humanity;" instead, what it suggests is "the end of a certain conception of the human." (Hayles 1999, 286). It refers specifically to the kind of humanism that asserts power, dominance, and autonomy.

[12] Part of this section includes the re-organization of a few different conference papers my collaborators and me previously published; previous works include "Symbiotic encounters: HCI and sustainable agriculture" in CHI '19, "Out of Control: Reframing Sustainable HCI using Permaculture" in *ACM LIMITS '18*, and "Exploring Noticing as Method in Design Research" in *ACM DIS '19.*

In this section, I introduce two posthuman theories that I draw extensively in this work, namely "natureculture" (Haraway 2003) and "the arts of noticing" (Tsing 2015). Coined by feminist STS scholar Donna Haraway (2003), the term natureculture seeks to overcome the straightforward dichotomy between nature and culture by thinking through ways humans coexist, cohabitate, collaborate, and co-create with nonhumans. The concept "the arts of noticing" and subsequently "noticing differently" were proposed by anthropologist Anna Tsing (2015) with the intention to reorient our attention from human-centeredness to seeing the world in a new light; I understand these two terms as the theoretical foundation that encourages moving away from designing for controlled systems to designing with multispecies stakeholders and shifting assemblages. In the following passages, I offer more descriptions to further situate posthuman theories in my dissertation.

To Latimer and Miele (2013, 11), the term natureculture is "a provocation for collapsing and transgressing the dominant metaphysics that dichotomizes nature and culture, and through which culture and all that is human is constituted as discontinuous with the rest of the world." In other words, what it suggests is a boundary crossing movement that challenges a taken for granted ontological divide in our modern traditions to instead advocate "human comes into being with this world" (Puig de la Bellacasa 2010). Useful in the term natureculture is its provocation in seeing and understanding the interdependency between human and nature. In thinking with natureculture, Haraway (2008, 19) writes, "species interdependence is the name of the worlding game on earth, and that game must be one of response and respect. That is the play of companion species learning to pay attention. Not much is excluded from the needed play, not technologies, commerce, organisms, landscapes, peoples, practices." The concept of natureculture has inspired interaction design researchers to notice what we tend to otherwise neglect (Light, Shklovski, and Powell 2017; Liu, Bardzell, and Bardzell 2018a), to redefine urban

spaces through the notion of cohabitation (N. Smith, Bardzell, and Bardzell 2017; DiSalvo and Lukens 2011), to explore the muddy ground between humans, nonhumans, and machines (Devendorf and Rosner 2017; Haraway 2006), and to reimagine the space of collaborative creativity (Liu, Bardzell, and Bardzell 2019a) to understand and illustrate it as a space where human actors "can both actively involved and passively fascinated." (Hitchings 2006, 376).

The term natureculture "signals how humans—and everything that humans are and do—are always in connection with the other nonhumans that make up the world at any one time" (Latimer and Miele 2013, 16). To anthropologist Anna Tsing, the ability to see the entanglement between human and nature is what she calls "the arts of noticing" (Tsing 2015). Tsing argues that paying attention to the multispecies encounters opens the door to "notice differently;" she writes, "the modern human conceit is not the only plan for making worlds: we are surrounded by many world-making projects, human and not human. World-making projects emerge from practical activities of making lives; in the process these projects alter our planet. To see them, in the shadow of the Anthropocene's "anthropo-," we must reorient our attention. […] These livelihoods make worlds too—and they show us how to look around rather than ahead." The arts of noticing take root in response to the current pressing ecological, political, and social concerns that we are facing, encouraging the re-examination of research assumptions, as means of pursuing alternative pathways towards preferable futures. However, to see "the divergent, layered, and conjoined projects that make up worlds" (Tsing 2015) is not an easy nor a pleasant task, as it involves paying attention to conditions of inequality and injustice (Haraway 2016; A. S. Taylor and Rosner 2017), cultivating the ability to acknowledge and simultaneously step in and out of familiar frames of reference (Lindtner, Bardzell, and Bardzell 2018; Liu, Bardzell, and Bardzell 2019b), as well as shifting the scales and proximity on questions about "what is and what can be" (Blevis 2018).

In the context of this dissertation, “the arts of noticing” is not only a theoretical concept but also a methodological provocation. Specifically, recent scholarship in interaction design has explored the notion of noticing as a strategy for cultivating alternative perspectives in design. Methods and approaches adapted or developed to “notice differently” have inspired researchers to engage with the challenges presented by environmental and social conflicts. Among them, Light, Shklovski, and Powell (2017) call to design for attentiveness; encouraging designers to reorient our attention from human-centeredness to our fellow-species with whom we constitute the world. Here, the arts of noticing involve the commitment of paying attention to situations that make us uncomfortable to avoid the conformity of “bovine design.” To others (A. S. Taylor 2017; Despret 2016), asking “the right questions”—the ones that acknowledge the agency of animals without anthropomorphizing them using human languages or imposing anthropocentric values—is the first step towards noticing differently. Specifically, Taylor defines the “the right questions” as those that “give animals the chance to convey their own interests and ways of doing things, and that give them the opportunity to communicate these to us humans.” (2017, 31).

In practice, the arts of noticing entail scholarly engagement in a myriad of nontraditional inquiry methodologies. For example, Lindtner, Bardzell, and Bardzell (2018) draw from feminist studies to inform their analytical sensibilities. In doing so, they contribute to the repertoire of social computing scholarship by expanding existing definitions of intervention for societal change. A different approach is experimented by Blevis (2018), in which he privileges visual components, as opposed to text, to show how design details reveal political tensions. He uses the example of production and design information printed on the back of iPhones to make visible the (unethical) boundaries between sites of innovation and sites of production. Additionally, Dew and Rosner (2018) employ the arts of noticing to consider the collection of timescales present in the range of environmental and ecological actors in a design practice. Drawing from their

ethnography in timber framing, where woodworkers interact with and respond to trees as living materials, noticing involves “reading and appreciating the material’s life history prior to and extending beyond the design moment without framing it solely in terms of its value to humans.”

Liu, Byrne, and Devendorf (2018) go further by designing, crafting, and embodying interventions for collaborative survival to both acknowledge and cultivate multispecies interdependency as necessary to persist in precarious times. To them, the arts of noticing are both hands-on and speculative, where they build multisensory tools to nurture a mutualistic relationship between humans and nonhumans. Livio (2019) enacts noticing through slow research with the American pika, a small relative of rabbits and a climate change indicator species. By carefully teasing out the relationships between pikas, humans, and machines, she reframes the biological concept of thermoregulation to add technology to its taxonomy. For my co-authors and I (Liu, Bardzell, and Bardzell 2019b), to notice differently involves inserting ourselves as design researchers to work alongside with eco-friendly farmers; by doing so, we learn how to see weeds and pests not as something to be eradicated but companion species to humans. Only after obtaining an embodied understanding of the earth ourselves, could we start to reflect and imagine ways of cultivating intimacy, as opposed to gaining control, towards the biosphere through technology.

In short, “the arts of noticing” have been explored as an approach related to decentering by contesting dominant narratives and questioning established ways of knowing in design research. Cultivating such arts include practices like close readings, developing embodied knowledge, maintaining long-term fieldwork commitments, as ways of surfacing and addressing pressing contemporary issues around social and environmental justice. While the concept of noticing has enabled researchers decenter dominant narratives and deconstruct knowledge hierarchies, there is a lack of methodological principles to guide this practice. In other words, it is not yet

clear to us, as interaction design researchers, how might we cultivate the sensitivity to "notice differently" and attune our bodies to recognize the world not as a system under human control but a "complex, dynamic, responsive, situated, historical" assemblages (Haraway 2017, M25). One of the goals I aim to achieve in this dissertation is to make posthuman theories more trackable and actionable for interaction design researchers and practitioners.

Finally, I note that there are various conceptual notions that also attempt to reconceptualize human relationship with nature. While it is beyond the scope of this dissertation to provide an exhaustive list of ideas that offer an alternative lens to study, analyze, and reimagine human-nature interactions, I do want to introduce two concepts that have also inspired work in SID/SHCI: similar to the posthuman concepts of "natureculture" (Haraway 2003) and "the arts of noticing" (Tsing 2015) that I draw from. Specifically, James Lovelock's Gaia hypothesis considers humans as "one of the partner species" who fully dependent on the living, responsive, and intelligent organism called the Earth (2009; 2007). Alternatively, Tony Fry uses the term "sustain-ability" to extend considerations of design by exploring ways to "sustain" all different aspects that constitute the world—lives, resources, and culture (2010). I encourage HCI researchers and designers to engage in literature outside of our field to "notice differently" (Tsing 2015).

2.2.2 Nonanthropocentric HCI

One of the most prominent examples concerning the catastrophic outcomes of human-centered design thinking is that of industrial farming. Specifically, in pursuing labor efficiency and profit maximization, industrial farming has developed high dependency on fertilizers, pesticides, and herbicides without adequately taking into consideration the capacity of the environment. Consequently, industrial agriculture and its analogous practices such as monoculture, intensive farming, and factory farming have resulted in the production of drug-resistant pests, virulent

diseases, industrial runoffs, and food insecurity. The underlying model for industrial agriculture lays the paradigm of control and correction and leads to undesirable socioenvironmental crises such as climate change, resource depletion, and global pollution.

To address the problems caused by human domination, HCI and interaction design researchers have proposed decentering humans in design—the term "nonanthropocentric HCI" describes the practice of considering "the human a single factor in a larger system of relations and interactions between humans and nonhumans alike." (DiSalvo and Lukens 2011, 421). In other words, the practice of decentering involves the realization that humans are neither detached from nor in control in the worldmaking process (DiSalvo and Lukens 2011; Forlano 2016; Liu, Byrne, and Devendorf 2018; N. Smith, Bardzell, and Bardzell 2017; Forlano 2017; Liu, Bardzell, and Bardzell 2019a; S. J. Jackson and Kang 2014; Jenkins et al. 2016). Drawing from posthumanism, nonanthropocentric HCI reorients our attention from a human-centered perspective to a multispecies worldview that foregrounds the moments "when species meet" (Haraway 2008). By decentering the human, it does not mean that humans are not important; rather, it is about placing humans back to the ecology rather than picture our existence as a privilege (N. Smith, Bardzell, and Bardzell 2017). Nonanthropocentric HCI is a relatively new area of research that emerges from and usually falls under the umbrella of sustainable interaction design (SID), but with a stronger commitment on posthuman theories when it comes to describing the complexity of environmental arrangements and the heterogeneity of stakeholders.

The discourse of nonanthropocentric HCI not only provides insights to design for multispecies interaction and cohabitation (Aspling, Wang, and Juhlin 2016; Mancini and Lehtonen 2018; N. Smith, Bardzell, and Bardzell 2017), it also reflects on how interspecies collaboration might open new opportunities towards global sustainability, collaborative survival, and aesthetic interaction

(Light, Shklovski, and Powell 2017; Aspling, Wang, and Juhlin 2016; Liu, Byrne, and Devendorf 2018; Lyle, Choi, and Foth 2015; Liu, Bardzell, and Bardzell 2018a). This is an exciting step in HCI toward nurturing a mutualistic relationship between humans and other-than-human actors with and through technology. For example, Smith, Bardzell, and Bardzell (2017) leverage three theoretical concepts in the Anthropocene—natureculture, hybrids, and decentering the human in design—to develop design strategies that refigure human-animal relations to support cohabitation and presumably even redefine cohabitation. The posthuman concept of "collaborative survival" was the jumping off point for Liu, Byrne, and Devendorf (2018) to design a set of wearable tools for mushroom foraging, and in the process, explore what post-anthropocentric design could mean. Light, Powell, and Shklovski (2017) challenge the prevailing "bovine design" model that compromises the needs of other species in service of human superiority. They call for the turn to the more-than-human world because it is "the least we might do as we strive for the grace to accompany fellow-species towards their own (and perhaps our) extinction." Furthermore, scholars in urban informatics have suggested integrating ideas such as hybridity (Devendorf and Ryokai 2015), coproduction (Devendorf and Rosner 2017), cohabitation (N. Smith, Bardzell, and Bardzell 2017), organic sensing (Kuznetsov, Odom, et al. 2011), and collaborative citymaking (DiSalvo and Lukens 2011) to expand the current landscape of designing interactive technologies.

Animal-computer interaction (ACI) is another neighboring field of research to PID (Mancini 2011). Except a few examples (Kobayashi et al. 2015; Pons, Carter, and Jaen 2016; N. Smith, Bardzell, and Bardzell 2017; French, Mancini, and Sharp 2016), works in ACI tend to focus on designing for domesticated animals, including creating interactive toys for dogs and cats (Trindade et al. 2015; Noz and An 2011; Baskin and Zamansky 2015), tracking and managing systems for farm animals or livestock (Makinde, Islam, and Scott 2019), and assistive or communicative

technologies for service animals (Melody M. Jackson et al. 2015; Zeagler, Byrne, et al. 2016; Zeagler, Zuerndorfer, et al. 2016). While domesticated animals are an important area of research and works in ACI provide me useful resources to build on human-centered design methods to design for nonhuman stakeholders, it is beyond the scope of this dissertation.

2.3 Sciences from the Margin[13]

In chapter 1, I have defined PID as the practice of designing interactive artifacts, systems, and services that take into account the needs of all stakeholders, regardless of whether they are human or nonhumans. I have also argued in prior sections that my home field of HCI and interaction design have been "all too human" when it comes to answering the questions such as who benefits from the design and who is neglected/hurt in the process. To explore strategies in decentering the human in design, this work was inspired by previous research that focused on stakeholders who are traditionally marginalized, underserved, or oppressed. Specifically, the works I draw from include feminist HCI (S. Bardzell 2010; S. Bardzell and Bardzell 2011; Erickson et al. 2016; D'Ignazio et al. 2016; Rode 2011; S. Bardzell 2018; Dennis et al. 2019), information and communications technologies for development (ICT4D), human-computer interaction for development (HCI4D), indigenous HCI, and rural computing (Hardy, Wyche, and Veinot 2019; Dillahunt 2014; Tomlinson et al. 2012; Dell and Kumar 2016), postcolonial computing and transnational HCI (L. Irani et al. 2010; Sultana and Ahmed 2019; Dourish and Mainwaring 2012; Awori, Vetere, and Smith 2015; Brereton et al. 2014), intersectional HCI (Schlesinger, Edwards, and Grinter 2017; Kumar and Karusala 2019; Trauth et al. 2012), and critical race theory in HCI (Ogbonnaya-Ogburu et al. 2020; Hankerson et al. 2016).

[13] The title of this section is inspired by feminist and postcolonial philosopher Sandra Harding's book (2008) *Sciences from Below: Feminisms, Postcolonialities, and Modernities*, Duke University Press.

One prominent common feature among the works I draw from is an orientation towards creating a more socially just world, which involves cultivating "sensitivities to inequality and marginalized voices" as well as a commitment to conflict reflexivity, and personal ethics/politics throughout the design process. (Dombrowski, Harmon, and Fox 2016). Overall, the shared goal is to engage and amplify the perspectives of "marginal users," including women, people of color, or individuals who are educational, financially, physically, or culturally challenged and oppressed (D'Ignazio et al. 2016; S. Bardzell 2010; Hayes 2020; Schlesinger, Edwards, and Grinter 2017). In other words, though works in this area have different definitions regarding who is in power and who is marginalized, they all aim to explore theories, methodologies, and systems that reorient our attention to the margins in order to promote participation, inclusion, emancipation, equity, and justice. It is beyond the scope of this dissertation to review all areas of work that have influence my doctoral research; however, here I offer a brief description to demonstrate how these previous works have inform PID, using feminist HCI as an example.

Following feminist theorist Bell Hooks who claims that "feminism is a movement to end sexism, sexist exploitation, and oppression" (2015, 1), feminist HCI researchers focus on issues of gender in design and call to treat gender more seriously. For example, Bardzell (2010) drew from feminist standpoint theories to advocate incorporating and alternatively privileging women's knowledge, perspectives, and experiences. She further proposed a constellation of qualities— pluralism, participation, advocacy, ecology, embodiment, and self-disclosure— as a general guideline for interaction design researchers and practitioners to integrate feminism into design and technology. She concluded by outlining two "general ways in which feminism contributes to interaction design", including *critique-based* study that leverage feminist lens to analyze designs and *generative research* that actively incorporate feminism approach in the decision making

process (S. Bardzell 2010). Rode (2011) went a step further to suggest researchers not only "engage with existing feminist theory" but also "create our own feminist socio-technical theory."

Through this (over-)simplified summary of feminist HCI, my goal is to illustrate how the large and diverse body of research I included at the beginning of this section provide useful concepts, approaches, and objectives for PID. Specifically, this dissertation engages with social justice-oriented interaction design research in three ways. First, responding to the pressing concern on climate change, I critically analyze the dominating human-centered design regime in interaction design and propose decentering the humans as an alternative approach. Second, I actively seek collaboration with underserved populations, such as nonhuman stakeholders, rural farmers, and community members who are at risk of environmental pollution to mobilize feminism "in decision-making and design process to generate new design insights and influence the design process tangibly." (S. Bardzell 2010). Finally, building on Rode (2011), this work draws from but does not stop at existing posthuman theories; rather, I will demonstrate throughout this dissertation how I leverage available concepts to first cultivate a sensitivity towards research then expand or concretize existing theories through field studies.

2.4 Towards Posthuman Interaction Design

By including a wide range of literature both inside and outside of HCI—sustainable interaction design, posthumanism, nonanthropocentric HCI, feminist HCI, rural computing and more—I do not mean to claim that this work would offer answers to solve different forms of social and environmental injustice; rather, my intention is to review works that share similar orientations, commitments, and goals toward building flourishing futures to motivate PID research.

Within the related work that I draw from, sustainable interaction design and feminist HCI are two relatively mature areas of research and have motivated recent work on promoting equity, diversity, participation, inclusion, accessibility, and social justice (Erete and Burrell 2017; Dombrowski, Harmon, and Fox 2016; L. C. Irani and Silberman 2013; Borning and Muller 2012; Schlesinger, Edwards, and Grinter 2017; Ogbonnaya-Ogburu et al. 2020; D'Ignazio and Klein 2020; Sultana et al. 2018; Baumer 2015). However, in my own reading, I notice that nonanthropocentric HCI remains relatively underexplored and marginal in the HCI discourse for the following three reasons; and with the goal of proposing PID as an alternative orientation, I would have to first address the following challenges in this work. First, as a fledging field, it is not yet clear how nonanthropocentric perspectives and posthuman concepts might be translated and applied into benefiting and expanding existing HCI theories, methodologies, applications, and findings. To address this, my preliminary work (Liu, Bardzell, and Bardzell 2018a) explores the visual and material language of nonanthropocentric design to help build an inventory for interaction designers interested in designing with, through, and for human-nature interactions. In addition, in this dissertation, I offer rich descriptions of my various field encounters with nonhuman stakeholders to mobilize and embody posthuman theories.

Another challenge that nonanthropocentric HCI, and thus a PID orientation faces, is the ingrained capitalist thinking that has fundamentally shaped our design practices. For a long time, the entire design and technology industry has been focused on profit maximization; while human-centered design provides useful methods and strategies in fulfilling the wants, needs, and desires of human stakeholders to encourage unsustainable purchasing behaviors, nonanthropocentric HCI focuses more on long-term sustainment of the planet. Capitalism is one of the most challenging issues in the modern society and it is far beyond the scope of this dissertation to address it. However, following Papanek (1972), PID aims to explore a different interaction design paradigm

that focuses specifically on creating works that “make sense” rather than “make money.” In this sense, the essence of PID is fundamentally different from capitalism and consumerism. While I do not intent to service or entertain any capitalist design agenda, I have illustrated earlier (chapter 1.3) and would demonstrate through the following chapters that a PID design orientation has the potential to both complement and benefit human-centered design, whether it is about elevating multispecies stakeholders or adding value to design.

Finally, and quite ironically, many arguments for decentering the human still rest on benefitting the humans, such as focusing on sustaining our own survival or wellbeing as a species (DiSalvo and Lukens 2011). I consider this as an inevitable paradox and a limitation of PID for the fact that myself and readers of this work are humans, and as humans, we are restricted to human languages, capabilities, epistemologies, and imaginations. Following Meijer, I also see PID as limited as it “remains anthropocentric because the human ultimately holds the strings” (Meijer 2019, 21:77). To tackle this inherent constraint, I suggest considering PID as a horizon to work towards to with which its destination may vary from project to project. To visualize this proposal, we can imagine human-centered design and nonhuman-centered design laying in two separate ends of a spectrum, in this imaginary, PID would situate itself in between the two extremes and is a process and practice that is always in progress. Similarly, what I try to offer in this work is not a laundry list that eventually leads to an (unrealistic) ideological world, but a set of practices that allows interaction designers to see the world in a different light.

Chapter 3.

"Arts of Noticing" for Posthuman Interaction Design

> We have a history of people putting Māori under a microscope in the same way a scientist looks at an insect. The ones doing the looking are giving themselves the power to define.
>
> -Mereta Mita[14]

> I think my problem and 'our' problem is how to have simultaneously an account of radical historical contingency for all knowledge claims and knowing subjects, a critical practice for recognizing our own 'semiotic technologies' for making meanings, and a no-nonsense commitment to faithful accounts for a 'real' world, one that can be partially shared and friendly to earth-wide projects of finite freedom, adequate material abundance, modest meaning in suffering, and limited happiness.
>
> -Donna Haraway[15]

In their seminal essay, Cooper and Bowers argue that "users are a necessary construct for HCI's legitimacy, in that they form a constituency awaiting adequate representation" (1995, 52). In this argument, the concept of "the user" is a discursive device central to the process of knowledge construction in interaction design and HCI. Key to their argument is that instead of treating the

[14] Mereta Mita, 1989. 'Mereta Mita On…', in *The New Zealand Listener*, 14 October, 1989, p30.
[15] Donna Haraway, 1991. *Simians, Cyborgs, and Women: The Reinvention of Nature.* Routledge.

concept of the users as a “rhetorical cipher,” they argue we should instead understand, illustrate, and most importantly, “represent” the lived experiences, nuanced identities, and complex feelings of unique individuals to motivate and guide technology development (Schlesinger, Edwards, and Grinter 2017; Satchell and Dourish 2009). Following Cooper and Bowers, in this dissertation, I draw from posthuman concepts while seeking to reconceptualize who the users are and resisting falling into the trap of human-centeredness as I attempt to represent them using human language.

However, while it becomes increasing compelling to me that posthumanism offers resourceful modes of thinking for making interaction design more sustainable, resilient, inclusive, and aesthetic, it is not an easy task to learn to understand and reconnect with the world through a posthuman lens. For one, the human-centered design (HCD) is simply prominent and ubiquitous to the extent that it has become a legacy defining not only what a good design is but also what should be included in design education. In other words, even if I were to expand considerations of HCD theories and methods, there is little guideline exist on how to do so. For another, posthumanism stays relatively distant to the field of interaction design and HCI, as its roles and contributions remains too abstract to be useful and applicable. For instance, as I first read about posthumanism, I was simultaneously fascinated by the possibility of humans “becoming with” with nonhuman species and bothered by how abstract this proposition was; obviously, I did not know how to do it. Reading did not help me much, as the majority of the work was done by anthropologists, whose background I did not share. I remember reading Haraway’s books one after another, and at one point I told my doctoral advisors that I needed to first become an anthropologist and go to some remote area to conduct ethnography for ten years before I can come back to continue working on my PhD in HCI. At that moment, I was facing some sort of existential crisis as a junior PhD student and were asking questions such as: as a human being,

how can I design for nonhumans stakeholders without falling into my (anthropocentric) habitual perceptions and interpretations? As a member of the HCI community, how can I help raise the awareness toward different species so we can better perceive, relate, and respond to nonhumans in design? Looking back, although it is certainly absurd to think that I need to complete a doctoral training in a different field before I can finish my PhD in HCI, these were good questions that I should be asking. After a few years of struggles and failures, I finally developed my own way of overcoming this existential crisis. And to me personally, it was to move from *reading* to *doing* and to resist the impulse of trying to figure out what to do exactly before experimenting (and failing) with different the approaches. Looking back, the approach that I am taking in writing this dissertation is deeply influenced by my own design background and the studio culture where I came from and will always be part of.

Just as designing in the Anthropocene is not business as usual, so does the commitment to engage in PID research. Specifically, it requires one to practice and engage in an alternative mode of knowing that challenges the dominate narratives, to cultivate and strengthen necessary sensitivities that see nonhumans as members who are integral to the ecosystem that we humans are part of, and to actively provide opportunities for others to amplify, augment, and attune their abilities to account for a wide range of perspectives. In other words, to work towards developing a PID as an alternative design paradigm involves exploring, creating, and experimenting new methodologies to mobilize Tsing's "arts of noticing" (2015). In this chapter, I will first introduce the methodological grounding of this work and the reasons behind using it (§3.1) and move on to discuss what and how I drew from a myriad of inquiry approaches in various field for my own inquiry in PID (§3.2). Finally, I will introduce the nature and composition of three different field sites I included in this dissertation—the lab, the rural, and the urban (§3.3). The texts included in

this chapter remains on a methodological level; more specific descriptions of the methods used in each field study will be provided in later chapters.

3.1 Reimaging the Margins: Methodological Grounding

> Critical approaches suggest we live in a power-rich context. These approaches seek to reflexively step outside of the dominant ideology (insofar as is possible) in order to create a space for resistive, counterhegemonic knowledge production that destabilizes oppressive material and symbolic relations of dominance. (Hesse-Biber 2017, 32)

In this work, I draw from critical epistemology to frame "the questions being asked, determined the set of instruments and methods to be employed, and shape the analysis" (L. T. Smith 2012, 144). At the heart of critical theory is its attempt to "reflexively step outside of the dominant ideology (in so far as is possible) in order to create a space for resistive, counterhegemonic (counterdominant) knowledge production that destabilizes oppressive material and symbolic relations of dominance." (Hesse-Biber 2017, 27). This critical approach has a metatheoretical basis rooted in Habermas' Theory of Communicative Action (Habermas 1984; 1985). Central to critical epistemology is its orientation to understand the relationship between power, value, thought, and truth claims (Carspecken 1996; Dennis 2018). In other words, meanings are constructed through communicative actions and are thus always intersubjective (e.g., between the researcher and the interlocuter, or between the participants and their social lifeworld). By positioning the process of meaning making as an intersubjective activity, critical qualitive approach provides me an opportunity to identify the social norms and implicit theories that might not become visible otherwise. Being a human, I recognize the difficulties in accessing the intensions, feelings, desires, goals, and lived experiences of my stakeholders, who may or may not be humans.

To mitigate this inherent gap and orient toward achieving a mutual understanding, I collaborated closely with my participants. That is, instead of treating the participants as "subjects" who are simply "out there" with facts to be discovered, the designers, farmers, and urban dwellers who I worked with are my interlocuters. These interlocuters engaged in various forms communicative acts with me, such as through speeches, physical interactions, written words, drawings, annotations, the designs they created, and even the crops they grew. In this work, the data collection and analysis are made possible by reconstructing the communicative acts. Before introducing in more details the methods I employed in this dissertation, let me begin this chapter by sharing the concerns and questions I had as I began this doctoral dissertation to describe why I find critical epistemology resourceful.

From the onset (when PID was only a vague horizon for me to work toward to rather than a term I use to describe my work), there were two main issues that I wanted to address in my doctoral research. First, I was troubled by climate change, or more specifically, how unsustainable design practices and purchasing behaviors induced global environmental crises such as resource exhaustion and species extinction. In my mind, no one benefits from climate change, but there are certain individuals and communities who are most affected by it. I remembered reading about how the Amazon Rainforest has been declining in unprecedented speed due to illegal logging and large-scale wildfire, how indigenous tribes were turned into climate refugees and being forcefully removed from their habitats, and how birds and marine animals die from plastic pollution and oil spill; there were simply too many tragic and heartbreaking stories to be told. To me, the ones who suffered the most were always the ones who were traditionally already being marginalized and oppressed. I came to realize that what I was concerned about was not (merely) climate change, but more preciously issues of social injustice that were brought to the forefront by climate change. Following critical theorist Phil Francis Carspecken, "criticalists find

contemporary society to be unfair, unequal, and both subtly and overtly oppressive for many people" (1996, 7), my desire to challenge the unbalanced power relationship reflects the activist value in the United States during 1960s and 1970s, where there were various social movements regarding women's right, civil right, and gay rights that aimed to support social transformation (Hesse-Biber 2017).

In addition to an orientation towards design for social justice and social change, an related aspect that I wanted to engage in my dissertation was to identify appropriate methods and strategies for interaction designers and researchers to "address new questions" (Hesse-Biber 2017, 30) and engage in "alternative ways of seeing" (J. Bardzell, Bardzell, and Blythe 2018, 6). I found Tsing's (2015) "arts of noticing" provocative as I began this work; she writes,

> The modern human conceit is not the only plan for making worlds: we are surrounded by many world-making projects, human and not human. World-making projects emerge from practical activities of making lives; in the process these projects alter our planet. To see them, in the shadow of the Anthropocene's "anthropo-," we must reorient our attention. (Tsing 2015, 22)

I was intrigued by the idea of reorienting attention to the world in order to "notice differently," but I was not quite sure how to do so as a design researcher who had no background in anthropology; and I was not alone. In fact, at one point during my doctoral study, several PhD students, who, like me, were concerned about issues of socio-environmental oppression and committed to support social justice for nonhumans (e.g., mushrooms, weeds, woods, pikas), formed a monthly reading group. Together, we read several books on topics including posthumanism, postcolonism, indigenous methodologies, and multispecies ethnography. However, after several months, we still had a difficult time identifying works that explicitly offered

methodological suggestions for design and technology researchers like ourselves. We finally came to a realization that 'maybe' there was no existing methods! At the end, we decided to co-organized a one-day design workshop to explore with HCI designers and researchers what "arts of noticing" might mean to the interaction design community (Liu et al. 2019). We did not come up with a comprehensive list of interaction design research methods at the end of the workshop as we focus more on evoking questions and facilitating reflections. However, it had become clear to us that cultivating the "arts of noticing" involves asking questions that are value laden, large scale, and wicked in nature.

To summarize, this dissertation has two main focuses: (1) a *social justice orientation* that seeks to "access subjugated knowledges—the unique viewpoints of oppressed groups" (Hesse-Biber 2017, 28) and emancipate individuals or communities that are left out in the event of climate change, and (2) a commitment towards *methodological exploration* that aims to create a reflective space for experimenting, practicing, and developing alternative inquiry approaches that differs from, but are complementary to existing HCI and interaction design methods to offer unconventional (counter-dominate) ways of seeing, hearing, thinking, and responding in order to fulfill the social justice orientation in PID. Critical methodology provides a great starting point to address both issues I try to focus on this work as it focuses on exploring "alternative ways of seeing" (J. Bardzell, Bardzell, and Blythe 2018, 6) to engage in socially just and responsible forms of technological intervention. Next, I introduce the interdisciplinary methodologies I explore and experiment in my doctoral dissertation.

3.2 An Interdisciplinary Approach towards "Noticing Differently"

I have argued that posthuman theories and methodologies, although have (proven) the potential to offer meaningful contributions, remain nebulous and abstract to the field of interaction design

and HCI. In other words, to practice and cultivate the ability to notice, respond, and reimagine outside of anthropocentric norms requires me to take on tools and lenses that are not part of a traditional human-centered interaction design research toolkit while there are little guidelines on how to achieve so. Accordingly, one of the main goals of this dissertation is to explore and identify concrete and actionable strategies to account for all stakeholders in interaction design research and practices. As I started this doctoral research, I based on critical epistemology and took an interdisciplinary approach with the goal to mobilize Tsing's "arts of noticing" (2015). The methods that I incorporate in my dissertation are multi-folded, including arts-and-design based methodologies (§3.2.1), ethnographic approaches from social science (§3.2.2), and humanistic methodologies that come from fields such language, cultural studies, women's studies, and philosophy (§3.2.3). I will describe in more details the methodological grounding and strength of each approach later in this chapter.

Briefly, approaches from arts and design (the "designerly methods"[16]) are both embodied (with a focus on understanding and interpreting product semantics and material culture) and future-forwarded (with the goal of proposing alternative and preferable futures), and included methods such as visual thinking, research through design (RtD), co-design, and what-if scenarios (Zimmerman, Forlizzi, and Evenson 2007; Koskinen et al. 2011; Gaver 2012; Gaver, Bill; Dunne, Tony; Pacenti 1999; Pink 2009; Ikemiya and Rosner 2014; Blevis, Odom, and Hauser 2015; Blevis 2016; 2018; Robbins et al. 2015; Bardzell, Bardzell, and Hansen 2015). Ethnographic approaches (e.g., critical ethnography, virtual ethnography) or methods from social science (e.g., interview, observation, cognitive mapping) concern about both what people do and "how they experience what they do" (Dourish 2014), with the goal of understanding the lived experiences with

[16] The "designerly ways of knowing" is a term coined by design theorist Nigel Cross to describe a collection of inquiry approaches that are distinct to design processes and design products.

individuals or communities through communicative acts between the participants and myself as a design researcher (Carspecken 1996; Habermas 1985; Hesse-Biber 2017; Madison 2020; Hesse-Biber 2013; A. S. Taylor 2018; Galloway 2013; L. Hamilton and Taylor 2017; Kohn 2013; Hine 2000; L. A. Ogden, Hall, and Tanita 2013; Otto and Smith 2013; A. J. Clarke 2011). Finally, humanistic methods (e.g., interaction criticism, close reading) rooted from critical theory to enact concepts such as enlightenment and emancipation with the goal of facilitating social justice and social change (J. Bardzell and Bardzell 2013; 2015a; J. Bardzell, Bardzell, and Blythe 2018; J. Bardzell 2011; Bell, Blythe, and Sengers 2005; C. K. Ogden and Richards 1923; Brummett 2009; Dourish et al. 2004).

In short, the different disciplinary methods I included in this research have their own focuses and goals, and thus collectively offer different ways of knowing and responding. By practicing, experimenting, and combining methods from different disciplines, my goal is to mobilize and develop "arts of noticing" appropriate for interaction design and HCI researchers. In the following sections, I introduce the different but complimentary methods I included in this work, their methodological grounding, research focuses, goals, and strengths.

3.2.1 Arts-and-Design Based Methods

Design theorist Nigel Cross named the array of inquiry methods originated from arts and design as the "designerly ways of knowing" (2006; 1982). Arts-and-design based methods are critical and speculative in nature since their focuses is not things are but "how things ought to be" (Simon 1996, 114). As a professionally trained designer, I am familiar with design studio culture and practices (e.g., research through design and co-design) and thus a significant portion of my works involve arts-and-design inspired research activities.

Based on my work on critical epistemologies, it is worth mentioning that I do not simply select any arts-and-based method but focus my inquiry on the critical and speculative aspects. For example, Koskinen et al. (2011) categorize different threads of research through design (RtD) approaches to the lab (e.g., aesthetic interaction), the field (e.g., participatory design), and showroom (e.g., critical design). Made clear in this categorization is that RtD differs from mainstream commercial or affirmative design approaches both in its service subject and in its goal. Specifically, while commercial design practices focus on creating commercially successful products that increase user engagements, RtD emphasizes instead on "generating new knowledge" and imagining alternative futures (Zimmerman and Forlizzi 2014); that is, RtD has a constructive, critical, and theory building angle (Zimmerman, Forlizzi, and Evenson 2007; Zimmerman and Forlizzi 2014; Gaver 2012; Koskinen et al. 2011; J. Bardzell, Bardzell, and Hansen 2015). As my research aims to envision alternative use scenarios and explore alternative paradigms, RtD's strength in identifying hidden assumptions and reframing problems has made it a complementary method to critical epistemologies and a powerful tool to PID research. Drawing from Haraway's concept of "becoming-with" (2008), Taylor described a specific thread of RtD I employed in my work—a new genre that explicitly engages with nonhumans (2017, 36):

> The opportunity arises to understand "through-design" not as a way to sketch out a vector space for research, but to speculate on "becoming-with": becoming with the world, and becoming with the conditions and capabilities design might make possible.

This narrative vividly captures the speculative nature of RtD and simultaneously reorients and expands conditions of design toward creating new possibilities; that is, rather than reenforcing anthropocentric norms and interests.

3.2.2 Ethnographic Fieldwork

Ethnography, as a method that has been heavily applied in HCI in the past few decades, originated from the field of Anthropology and involves "long-term immersion of a researcher in a social setting with the aim to observe and document everyday practices" (Otto and Smith 2013, 2). The ethnographer and their positionality plays a critical role in ethnographic research as the process is essentially "the attempt to understand another life world using the self… as the instrument of knowing" (Ortner 1995, 173). In the 1970s, ethnographic approach was brought into the design profession to challenge the dominate models of user behavior as well as the stereotyped assumptions around contemporary life and values (A. J. Clarke 2011; Gunn, Otto, and Smith 2013). Suchman's (1987) work is one prominent example for applying ethnographic approach in HCI research. Specifically, she observed the workflow and detailed people's situated actions using computers to illustrate the gap between how a work plan is pictured in a designer's head and how it is actually executed in real-life. As traditional ethnography entered the field of interaction design and HCI, it becomes increasing action-oriented, future-forwarded, and also more about engaging in "speculative mode of inquiry" (Hunt 2011). While ethnographic approaches need not to be critical, I focus this work on critical ethnography to help me "notice differently" (Tsing 2015). Quoted in length, Madison (2020) argues that critical ethnography

> begins with an ethical responsibility to address processes of unfairness or injustice within a particular *lived* domain. By 'ethical responsibility,' I mean a compelling sense of duty and commitment based on moral principles of human freedom and well-being, and hence a compassion for the suffering of living beings.

Critical ethnography goes particular well with PID because it "disrupts the status quo, and unsettles both neutrality and taken-for-granted assumptions" (Madison 2020, 4). A particular

thread of critical ethnography I engage with in my work is multispecies ethnography, which illustrates “a mode of attunement to the power of nonhuman subjects to shape the world and to the ways in which the human becomes through relations with other beings.” (L. A. Ogden, Hall, and Tanita 2013). In other words, multispecies ethnography departs from and mobilizes posthuman epistemologies by placing anthropogenic systems into shifting and interspecies assemblages (L. Hamilton and Taylor 2017; L. A. Ogden, Hall, and Tanita 2013; S. E. Kirksey and Helmreich 2010; Haraway 2008; Tsing 2015; Dooren, Kirksey, and Münster 2016). However, as an emergent form of field studies, there is not yet a set of strategies and guidelines for how to effectively cultivate “arts of attentiveness” (Dooren, Kirksey, and Münster 2016) and “becoming-with” (Haraway 2008) nonhuman others through ethnographic approaches.

To attend to the world of nonhumans where “language is less significant” (L. Hamilton and Taylor 2017), I work alongside with my interlocuters who exhibit long-term relationship with nonhuman actors (both collaboratively or competitively) and employ multisensory methods to avoid limiting the inquiry and observation on linguistic dimensions. Specifically, as I will explain in more details in later sections, my employment of ethnographic approaches often involves visual thinking, embodied interaction, making, drawing, annotating, and designing. Again, the goal here is to engage in alternative modes of knowledge production to help myself to “notice differently.”

3.2.3 Humanistic Methods

Humanistic approaches “support our ability to speculate, to think otherwise, and to change perspective” (J. Bardzell, Bardzell, and Blythe 2018) and thus are highly relevant and useful to PID’s commitment in resisting one singular dominating perspective, embracing heterogeneous alternatives, privileging the marginal, and exploring emerging ways of knowledge production. Humanistic methodologies play two roles in this dissertation: (1) in informing my execution of

arts-and-design and ethnographic methodologies (e.g., from making and crafting to critical and speculative RtD; from anthropogenic ethnography to critical and multispecies ethnography) and (2) in offering alternative and complimentary methods (i.e., close reading, interaction criticism) that foregrounds the "subjectivity," "sensibility," and "judgement" of the researcher (J. Bardzell and Bardzell 2015a).

For (1), an example is that while arts-and-design based approaches allows me to effectively leverage my design background in conducting interaction design studies, the "designerly ways of knowing" (Cross 1982) have their own limits. Specifically, I notice that I am naturally drawn to the material and tangible aspects of the field site, the practice, and the designed object; my observations often start focus on how interactions unfold through tools, devices, infrastructure, or other kinds of physical compositions; missing here are the dimensions that are more symbolic and less tangible. To address the inherent bias and limitations while leveraging the strengths that exhibit among different disciplinary approaches, I take an interdisciplinary approach in my work.

For example, by incorporating design criticism and humanistic expert interpretation, Bardzell proposed interaction criticism as a interaction design method that involves "rigorous interpretive interrogations of the complex relationships between (a) the interface, including its material and perceptual qualities as well as its broader situatedness in visual languages and culture and (b) the user experience, including the meanings, behaviors, perceptions, affects, insights, and social sensibilities that arise in the context of interaction and its outcomes." (2011, 604). Significant in humanistic methods lays in its ability to cultivate and expand "our ability to notice and make sense of the relationships between the formal and material particulars of cultural artifacts and their broader socio-cultural significance" (J. Bardzell 2011).

3.2.4 Section Conclusion: From Noticing to "Noticing Differently"

To notice means to perceive and to become aware of; in comparison, the term "noticing differently" is more deliberate and active as it speaks directly to one's conscious attentiveness rather than unintended perception. According to Tsing, the ability of "noticing differently" means to acknowledge, engage, respond, and cultivate relationality between multiple frames of reference, including human and nonhuman live worlds (Liu, Bardzell, and Bardzell 2019b; Tsing 2015). Tsing referenced her personal experience learning polyphony, a style of music combining two or more individual melodies together, to introduce the concept of noticing differently; she wrote, "when I first learned polyphony, it was a revelation in listening; I was forced to pick out separate, simultaneous melodies and to listen for the moments of harmony and dissonance they created together" (2015, 24). To conclude this section, I would like to share a few thoughts about how the methods I employ in this work helped me to better engage with different perspectives, and even with the ones that are not anthropogenic.

To begin with, I take an interdisciplinary approach in this dissertation, combining methods from arts-and-design (e.g., RtD, co-design), social science (e.g., ethnography, interview, cognitive mapping), and the humanities (e.g., close reading, interaction criticism). This is a mindful choice as each disciplinarily approach has its own focus, standpoint, strength, and limitation; an interdisciplinary approach provides various points of engagement, which is fundamental for mobilizing arts of noticing.

In addition to the taking an interdisciplinary approach, I base my inquiry on critical epistemology and methodology. This is another deliberate choice here because critical theory not only offers "a perspective-changing holistic account of a given phenomenon" (J. Bardzell and Bardzell 2013, 3304) but also exhibit a strong social justice orientation enacted by "changing assumptions and

biases that obscure difference and diversity through the development of power relations" (Hesse-Biber 2013, 54). To put critical epistemology into practice, I employ methods directly from the humanities (e.g., close reading, which is developed based on critical epistemology) and draw from critical epistemology to "season" or "shape" existing methods in order to experiment a path into noticing differently. In execution, this is often achieved either by working alongside with my interlocuters who exhibit long-term relationship with nonhuman actors, or through the employment of multisensory methods to avoid limiting my inquiry on linguistic dimensions.

Finally, I note that the list and combination of approaches are not intended as definite or static rules; rather, they themselves are part of the experiment I conducted to move closer to designing with, through, and for human-nature interaction. Citing philosopher John Dewey (1934, 50), "if the artist does not perfect a new vision in his process of doing, he acts mechanically and repeats some old model fixed like a blueprint in his mind;" I believe that a commitment to "noticing differently" involves constantly adopting and reimagining the "arts of noticing" in the interaction design community to respond to new ideas, perspectives, and assemblages of social actors.

3.3 Motivation of Three Different Sites

> It matters what matters we use to think other matters with; it matters what stories we tell to tell other stories with; it matters what knots knot knots, what thoughts think thoughts, what descriptions describe descriptions, what ties tie ties. It matters what stories make worlds, what worlds make stories. (Haraway 2016)

In the previous section, I shared the myriad disciplinarily research approaches I include in this work in order to cultivate my own sensibilities toward nonhuman stakeholders and to practice noticing differently. This section introduces the three field sites, which, as a collective whole,

helped me to explored and map the landscape of PID. In this dissertation, I describe the three sites using analogous terms to more succinctly capture their characteristics and differences. Specifically, the sites where I conducted my empirical studies included “the lab”, “the rural”, and “the urban”; each site is highly distinctive from one another by geography, infrastructure, culture, and the composition of actors. Collectively, these three distinctive sites offered me a concrete starting point to explore not only the landscape of PID but also the contributions it offers to HCI as a whole. Additionally, it is not only the objective facts (e.g., terrain, population, and physical construction, to the extent that there might be little or minimum disputes among the offered descriptions) that unify the three sites, but also the action of inquiry that involved in this work. In conducting fieldworks for my dissertation, I did not have all these three field sites lay out from the outset; rather, the inquiry is an iterative and reflective process in which I gradually learn to think about “what knots knot knots, what thoughts think thoughts, what descriptions describe descriptions, what ties tie ties” (Haraway 2016).

Specifically, the three studies I included in this work align in *epistemology*, in that the observation and analysis draw from posthuman concepts; in *orientation*, with the shared goal to decenter the privileges and empower the margins; in *intended users*, in that the inquiries aim to services the needs of underserved populations, regardless whether they are humans or nonhumans, and in *process*, in that they encourage a constant and fluid change in perspectives and identities by understanding the world through the perspective of the interlocuters, whether they are designers, farmers, or urban dwellers. More detailed descriptions regarding each field site are available in the later parts of this dissertation. In the following passages, I illustrate (1) why I was drawn to these three sites, and (2) how, however seemingly irrelevant and disconnected, the sequence and combination of the three distinctive sites provides me a starting point to answer the question:

how technological intervention might amplify the agency of different species to support more sustainable, inclusive, and aesthetic forms of human-nature interaction.

The lab. Considering how underexplored and nebulous it is to inform interaction design practices by drawing from concepts in posthumanism, as a designer myself, I naturally turned to art studio practices as I embarked my research in PID. Specifically, I combined arts-and-design based methodologies (i.e., research through design) with humanistic approaches (i.e., interaction criticism) to first critically analyze existing designs that embody posthuman thinking, identify concrete tactics to incorporate nature in the process of making, and then experiment these tactics through a series of making exercise using ceramics as a medium. Here, the term "lab" can be interpreted both on a literal sense and on a semantic level. In both cases, the lab implies that the physical construction of the field site itself (i.e., arts studio) and the inquire process exhibit higher degrees of structure and control compare to the other two sites in "the wild."

The rural. Moving out from the lab, the second site that I incorporate in this work is a collection of environmentally friendly farms in rural Taiwan. Through working alongside (i.e., ethnographic fieldwork) with the farmers who restrain from using chemical compounds to experiment ways of building a more symbiotic relationship with nature (including not only their crops but also the weeds and pests), I investigate whether the collaborative relationship between human and nature I identified in "the lab" might be applied to a different context, such as from creating designs together to growing foods together. As the second field site I included in this dissertation, "the rural" offers me the opportunity to learn to see the world through the eyes of eco-friendly farmers, to gain embodied understanding of the earth, and to help others experience the kind of intimacy human actors and have with nonhuman actors through interaction design.

The urban. Following the previous two sites where I focus on investigating and understanding how human and nature may exist in mutualistic and collaborative forms, I aim to unpack the non-innocent relationship (i.e., in the form of air pollution) between nature and culture in my third study— tracing back to the motivation of this work. To do so, I traveled to Pacific Northwest and worked closely with residents in the Seattle metropolitan area, who have experienced one of the worst air apocalypses in recent years due to the increasing occurrence and intensity of wildfire. Differs from the previous field sites, the urban landscape is where conflicts and dissonances become the most visible in human activities. In sum, each of the three different sites I include in this dissertation provides affords distinct embodiments, arrangements, manifestations, and constrains that helps me to investigate and map the landscape of PID.

It is worth mentioning that there are certain assumptions and connotations (e.g., a hierarchical thinking that the rural areas are less developed or refined than the urban spaces) associated with the terms I use to describe the fieldsites involved in this work—the lab, the rural, and the urban. In using these terms, I do not mean to intensify the hierarchical separation between the various sites that is highly problematic (Ong and Collier 2008), but to treat them as analogies that illustrate the different arrangements and qualities exhibited in these three sites. Specifically, in the context of this dissertation, I use the lab to describe a more "controlled" space built for scientific and creative experiments (thus an ideal place to embark on my inquiry), the rural as a more "natural" area outside of the built environment, and the urban as a highly "cultured" space with dense population and constructions.

Additionally, as I will illustrate further in Part II of this work, my experience being in the field also challenges how I understand these different sites. For example, as an individual who received a Western education and growing up in a big city (i.e., Taipei, Taiwan), I used to see "the lab" and

“the urban” as places where innovation happens. However, the time I spent in the farming villages in rural Taiwan has fundamentally changed these assumptions I used to hold. In particular, I now see “the rural” as another site of innovation. On the one hand, it has specific rhythms and cycles that resemble the quality of a lab; on the other hand, it provides the urban spaces not only fresh produce but also scientific knowledge and technological breakthrough (e.g., AgTech), further blurring the distinction and boundary between these three different sites.

Chapter 4.

Designing (with) Natureculture [17]

> Humanity and nonhumanity have always performed an intricate dance with each other. There was never a time when human agency was anything other than an interfolding network of humanity and nonhumanity.
>
> – Jane Bennett[18]

As I have mentioned in Chapter 1, this dissertation is strongly motivated by my concerns about consumerism and technology obsolescence. In particular, as a practicing product designer, I have witnessed truck after truck of hardware and electronic waste being transported to landfills every year; as a nature lover, my heart aches every time when I read about how wildlife suffer and die from environmental pollution generated from unsustainable manufacturing process and consumption behaviors. As I began my doctoral research, I was particular curious about how human and nature might coexist in harmony as opposed to in dissonant or conflict. This curiosity has led me to focus on the "contact zone" between human and nature (Haraway 2008) and

[17] The majority of this chapter was previously published as a peer-reviewed archival paper at ACM TEI 2019 titling "Decomposition as Design: Co-Creating (with) Natureculture." This chapter has been lightly edited from the previous published version by adding an introductory paragraph and expanding the discussion (§4.5). I note that while I conducted the design curation/analysis independently and led the ceramics-making experiment, Jeffrey Bardzell and Shaowen Bardzell helped guide the inquiry and contribute to refining my research questions and writing. Additionally, I received mentorship and assistance from Chase Gamblin and Wei Tseng while working on the ceramic experiments. I also acknowledge Patrycja Zdziarska for copy-editing the final manuscript.

[18] Jane Bennett, 2011. *Vibrant Matter: A Political Ecology of Things.* Duke University Press.

started capturing and curating a collection of photography that captures such encounters[19]. In many ways, this photo essay has played a critical part as I embarked on my PID research. First, on a personal level, this photo essay helped me to visualize, translate, and make tangible the abstract theory of natureculture by capturing it in visual forms. This is crucial to me, as a first-generation PhD student who was not accustomed to (and also often intimated by) academic writing, this collection of photographs helped me understand that my training is design (e.g., visual thinking, making and crafting) is still relevant to HCI, and that it gave me the opportunity to leverage my design background to overcome my fear of academic research. Second, this photo essay is also critical to the development of PID: besides reading about the concept through written words, readers now can also try to understand the concept of natureculture through visual forms: as spatiotemporal movements, sediment-like layers, heterogeneous gatherings, formal homonyms, emotional experiences, and aestheticized expressions of style. Finally, this photo collection helped me understand that humans are not most comfortable living in isolation from nature; instead, we prefer our lived environments to be rich with natural materials, color palettes, and structural forms. This observation has led me to investigate how interaction designers may incorporate nature into our creative processes to help add value, characteristic, intimacy, and aesthetics into design.

4.1 Co-Creating with Nature

Humans are not the only entity on the planet, living alongside with other nonhumans actors such as plants, animals, and microorganisms. In the past decade, researchers in HCI have argued the need to move from a human-centric design agenda to one that encompasses a multispecies

[19] The collection of artistic photographs is previously published as a photo essay in ACM DIS 2018. Szu-Yu (Cyn) Liu, Jeffrey Bardzell, and Shaowen Bardzell. “Photography as A Design Research Tool into Natureculture.” In *Proceedings of the 2018 Designing Interactive Systems Conference: DIS ‘18*. ACM: New York, NY, USA, 777-789.

worldview (N. Smith, Bardzell, and Bardzell 2017; Jen Liu, Byrne, and Devendorf 2018; Light, Shklovski, and Powell 2017). This body of research not only provides insights to design for multispecies interaction and cohabitation (N. Smith, Bardzell, and Bardzell 2017; Mancini and Lehtonen 2018; Aspling, Wang, and Juhlin 2016), but also reflects on how interspecies collaboration opens new opportunities to environmental sustainability, collaborative survival, and aesthetic interaction (Liu, Byrne, and Devendorf 2018; Light, Shklovski, and Powell 2017; Lyle, Choi, and Foth 2015; Aspling, Wang, and Juhlin 2016). This is an exciting step in HCI toward nurturing a mutualistic relationship between humans and other-than-human actors with and through technology.

However, the philosophy of de-centering humans in design remains quite abstract and theoretical to date. Except for a few examples (Kobayashi, Ueoka, and Hirose 2009; Liu, Byrne, and Devendorf 2018; Smith, Bardzell, and Bardzell 2017; Devendorf and Rosner 2015; Jackson and Kang 2014), little research has been done to translate nonanthropocentric theories into actual design practices. With an interest in designing with nonhumans in mind, we ask, what exactly can designers do once we get out of the realm of high-flying theories and get our hands dirty? In this paper, we draw from the theory of natureculture—a concept that resists a human-centric perspective by "dis-objectify[ing] nonhuman worlds by exposing their liveliness and agency" (Puig de la Bellacasa 2010)—and engage in design activities to explore concrete ways of co-creating with nature.

Under the theory of natureculture, we look into the process of winemaking. In turning grapes into wine, a series of collaborations between humans (e.g., grape farmers, wine producers) and nonhuman agencies (e.g., soil, grapevine, yeast) are involved. For example, wine makers provide yeast with sugary grape juice and an oxygen free environment, within which yeast drives the

fermentation process and converts sugar into alcohol and carbon dioxide (Alba-Lois and Segal-Kischinevzky 2010). We are particularly inspired by the idea of human actors cultivating a space of co-creation that invites nonhumans to participate, sometimes even to take over the original composition. A similar concept, decomposition—breaking down organic matters to smaller particles—is yet another process of destruction and reconfiguration driven by nonhuman agencies such as earthworms and fungi. Although the term decomposition is often associated with negative connotations such as decay, rotting, aging, and death, it also opens new pathways to growth, renewal, transformation, and rebirth (DeSilvey 2006). We consider decomposition as a creative process through which nonhuman others bring their own form of agency into the creative process and add value, character, function, aesthetics, and sustainability into design.

Within HCI, nonanthropocentric perspectives have become increasing popular in addressing and overcoming the present sociotechnical challenges. For example, sustainable HCI researchers have explored ways of urban farming and foraging in response to issues over food safety, scarcity, and environmental sustainability. Scholars in urban informatics have suggested integrating ideas such as hybridity (Devendorf and Ryokai 2015; Zoran et al. 2014), coproduction (Devendorf and Rosner 2017), cohabitation (N. Smith, Bardzell, and Bardzell 2017), organic sensing (Kuznetsov, Odom, et al. 2011), collaborative citymaking (Forlano 2016; DiSalvo and Lukens 2011), and collaborative survival (Liu, Byrne, and Devendorf 2018) to expand the current landscape of interactive technologies. We situate our work in nonanthropocentric HCI to contribute to the growing interest in building collaborative kinship with other species. In this paper, we build on the natural process of decomposition and explore through design curation, analysis, and making the concrete ways of designing with nature. We propose the notion of decomposition as a tangible and actionable design tactic in incorporating nature into design.

Our contribution to HCI is multi-fold. First, we present the natural process of decomposition as a way of natureculture co-creating with humans though actions of destruction. Such a provocation has the potential to spark the imagination of what designers can do to engage in creative activities with nonhuman actors. Second, we concretize the theoretical concept of natureculture and decomposition by curating and analyzing the physical representation of natureculture in design works, and experimenting with materials and objects to produce our own representations. And finally, we propose the concept of "scaffolding" and conclude by presenting fragmenting, aging, liberating, and tracing as actionable design tactics for those who are interested in experimenting with nonanthropocentric approaches to design.

4.2 Natureculture and Decomposition

This work departs from the provocation of decentering the human in design. For Puig de la Bellacasa (2010), such an attempt requires a shift in perspectives that considers "the social as a tissue of associations between humans, nonhumans, and objects working in the realization of new relational formations." Central to our theoretical foundation is the concept of natureculture, which advocates for humans to (re-)connect with nonhumans and move away from the perspective of species isolation and superiority (Latimer 2013; Haraway 2003). Anthropologist Anna Tsing describes this raise in awareness as the "arts of noticing" (Tsing 2015); constituted in these arts is cultivating our ability to notice, appreciate, respond, and imagine outside of anthropocentric norms (Liu, Byrne, and Devendorf 2018). When applying the concept of natureculture into design, we are better positioned to understand design activities not as a pure cultural practice but as a creative space where humans "can be both actively involved and passively fascinated" (Hitchings 2006). Within the context of natureculture design, we are particularly inspired by Light et al.'s (2017) call to "embrace the rhythms of life and death around

us" with and through design. They write, "the radical act of paying attention to things that we do not wish to see and that make us uncomfortable can be aided by design if it takes up the challenge of resisting smoothness and self-centeredness." We build upon this invitation to explore moments of vulnerability once we get out of the realm of human exceptionalism and come to interact with the nonhuman lifeworld.

In this chapter, we focus our inquiry of natureculture design on the notion of decomposition—a natural phenomenon that implies a constant process of "death and rebirth", "loss and renewal" (DeSilvey 2006)—as well as its analogous concepts such as decay, aging, corruption, destruction, decline, obsolescence, and death. As much as we try to avoid these unpleasant encounters, they are simply natural and inevitable during the course of life—for humans, animals, plants, artifacts, and technologies alike. In response to the call of "staying with the trouble" (Haraway 2016), HCI researchers have explored ways of adding value to design through deconstructive actions; they have also argued that designers might intervene into deconstructive processes, which often are beyond human capacity to control. For example, work on breakdown and repair investigates how forms of meaning, care, and creativity can be enacted through the limits of engineering-centered infrastructure design (Houston et al. 2016; Rosner and Ames 2014; Jackson and Kang 2014; Maestri and Wakkary 2011; Thomas, Remy, and Bates 2017). Rosner et al. (Rosner et al. 2013; Ikemiya and Rosner 2014) and Giaccardi et al. (2014) experiment through material forms and reveal how traces of use present a quality that is aesthetically pleasing and emotionally meaningful in constructing relationships with technologies. Murer and colleagues go further by suggesting "un-crafting" and other deconstructive practices as an initial and essential part of creating interactive artifacts (Murer, Fuchsberger, and Tscheligi 2017). This body of work resonates with the theoretical foundation that we aim to emphasize in this work: the notion of decomposition and its synonyms provide an alternative trajectory of adding value

(e.g., durability, sustainability, function, personality, aesthetics) to design through a course of destruction and reconfiguration unfolding across humans and nonhuman agencies.

4.3 Exploring Decomposition as a Nonanthropocentric Design Theory

We consider decomposition not as a form of degradation but as a pathway towards transformation and as such, a potentially creative process. Such a process can be driven by a collaborative effort between humans and nonhuman agencies through and manifested in material forms. In this paper, we ask, how can designers draw from the process of decomposition to cultivate a space of natureculture co-creation? A primary goal of this chapter is to concretize the notion of decomposition by moving it from an abstract theoretical argument towards actionable design tactics. To gain insights to this inquiry, our methods are two-fold, involving design analysis and research through design.

In the first phase of the research, we aim to illustrate through actual design exemplars the physical manifestations of decomposition and explore tactics of designing with nature through destructive actions. We build a design inventory with more than 100 cases in analogous fields such as product design, architecture, textile, interaction design, and crafting. We searched popular design websites, blogs, competitions, and magazines to curate exemplars that suggested the involvement of natural forces, actors, and courses such as destruction and decay in the design-making process. To make sense of the emerging collection, help shape its growth, and discover patterns and clusters within it, we turned to interaction criticism. According to Bardzell, interaction criticism entails “rigorous interpretive interrogations of the complex relationships between (a) the interface, including its material and perceptual qualities as well as its broader situatedness in visual languages and culture and (b) the user experience, including

the meanings, behaviors, perceptions, affects, insights, and social sensibilities that arise in the context of interaction and its outcomes." (2011, 604).

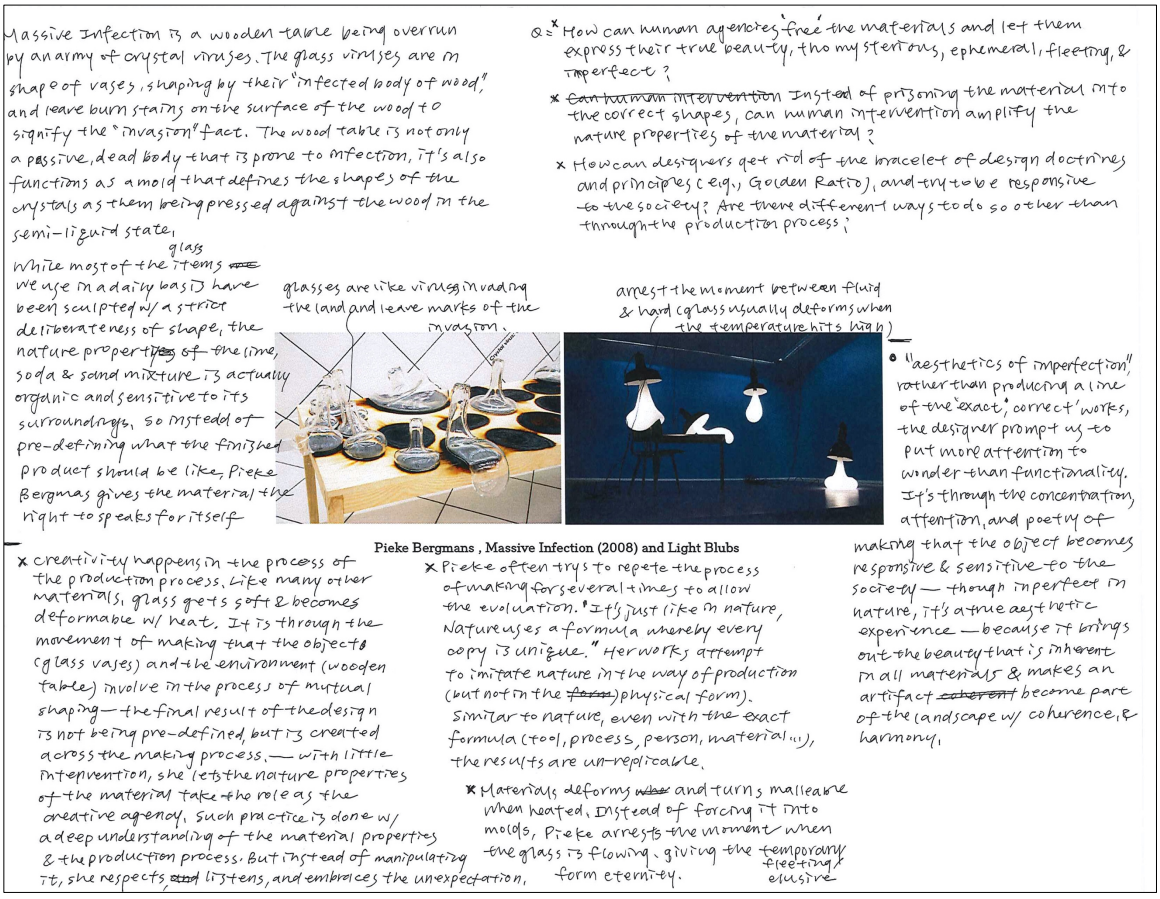

Figure 2: Interaction criticism in action. One example showing how I critically analyze design examples: starting from artistic description (left-side) to illustrate the objective quality of the design (e.g., material, form, process), I then moved on to artistic interpretation (right-side) that focuses on subjective perception and critical questions regarding the notion of decomposition.

In practice, this part of the research involved iteratively identifying design exemplars and producing critical discourse about them; two separate activities are involved: aesthetic description and aesthetic interpretation (Figure 2). *Aesthetic description* refers to an attempt to characterize the exemplars in question, to articulate their qualities, materials, and forms in a

language both rich and relatively objective. It is rich in that it makes use of associations and metaphors to capture subtle nuances and qualities, and it is objective in that its purpose is to characterize the object in a way that most qualified viewers would agree to. Aesthetic description responds to questions such as the following: what is it? what is the broader context of creating?

how is it made? And it results in a set of annotations that characterize the form, function, material, and medium of the design. *Aesthetic interpretation* refers to our take, that is, our own efforts after meaning. An interpretation is more subjective than the description, that is, dependent on the perception, imagination, literacy, and deepening understanding of an individual interpreter (or, in this case, small team of them). An interpretation also reflects an intellectual purpose; in our case, it was to perceive and appreciate diverse ways that processes of decomposition contribute to design by accounting for the nonhuman actors, what is there to be decomposed, what drives the process, and what forms of interaction it entails. We iteratively compared and contrasted the exemplars and their qualities to discover patterns and to identify possible categorizations, leading to a set of possible processes that designers might be able to emulate—what we would come to think of as design tactics.

As an outcome of this work, we identified four design tactics of decomposition: fragmenting, aging, liberating, and tracing. These four tactics diversely demonstrate how the notion of decomposition can (co-)create material forms. We also note that the tactics are not mutually exclusive but complement one another. We describe each tactic through actual design cases and reflect on how different modes of working with nature can be promoted and perceived through material forms. Our aim is not to develop an exhaustive list of design strategies; rather, it is intended to help us move from promising yet vague, toward something that is actionable enough to develop design experiments that could be tested.

4.3.1 Fragmenting

Fragmenting is a tactic focusing on material fabrication. It breaks, combines, and repurposes the original materials to create a new composite that displays qualities of one-off products, manifested in patterns, textures, and aesthetics.

Figure 3: Marmoreal by Dzek and Max Lamb (2014). An engineered marble made by combining marble mix and polyester resin © Dzek and Max Lamb.

Decomposition is a natural process when organic composites break down to simpler particles through physical, chemical, or organic means. We observed that this natural process has inspired designers to create new material composites by first fragmenting and then reassembling the original constituents through pressure, heat, and adhesives. The notion of decomposition in this case involves the physical breakdown of materials, the process then opens up a space for material re-composition and rearrangement, which often results in unique, unexpected, even enchanting and decorative patterns and embellishments.

For example, Marmoreal (2018) is an engineered marble designed by Max Lamb and produced by Dzek (Figure 3). Composed of different types of classic Italian marbles from the Verona region, Marmoreal can be used for various interior applications ranging from tiles to furniture. The

production process celebrates the sustainable root of terrazzo, sourcing waste stones from local Italian quarries. Combining together approximately 95% marble mix and 5% polyester resin, the material is casted in molds using a mixture of pressure, vibration, and vacuum. The new composite is stronger and more durable than natural marbles because the small batch of polyester resin fills the porous structure in the original stones. Max Lamb considers this material exploration as one that "celebrates the individual qualities of these stones while acknowledging that the sum of its parts makes for something far more compelling (Lamb 2014)."

Through the example of Marmoreal, we can see that fragmenting as a design tactic envisions a new form of natureculture co-creation, which is particularly useful in fabricating novel materials. Through a process of recycling, smashing, shuffling, and reassembling, the original ingredients remain visible while the new composite offers a wider possibility in aesthetics, function, and durability. The tactic of fragmenting can be easily integrated into the highly controlled mass production processes to add ambiguity and uniqueness to standardized products.

4.3.2 Aging

Aging is a material exploration tactic, which incorporates materials that are sensitive to the passage of time, manifested in physical transformations such as form, texture, and color.

Aging is a natural phenomenon that amplifies the inevitable passage of life—carried through a course of "death and rebirth", "loss and renewal" (DeSilvey 2006). The tactic of aging addresses the beauty of ephemeral presentation and continual evolution. Such appreciation of decay is coined in literature as "graceful aging" (Rognoli and Karana 2014) and "aesthetic obsolescence" (Burns 2010). Aging as design tactic tends to emphasize the process of rotting and deteriorating by including materials that are sensitive and responsive to their surroundings. This tactic is

closely related to the aesthetic of wabi-sabi, which aims to manifest the beauty that is imperfect, impermanent, and incomplete by capturing the inherently unstable, fleeting moments of deterioration (Loren 1998; Martin 2007). A common design approach to aging is to mix metal powders (e.g., copper, brass, iron) with resin composites to create a marble-like finish. The color and texture of the object changes over time as the metal oxidizes to signify the process of aging.

Figure 4: The Rust Collection by Ariane Prin (2015). Objects in this collection were made by mixing metal dusts (whose color and texture change over time due to oxidization) with plaster and jesmonite © Ariane Prin.

For example, for Rust Collection (Figure 4), designer Ariane Prin recycles leftover metal dusts and mixes them with plaster and jesmonite (a composite, gypsum-based material) to create containers that change the color and texture overtime as the metal oxidizes. “Every time I go to my studio, I’m excited to see the objects’ changing textures. It’s like each one of them was alive and mutating with time,” she explains (Prin 2017). The corrosion of metal powders is then stopped with a layer of water-resistant coating, so one can safely use them as regular pots, trays, vases and jewelry boxes. In the process of creating, the designer lets the materials take their own life to develop patterns and colors that are unique and unpredictable.

Regardless of the form or material of an object, all surfaces inevitably display changes of their original qualities through time, reflecting the use context, the nature of material, and the environment. Though most products focus on enhancing the durability and stability while preventing deteriorating and ruining of artifacts, aging as a design tactic harnesses the passage of decay to develop a natural, un-replicable look and feel of objects. It refuses to treat objects as static substances but allows materials take on their own life. Means of human intervention include using heat, humidity, and chemical erosion to catalyze the transformation. Aging as a design tactic explores and utilizes the natural process of material degradation and deconstruction to entail the uniqueness of objects. In this making, human intervention presumably constructs the overall aesthetic qualities, but as nature takes part in the creative process, no finished products will be exactly the same.

4.3.3 Liberating

Liberating is a production tactic that resists posing physical controls and constraints during the course of forming. It encourages an honest presentation of materials and often results in objects of fluidity and randomness.

Here, we focus on how the notion of decomposition arrests the temporality, sensitivity, and resiliency of materials during the formation of an object. Liberating as a design tactic rejects standardization. Specifically, thinking about mass-produced products, we are likely to picture artifacts that are precisely engineered, well-defined, and perfectly polished. To achieve this, molds are combined with matrixes of control to regulate the manufacturing process. The result is products of uniformity, where traces of manual labor are nowhere to be found (Rognoli and Karana 2014). On the contrary, the tactic of liberating strives to capture the material properties during the course of design production. When standardized molds and manufacturing formulas

are removed, the tactic of liberating facilitates the creation of one-off products that display different qualities in forms, textures, and finishes.

Figure 5: Ripple by Poetic Lab (2013). By incorporating a mouth-blowing technique, Ripple has uneven glass surface that resembles the ever-changing ripples © Poetic Lab.

The design tactic of liberating celebrates the beauty of craftsmanship through a poetic encounter between the craftsman, the environment, and the material. For example, Ripple (Figure 5) purposefully incorporates a mouth-blowing technique to create an uneven glass dome that resembles the ever-changing ripple pattern. Molds and jigs were still used to assist forming and measuring, but they did not define the final look of the product. Designers Hanhsi Chen and Shikai Tseng state, “the process starts with this hot tube of [glass] material, and interacts with the air, gravity, and movements of the blower. […] Time and memory is frozen […] and with a small pinch of light, you can extract that moment” and "it's about the experience and the emotion that is created by this moving light” (“Ripple” 2013). Indeed, designers or crafters do not have full control over the finishing look; it is the entangled correlation between material properties, human movements, and environmental conditions that co-create the product.

In industrial manufacturing, defects occur due to inaccurate control. The notion of decomposition pictures imperfections as aesthetic and desirable. Liberating as a design tactic deliberately seeks to release the subject from rigid human interventions and machine control during the phase of forming. It amplifies the properties of materials and conditions of environment by intentionally adding anomalies to create uniqueness—passages of making are inscribed in imperfections (e.g., bubbles, dimensional changes, uneven surfaces) to add value to the product.

4.3.4 Tracing

Tracing is the tactic of foregrounding traces of force, use, and repair. The history of an artifact is objectified and synthesized in terms of forms, textures, patterns, or breakages.

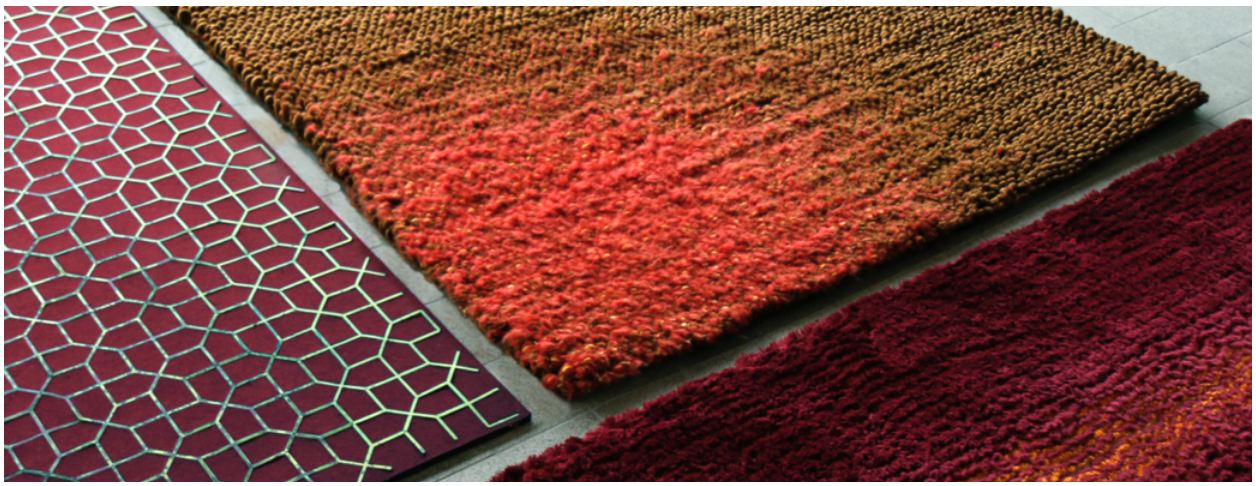

Figure 6: Ripening Rugs by Adrianus Kundert (2015). By creating layers of yarn with different colors, patterns, and texture, the appearance of Ripening Rugs changes after use and wear. © Adrianus Kundert.

The predominate production technology has been driven by the pursuit of perfection and endurance, aiming to produce objects in their pristine states. However, while scratches, breakages, and blemishes are often considered as defects, traces of use and repair inscribe the

relations between an artifact and its user, adding a value that goes beyond the functional significance, and moves towards becoming an extension of the user (Ikemiya and Rosner 2014; Jackson and Kang 2014; Robbins et al. 2015). Tracing as a design tactic not only calls attention to the entanglement between the object and its user, but also raises questions about durability, fragility, and resilience. Here, a common design tactic is to highlight the degradations with contrasting materials.

For instance, designer Adrianus Kundert believes that the durability of an object increases through use. The beauty of wear and tear is captured in his Ripening Rugs collection: the rugs gradually change their colors, patterns, and texture as the outer layer of the yarn is worn and the inner weave is revealed through use (Figure 6). Kundert says, “the gradual erosion is what makes these floor coverings gain in attractiveness, each in its own way, instead of rendering them valueless and ending their lifetime.” In this case, traces mark the identity of a product and signify its evolution. Another strategy of strengthening the emotional resonance to an artifact is through actions of repair. For example, Kintsugi— a Japanese crafting practice of restoring broken ceramic potteries mixing powers of gold, silver, or platinum with lacquer (Farris 2014)—captures the notion of tracing through repairing. Kintsugi shows no attempt to hide the damages but to appreciate and illuminate the traces of use with contrasting color and material.

Tracing can be considered a creative practice emerging from the course of use and repair. Whether deliberate or accidental, every crack inscribes and manifests the story behind an artifact. As a design tactic, tracing appreciates and harnesses the use traces (e.g., breakage, wear, and tear) and material imperfections (e.g., impurity, asymmetry, and roughness) of an artifact; in other words, it shows no attempt to hide the damages or touches of repair, but to illuminate them as an aesthetic existence and the signature of an object. Here, decomposition is treated as both

the process and result of justification and identification. At an objective level, designers can utilize the tactic of tracing to produce un-replicable objects and foreground signs of break and repair by presenting them as decorative arts. At a subjective level, end users are empowered to create unique products and express emotional resonance through marks of use and decay. Eventually, the tactic of tracing constructs personal memories and shared experiences over time, making an object one of a kind both on a physical and emotional level—a long-lasting relationship triggered and sustained by the imperfection of materiality.

4.3.5 Section Conclusion: To Decompose Is to Scaffold

From curating and analyzing design exemplars, we arrived at four decomposition-inspired design tactics—fragmenting, aging, liberating, and tracing—that all might be understood to fall under the broader umbrella of "scaffolding." In architectural practice, a scaffold is a temporary structure that supports construction efforts (e.g., holds materials or workers). In the context of this paper, we define a scaffold as a *soft structure*, a *transient composition* that is intentionally built to invite natural entities to build upon and eventually take over the original cultural construct. In a scaffold, both time and space are constructive media of the design.

The notion of scaffolding we propose here differs from anthropocentric design approaches: whereas in traditional design processes, phenomena outside of human control are avoided to reduce rates of product deficiency or slow down technology obsolescence, in scaffolding co-creation with nature, they are intentionally incorporated and celebrated as part of the design practice. In other words, we consider decomposition as a creative process through which nonhumans bring their own form of agency into design to add value, character, function, aesthetics, and sustainability. To further illustrate, let us compare a scaffold to the mold, a common manufacturing tool in mass production process that gives standardized shapes to

materials. With precise environmental and material control, a mold can produce up to a million pieces of product with exact, pre-defined shapes within its life expectancy. If we describe an industrial mold as a “hard structure” that foregrounds regulation, standardization, and efficiency, then a scaffold is a “soft structure” that loosens human control, brings nonhuman agency into design, and celebrates the in-expectancy and un-replicability of the final outcome.

To further unpack the notion of scaffolding, we look into the concept of structure-preserving transformations, proposed by architect and design theorist Christopher Alexander as the way nature constructs and evolves the environment. He writes, “throughout nature, we see a continuous smooth unfolding of the wholeness, which preserves structure at every moment, even when it seems to be introducing new structure.” (Alexander 2002, 56). We consider the natural process of decomposition as a structure-preserving transformation though which decaying organic matter is broken down to smaller particles, culturing new forms of lives. Through the course of decomposition, “nothing entirely new has been injected—the newness has been created by intensification of what exists” (Alexander 2002, 53). The design framing of scaffolding (as opposed to molding) we propose here, then, is a result of translating and leveraging the natural process of decomposition into actionable design tactics, further consolidated as design actions including fragmenting, aging, liberating, and tracing.

We are aware that the cases we select to present here are not interaction design exemplars but product design instances; this reflects the training of Liu. We have described earlier in the methods section that interpretation is an important means of knowledge production; as a result, we turn to our own expertise as a resource for translating nonanthropocentric theories into material design practices. In addition, every interaction design is also a product, with a specific form, function, aesthetic, material, character, and value orientation. We believe that the lessons

learned from curating and analyzing product design examples are applicable to tangible and interactive interfaces. Finally, and perhaps most importantly, issues of consumerism, obsolescence, and sustainability, have long been explored and addressed in realm of product design; we believe it is important for HCI researchers and practitioners to learn and leverage what has been done in this analogous field.

4.4 Design through Decomposition with Ceramics

Figure 7: Ceramic experiment sketches. The ceramic making experiments aim to evaluate the four design tactics associated with scaffolding by implementing them in material forms.

The ceramic design experiments presented here were led by Liu; the making and execution were a collaborative effort assisted by Wei Tseng, a senior undergraduate student, a novice in design and crafting. All authors had little experiences in ceramics making, so we turned to Chase Gamblin, ceramics studio coordinator at Indiana University with over twenty years of experiences. He showed me how to properly use the facilities and tools in the studio, but he encouraged us to engage in trial and error ourselves. Every little adjustment in the ceramics making process can lead to dramatic changes in the outcomes, “you might fail, you might succeed,” he always said. Figure 7 shows some of the initial sketches for ceramics experiments made by Liu.

We started by getting our hands dirty, playing with clay and ceramic slip. Probably not surprising, many of our concepts failed—in a sense that the design outcomes did not follow our expectations. From an analytical perspective, the designs failed because we were not familiar with the material properties to the point that many of our designs cracked and fell apart during the course of drying. However, from a research through design perspective, the decomposed ceramics served quite well in manifesting and materializing the notion of decomposition. For instance, we were inspired by the tactic of tracing and had an idea of creating cracks on the surface of the clay body by leaving it outside in the snow during the course of drying. Our plan was to then use resins to fill the cracks to trace and foreground nature’s force. Within this experiment, the scaffold is the clay bowl we made, which is considered as a soft structure because the material is still pliable with external forces. The nonhuman factor is the natural environment, filled with unpredictable weather conditions. Our hypothesis was that through fast freezing and drying, the surface of the clay might decompose and result in distinct patterns. However, the clay bowl become slushy and eventually fell apart as the snow melted.

We started to obtain some basic understanding of the clay's material properties after a few failures: it cracks during fast drying, becomes sloppy when it meets water, and shrinks significantly while drying. Next, we present our design iteration on the tactic of liberating using slip: a liquid state of clay made by suspending clay particles in water. Slip is often used to create sophisticated shapes by casting it with molds or using it to paint the surface of wet clay bodies to make decorative patterns. In testing the tactic of liberating through slip, we resisted using molds but used scaffolds instead for slip to build upon. Here, the notion of decomposition takes place during two different stages of making: when the original scaffolds are covered and obscured with slip and when the scaffolds are eventually brunt away during firing.

4.4.1 Experiment One: Waxed Paper Cups + Slip

In our first experiment, testing the tactic of liberating, we used waxed paper cups as the scaffold and slip as the natural entity whose performance is defined by multiple factors in the environment, such as the gravity, temperature, and humidity. By free dripping slip onto the paper cups we turned the cups into soft structures which allow slip to cover, alter, and take over the original surface with different shapes and patterns (Figure 8). In this process, we as designers still exerted a certain degree of control to reach our desired aesthetics. For example, we can choose, to a certain degree, where on the cups we want to pour the slip, how much slip we want to pour, how fast we want to pour, and even how fast we want the slip to dry (we used the heat gun to facilitate the drying process for some). However, the outcomes of the design remain ambiguous because there are many constraints to how much the we can actually control. For instance, a paper cup can only hold slip up to a certain amount; once it exceeds the capability of friction, the slip falls. However, we have also noticed that the slip poured onto the paper cups need to maintain a certain thickness or the design will soon crack and fall apart when it starts drying.

Figure 8: The making process of using paper cups (with a wax coating inside) as scaffolds. Left: ceramic slip took different forms during free dripping, depending on the weight and fluidity of the slip as well, as the humidity and temperature of the environment. Right: ceramic slip shrinks when it dries but the wax layer on the paper cups prevents the slip from shrinking: the pressure continued to accumulate and eventually cracked the slip, creating surprising polygonal imprints.

We envisioned applying the tactic of liberating to capture through slip an intricate interaction between slip, gravity, paper cups, and friction. However, the result is again against our expectation. Specifically, slip shrinks when it dries but the wax layer on the paper cups prevents the slip from shrinking; the pressure got accumulated and eventually cracked the slip when it hardened (Figure 9). The ceramic master predicted the crack, but he still encouraged us to try because “you might succeed, since the wax inside the cup is not too thick.” The result reveals the unpredictable quality of slip and the fact that if we want to “work with” (i.e., understanding and experimenting) this unruly material, we need to find alternative scaffold materials.

Figure 9: Result of experiment one. Drying slip left one-off polygonal imprints onto the cups.

What is surprising and completely unexpected is that the pressure from the shrinking clay has imprinted polygonal patterns onto the waxed paper cups, leaving a unique trace of natureculture co-creation. This experiment has challenged and pushed forward our previous analysis. Specifically, we pictured a scaffold as the foundation for natureculture co-creation to build upon and something to be discarded afterwards (e.g., burnt away during firing). We did not foresee the scaffold turning into a beautiful design object itself. Through this ceramic making activity, we discovered that a scaffold is not only "soft" in the way that it loosens factors of human control; it is also "soft" and malleable in itself, allowing force to leave unique marks and traces onto the scaffold. Such a process seems to resemble the tactic of *tracing* more than *liberating*, suggesting from this experiment that the tactics we concluded in the previous section are not mutually

exclusive to one another. Indeed, natureculture co-creation is a space where designers “can [be] both actively involved and passively fascinated” (Hitchings 2006).

4.4.2 Experiment Two: Kitchen Towels + Slip

With the goal of capturing and displaying through clay the negotiation between the cultured scaffold and the natural environment, we iterated on the material selection of the scaffold. We learned from experiences that the scaffold needed to be hard enough to maintain its shape while holding the weight of slip, and yet the scaffold also needed to be soft enough to allow the slip to shrink during the course of drying. We decided to use two different versions of scaffold in our next experiment. In execution, we first wrapped or taped kitchen towels onto the waxed paper cups and free dripped slip onto their surfaces. We then let the slip sit and dry for about 30 minutes when its surface became hard enough to sustain the shape without actually having a cup underneath it. Next, we carefully removed the waxed paper cups and set the slip covered kitchen towels on the drying rack for two days (Figure 10).

Figure 10: The making process of using paper towel wrapped paper cups as scaffolds. Top left: paper towels were wrapped or tapped to the paper cup before free-dripping ceramic slip to the cup. Top middle: paper cups were removed after the slip took its initial shapes. Top right: further drying the slips on the rack after removing the cups. Bottom: batch firing in electric kiln.

This time our ceramic work did not crack; instead, the final result displayed a hybrid materiality of all materials involved in the process of making (Figure 11). Specifically, paper cups scaffolded the slip to display a certain unity and hardness of the pre-made containers, the texture and layers

of the kitchen towels were inscribed onto the design as unique patterns, and the ceramic slip managed to visualize its own fluidity and stickiness when it came to interact with force (e.g., gravity and friction) in the environment. After firing, the kitchen towels dissolved while the clay body converted into bisque: a durable, much more permanent state of the clay. In this experiment, both the scaffolds and the nonhuman factors deformed to a degree by taking shape of one another. This hybridity almost obscures what is there to be changed and what is there to initiate the transformation. What can be observed through the material forms is that the process of decomposition transforms the soft, temporal, and invisible into something much harder, permanent, and physical.

Figure 11: The final objects of experiment two displays a hybrid materiality. The unity of paper cup, the patterns and textures of kitchen towels, and the fluidity of ceramic slip were all captured and displayed in the final outcome of the experiment.

4.4.3 Experiment Three: Denim + Slip

In the following experiment, we folded and stitched denim fabrics to create three-dimensional objects. Without limiting the scaffold to pre-made paper cups, we gain more freedom in determining what our design may look like. That is, as designers, we tried to soften the scaffold even further so that nonhuman entities can have more voice in the co-creation process.

Figure 12: Hand-stitched 3D denim as scaffolds. Left: the denim scaffolds came in various forms to offer more freedom in design. Right: ceramic slip dried on the fabric scaffold before firing.

We used denim to make the scaffolds by cutting, layering, folding, and loosely stitching the fabrics together (Figure 12). We selected denim because it has enough firmness to hold the slip without collapsing; the fabric is also soft enough for the slip to shape and dry without cracking. In execution, we put our hands inside the fabrics and dipped them into a bucket of slip. The items were placed on the shelf to dry and then sent to the kiln for firing. In Figure 13, we can see that the denim scaffold was brunt away during firing, leaving a thin layer of clay in the state of bisque. The final result displays a mixed property of fabric and clay. On the one hand, it has flaky edges that resemble the threads on the brink of the denim, with wrinkles and folds that capture

the softness and thinness of fabrics. On the other hand, the wrinkles and folds are permanent: they no longer deform with gentle touches.

Figure 13: The final objects of experiment three. The flaky edges on the bisque resembles the texture of the fabric; the wrinkles and folds on the objects are made permanent after firing.

4.5 Discussion: Decomposition as Design

Responding to HCI's recent call in shifting from an anthropocentric design agenda towards one that integrates a more inclusive multispecies worldview, we draw from the theoretical concept of natureculture to explore how the field of interaction design might help us reconnect with nature and build more flourishing futures. In the remainder of this chapter, I outline the implications for interaction design theories, processes, and systems more broadly.

4.5.1 Co-Creating with Nature

In writing about natureculture, Anna Tsing (2012, 142) describes her excitement about mushroom foraging, “these mushrooms are not the product of my labour, and because I have not toiled and worried over them, they jump into my hands with all the pleasures of the unasked for and the unexpected. For a moment, my tired load of guilt is absolved, and, like a lottery winner, I am alight with the sweetness of life itself.” Such a delight is experienced when she receives a gift from nature—unanticipated and probably also quite tasty. In many cases, humans seem to live in out fullest while cohabitating with nature: treating dogs and cats as our “significant others” (Haraway 2003); planting trees and flowers to decorate the dull concrete blocks in the cities; and venturing to the wilderness to enjoy a tranquil moment with other lifeforms on Earth—getting close to nature seems to be an innate trait of being human. Such a desire goes beyond meeting the basic needs in order to survive but to also find joy and fulfillment in life. However, this is only one side of the story. In constructing the material world, through design and engineering, we assert and enforce boundaries between nature and culture. In cities, skyscrapers roar into the skyline, competing with trees for the sunlight which they depend on for their lives; lands are taken by roads and buildings, expelling wildlife from nesting and foraging; and soils are covered with all sorts of construction, leaving no room for plants and animals to thrive.

In this chapter, we wish to rediscover the excitement of sharing intimacy with nature, a joy that got lost while humans (physically and conceptually) draw boundaries to separate ourselves from nature. In exploring ways of reconnecting with nature through design, we observe the natural process of decomposition and use it as the guiding principle in collecting, thinking, writing, and making designs. With the interest of co-creating with nature, we propose moving from the process of molding towards scaffolding to loosen factors of control. Specifically, we consider

PID as a practice of scaffolding, which is more about cultivating a space to facilitate nature's participation than trying to exclude it from design.

From a design perspective, we have showed that a proper scaffold balances the constraint and freedom it offers for natureculture co-creation. From a theory-building perspective, we have made more tangible the theoretical concept of natureculture by focusing on the natural process of decomposition and materializing it through physical forms. We have learned through our various design research activities that the visual language of natureculture often exhibits mixed material properties of the cultural (e.g., the scaffold) and the natural (e.g., the nonhuman actors and the environment), and the product of natureculture co-creation cannot ever be fully predicted or replicated—such a result is not so much about the designers' incapability, but more about their willingness to listen, observe, and respond to what nature has to say, as well as willing to be vulnerable and amazed in the design process.

4.5.2 Supporting Participation

Much of this chapter has been about materials, forms, crafting, design processes, and the material involved in our making experiments—ceramics, papers, and fabrics. These may seem to be unfamiliar to interaction design researchers. Even so, the lessons learned in our research activities might offer some thoughts in designing information technology systems. The concept of scaffolding, for example, foregrounds questions such as "who is included/excluded in the process?" and "who has a say?" In other words, the notion of scaffolding offers a theoretical contribution to HCI and simultaneously opens new pathways for methodological and empirical explorations. For example, if we were to encourage participation through design, we might architect digital infrastructure that supports open sourcing and collaborative working instead of creating closed or black-boxed systems that is only accessible to a small group of people:

Wikipedia [20] is one well-known example. In fact, researchers have demonstrated that participation creates ownership and care, which in many cases help deliver more inclusive and products and user experiences (Barricelli et al. 2016; D. Howard and Irani 2019). Note that the concept of scaffolding works for both non-profit and for-profit products; some of the noticeable prototyping tools for non-experts include Figma[21], Lens Studio[22], and Arduino[23]. Other platforms that support crowdsourcing include Amazon Mechanical Turk[24] and Upwork[25]. Within HCI, there are multiple threads of research that aim to support cultures of participation; the topics vary from maker culture (S. Bardzell, Bardzell, and Ng 2017; S. M. Lindtner 2020), citizen science (Kuznetsov, Santana, and Long 2016; R. Clarke et al. 2019) to smart cities (Freeman et al. 2019; N. Smith, Bardzell, and Bardzell 2017) and policy intervention (Thomas, Remy, and Bates 2017).

On a technical level, the notion of scaffolding also has a lot to offer for computational algorithms. Specifically, we might consider the design logic behind artificial intelligence (AI) and machine learning (ML) as a digital scaffold, in so far that computer engineers lay out the basic logic of processing, but the machine evolves overtime by finding associations and recognizing patterns through data. However, while AL and ML models are power tools for supporting complex decision making, the opacity concerns how computers arrive at certain decision has also turned ML algorithms into the unwelcomed “alchemy” (Hutson 2018). In fact, many researchers have reported that AI holds biases and learn to discriminate against certain gender, race, sextual orientation, or socio-economic status (Noble 2018; Hicks 2018; Karen Hao 2019); one example that has received a lot of media attention is that Amazon tried to build an AI system to help with

[20] https://www.wikipedia.org/
[21] https://www.figma.com/
[22] https://lensstudio.snapchat.com/
[23] https://www.arduino.cc/
[24] https://www.mturk.com/
[25] https://www.upwork.com/

recruitment but had to terminate it because it showed a bias against women (I. A. Hamilton 2018). To mitigate algorithmic bias, recent AI and ML explorations aim to move away from the black box model toward supporting public understanding and participation. For instance, explainable AI (XAI) is an emerging field that helps users understand and interpret how ML models arrive at their decision to increase transparency, accountability, and trust (Liao, Gruen, and Miller 2020; Hind 2019). A similar example is machine teaching which "highlights the role of humans as teachers and their interaction with data as a key factor in building ML-based systems" (Lindvall, Molin, and Löwgren 2018, 53). In other words, the concept of machine teaching offers opportunities for computers to learn from people rather than simply extracting knowledge from data. By giving the power of "scaffolding" to everyday people (who are experts in different fields but may or may not be technologists), machine teaching can significantly increase machine training efficiency and support algorithmic transparency.

4.6 Conclusion: Designing (with) Human-Nature Interaction

In response to concerns about consumerism and sustainability, HCI in recent years has shown an increasing interest in decentering humans in design. Scholars have introduced theoretical notions such as natureculture to support the move of decentering, but how to translate theories into material design practices remains an open question. This research seeks to broaden the repertoire of nonanthropocentric design practices in HCI. Specifically, it draws on the natural processes of decomposition as a creative approach to develop and test design tactics. To do so, we curate and critique hundreds of examples of decomposition in architecture, design, textile, crafting, and food making. We observe that decomposition often depends on what we call a "scaffold," and we further propose four variants of it as design tactics: fragmenting, aging, liberating, and tracing. We then tested the tactics over a period of four months in a ceramic

studio using diverse materials, with a mixture of successes and failures. We conclude by reflecting on how the design tactics might be deployed in nonanthropocentric HCI/design.

Chapter 5.

Designing (through) Symbiotic Encounters [26]

> Multiplying perspectives is not simply about assembling diversity, nor is it about the adoption of an easy relativism; rather, it is about "staying with the trouble" in an effort to meaningfully navigate one's way through the complexity of worlds in process. This navigation is fundamentally a question of ethics and politics.
>
> – Dooren, Kirksey, and Münster[27]

In the previous chapter, I identified the notion of scaffolding and its subsequent design tactics as tools to encourage collaboration between nature and culture; I also argued that by replacing, both conceptually and physically, molds ("hard structures") with scaffolds ("soft and transient structures"), we can cultivate a space that welcomes co-creation and facilitates participation. And finally, I note that the inquiry originally conducted in art design studios offers implications for interaction design and technological development, including creating platforms for civic

[26] The majority of this chapter was previously published as a peer-reviewed archival paper at ACM CHI 2019 titling "Symbiotic Encounters: HCI and Sustainable Agriculture." This chapter has been lightly edited from the previous published version by adding an introductory paragraph and expanding the discussion (§5.5.3 and §5.5.4). Additionally, while I conducted two of the ethnographic fieldworks outlined in this chapter independently (§5.4.1 and §5.4.2), Shaowen Bardzell and Jeffrey Bardzell have contributed significantly to the inquiry, analysis, and writing. Additionally, Patrycja Zdziarska helped with copy-editing the final manuscript; both Tony Lam and Aehong Min supported with formatting my first LaTeX publication. I also thank my interlocutors in Taiwan for their generosity.

[27] Van Dooren, Thom, Eben Kirksey, and Ursula Münster. "Multispecies Studies: Cultivating Arts of Attentiveness." *Environmental Humanities* 8.1 (2016): 1-23.

participation and making machine learning models more transparent—all these have the potential to create more socially just futures that I aim to explore through this dissertation.

Moving on, I became interested in understanding whether this symbiotic and cooperative form of human-nature interaction might be applied to a different practice or site, such as moving from creating designs together to growing foods together. In particular, I asked, "how might collaborative and responsible forms of human-nature interaction inform alternative farming practices and to build sustainable food systems?" To answer this question, I visited three small-scale eco-friendly farms in rural Taiwan and worked alongside with the farmers to learn to how notice, respond, and engage in symbiotic encounters with companion species.

5.1 Growing Foods with Weeds and Pests

We are living in an age of substantial environmental crises: climate change, water pollution, soil depletion, biodiversity loss, and food crisis, just to name a few. In sustainable HCI, there are several ongoing threads aiming to address environmental concerns: one develops theories and methods to support sustainable interaction design practices (Choi and Blevis 2010; Raghavan et al. 2016; Blevis 2018; Remy et al. 2018; Raghavan and Pargman 2017; Tomlinson and Aubert 2017; Tomlinson et al. 2013; Blevis 2007; Nardi 2016; Quitmeyer 2017), another focuses on human-food interaction, including farming, cooking, consumption, distribution, and disposal (Kuznetsov, Santana, and Long 2016; Steup et al. 2018; Håkansson and Sengers 2013b; Blevis and Morse 2009; Heitlinger, Bryan-Kinns, and Jefferies 2013; Odom 2010; Lyle, Choi, and Foth 2015). Many have argued that building a more resilient future requires a broader shift of perspective than monitoring and regulating individual behaviors (DiSalvo, Sengers, and Brynjarsdóttir 2010; Dourish 2010; Liu, Bardzell, and Bardzell 2018b; Brynjarsdottir et al. 2012; Pierce and Paulos 2012; P. Aoki et al. 2017). In response, some propose considering the macro

sociotechnical context within which individual behaviors are situated (Møllenbach and Hoff 2012; Pierce and Paulos 2012; Dourish 2010; Brynjarsdottir et al. 2012), others call attention to collective activism and community engagement in supporting sustainable food practices (Lyle, Choi, and Foth 2015; Steup et al. 2018; Choi and Blevis 2010). And a relatively new thread draws from concepts in posthumanism to incorporate the perspective of nonhuman others, such as animals, plants, and fungi (Jen Liu, Byrne, and Devendorf 2018; N. Smith, Bardzell, and Bardzell 2017; Light, Shklovski, and Powell 2017; Kobayashi, Ueoka, and Hirose 2009).

Nonanthropocentric HCI scholars argue that human-centered design approaches are not sustainable, and in fact they are catastrophic. For example, in the pursuit of labor efficiency and greater yields, industrial farming has developed high dependency on fertilizers and pesticides. Without adequately taking the capacity and adaptability of the environment into consideration, these practices have resulted in the production of drug-resistant pests and virulent diseases. To address the problems caused by human domination, HCI and design researchers have proposed decentering humans in design (Forlano 2016; N. Smith, Bardzell, and Bardzell 2017; Liu, Byrne, and Devendorf 2018; DiSalvo and Lukens 2011). By de-centering humans, they do not mean to negate humans; on the contrary, it refers to placing humans in the ecology along with other species, a realization that humans are neither detached from nor in control of worldmaking. In other words, nonanthropocentric HCI reorients our attention from a human-centered agenda to a multispecies worldview (Tsing et al. 2017).

As researchers who identify with this non-anthropocentric research agenda in HCI and design, we also recognize how far we are as a field from achieving our collective potential in this area. Today, several theories have been explored and applied in HCI—natureculture (Latimer and Miele 2013; María Puig de la Bellacasa 2010; N. Smith, Bardzell, and Bardzell 2017; Liu, Bardzell,

and Bardzell 2018a), posthumanism (Braidotti 2016; Wolfe 2010; Hayles 1999; Liu, Byrne, and Devendorf 2018; Jackson and Kang 2014), global assemblages (Collier 2006; Collier and Ong 2008; S. Lindtner, Bardzell, and Bardzell 2016)—but that as a community we've only just begun to unpack how this will translate into in HCI theories, methodologies, and findings.

We contribute to this developing nonanthropocentric HCI agenda through our ethnographic work on farms in Taiwan. These produce food sustainably in part by building on symbiotic encounters between humans and non-humans, including insects, weeds, snails, and food waste. Guiding the study itself and our presentation of it here are a set of theories from posthumanism and multispecies thinking, in particular, Donna Haraway's notion of "companion species" (2008; 2016) and Anna Tsing's practice of "noticing differently" (Tsing 2015). We apply these theoretical resources to support our interpretation of our ethnographic data. These theories help us to construct a perspective that enables us to provide images of human/non-human collaboration, exemplifying how humans and natural environments can cooperate for mutually beneficial ends. In doing so, we consider our contribution to be two-fold. First, we respond to the call of de-centering humans in sustainable HCI by making posthuman concepts more tractable, grounded on our ethnography. Second, we analyze our ethnographic encounters with a layer of abstraction concerning how these concepts and our empirical study might bring new, nonanthropocentric perspectives to different research interests in HCI, including potential roles for technology to support symbolic encounters, as well as ways that HCI methodologies might themselves be influenced by this work.

5.2 Related Work

We position this work broadly within the domain of sustainable HCI, and more narrowly within a body of recent research pushing beyond human-centered approaches to HCI.

5.2.1 Sustainable HCI

An on-going thread in HCI focuses on sustainable human-food interaction, including farming, cooking, consumption, distribution, and disposal (Hirsch 2014; Liu, Bardzell, and Bardzell 2019b; Odom 2014; Lyle, Choi, and Foth 2015; Lyle, Choi, and Foth 2014; Steup et al. 2018; Liu, Bardzell, and Bardzell 2018b; Blevis and Morse 2009; Kuznetsov, Santana, and Long 2016; Thompson 2015; Hirsch et al. 2010; Choi, Foth, and Hearn 2014; Ganglbauer, Fitzpatrick, and Comber 2013; Steinfield et al. 2015). Works within this thread have offered practical guidelines and useful lens to our study on experimental farming, collaborative food making, decomposition in agriculture, and design to explore ways of working with nature, as opposed to controlling or working against it. Within HCI, the emergence of human-food interaction research is a response to the raising pressure in food security and scarcity. According to U.N.'s 2017 annual report, approximately 821 million people are living in hunger, comprising 11% of the global population (2018). Food crisis is a complicated issue merging together problems of climate change, urbanization, and various forms of pollution and resource depletion (Norton et al. 2017). Recognizing the complexity of building a sustainable food culture, HCI researchers Choi and Blevis (2010) call for transdisciplinary collaboration and argue that building a resilient future requires "an iterative and evolutionary process involving interactions amongst people, place, and technology." This framework is useful in my dissertation work because it breaks down an intricate issue into three domains to make it more workable.

Farming research in HCI has explored different sociotechnical environments where sustainable food practices take place. Work in urban agriculture focuses on encouraging community engagement, collective activism, and citizen science (Choi and Blevis 2010; Heitlinger, Bryan-Kinns, and Jefferies 2013; Hirsch 2014; Odom 2010; 2014). For example, Odom's (2014; 2010) work on urban community gardens reveals the members' resistance in implementing

technologies in their gardening practices but are widely interested in bringing visibility to urban agriculture sites through web campaigns and workshops. Steup et al.'s (2018) study shows that small-scale farmers collectively act as a "tiny public" to shift food sovereignty away from large supermarket chains to local food producers and policies. Other researchers have looked into farming in rural areas or developing regions where their cultural-material constructions are distinctive to urban spaces. This line of research tends to address challenges in technology accessibility and adaption (Given, Winkler, and Hopps-Wallis 2017; Mubin et al. 2015; Oduor et al. 2018; Steinfield et al. 2015; Wadkar et al. 2017). For example, a study in rural Kenya by Oduor at al. (2018) suggests that rural farmers are interested in accessing farming information that increase yields (e.g., soil fertility, distribution of irrigation water, and sales opportunities); however, they are less tech savvy and require more knowledge in order to utilize ICT technologies.

We are inspired by the current corpus of farming research in HCI because they fuse cultural, political, economic, and technical concerns to construct a broader understanding of sustainable food practices. However, if we go back to Choi and Blevis's design framework (2010), we see that people and technology are often at the center of analysis. Instead, the notion of place is often loosely described in terms of its cultural-material constructions. What is often backgrounded is how nonhuman stakeholders—insects, pests, wild plants, bacteria, microorganisms, and other critters—come into play. Although nonhuman stakeholders comprise the major landscape of the farmlands, they remain relatively passive and even irrelevant in our shaping food cultures.

There are a few exceptions. For instance, in the spirit of creating sustainable global food systems, Raghavan et al. (2016) turn to agroecology: a farming method that leverages ecological principles (e.g., the flow of natural resources, the rhythm of growth) to produce high yields while reducing

negative environmental impacts. Similarly, Liu. Bardzell, and Bardzell (2018b) propose using the permaculture philosophy of working with nature to replace the traditional control model in industrial farming and sometimes in the agenda of sustainable HCI. This line of research has made explicit that the natural environment—its rhythm, capability, limit, and agency—bear potential in shaping sustainable food culture. In the present work, we seek to surface the multispecies world in the farms. Specifically, we are interested in unpacking the interactions between human and nonhuman stakeholders.

5.2.2 Strange Companions and Symbiotic Encounters

HCI researchers have in recent years directed attention to the concept of Anthropocene (Crutzen 2002) to understand and account for the impact of humanity on the planet. Specifically, several research proposals have advocated for the decentering of the human in technological design because human exceptionality is problematic, and both human and non-human shape complex socio-technical entanglements (DiSalvo and Lukens 2009; 2011; Forlano 2016; Jenkins et al. 2016). For example, Smith, Bardzell, and Bardzell (2017) leverage key concepts in the Anthropocene—naturecultures, hybrids, and decentering the human in design—to develop design strategies that refigure human-animal relations to support cohabitation and presumably even redefine cohabitation. The posthumanist concept of "collaborative survival" was the jumping off point for Liu, Byrne, and Devendorf (2018). to design a set of wearable tools for mushroom foraging, and in the process, explore what post-anthropocentric design could mean. Light, Shklovski, and Powell (2017) challenge the prevailing "bovine design" model that compromises the needs of other species in service of human superiority. They call for the turn to the more-than-human world because it is "… the least we might do as we strive for the grace to accompany fellow-species towards their own (and perhaps our) extinction." How might HCI reconfigure itself to design for humans and nonhumans in a relational perspective?

As a response to these challenges, we have taken up two alternative analytical sensibilities from anthropology and posthumanist scholarship: Anna Tsing's "noticing differently" and Donna Haraway's "companion species" (Haraway 2008; Tsing 2015). To introduce her understanding of "noticing differently," cultural anthropologist Anna Tsing recounted her own experience learning polyphony, a style of music combining two or more individual melodies together. She recalls, "when I first learned polyphony, it was a revelation in listening; I was forced to pick out separate, simultaneous melodies and to listen for the moments of harmony and dissonance they created together" (Tsing 2015, 24). "Noticing differently" refers to the ability to acknowledge and simultaneously step in and out of multiple simultaneous frames of references. We can attend to a single thread or a relationship. Sometimes those relationships are temporary but effective, nonetheless. As we will show, noticing differently can mean perceiving the potential of a temporary relationship and developing—or, more literally, cultivating—it. We view these as symbiotic encounters, building on Tsing (2017, M5), who writes:

> Twenty-first century research on organisms ranging from bacteria to insects to mammals has shown that symbiosis is a near-requirement for life […] our bodies contain more bacterial cells than human ones. […] Life, put simply, is symbiosis 'all the way down.' As Donna Haraway suggests, recognizing the importance of symbiotic makings is just the beginning of 'staying with the trouble.' Symbiotic relations must be constantly renewed and negotiated within life's entanglements.

The farmers we studied are engaged in this work of renewing and negotiating within the entanglements that constitute their farm plots, in some cases even referencing contemporary theories of the Anthropocene. A related concept is that of companion species, offered by Donna Haraway (2003; 2008). This concept emphasized moments when species meet, "species

interdependence is the name of the worlding game on earth, and that game must be one of response and respect. That is the play of companion species learning to pay attention. Not much is excluded from the needed play, not technologies, commerce, organisms, landscapes, peoples, practices" (2008, 19). Accordingly, companion species is about interspecies relationality, calling our attention to the present when "myriad unfinished configurations of places, times, matters, meanings" take place (Haraway 2016). The call for the cultivation and sustainment of the companionship between human and nonhuman go beyond the domesticated and include all nonhuman actors, including plants, molds, bacteria, and even those that pose a threat to humans.

5.3 Ethnographic Field Research in Rural Taiwan

As a research group, we have been researching bottom-up innovation, creative industries, and entrepreneurial life in Taiwan since 2011. The present work draws from and is informed by our long-term fieldwork (S. Bardzell 2018; S. Bardzell, Bardzell, and Ng 2017; Freeman, Bardzell, and Bardzell 2018; Liu, Bardzell, and Bardzell 2018b; Freeman, Bardzell, and Bardzell 2017). In the context of this chapter, we foreground the ethnographic field research we conducted between June 2017 and August 2018 in two farming villages in rural Taiwan.

Sites. Pinglin district and Yilan counties are known in Taiwan as hubs of agricultural experimentation. Many farmers in the two sites engage in eco-friendly farming, small-scale farming, organic farming, and AgTech farming. Common among them is the commitment to explore and practice alternative farming activities to unsustainable industrial agriculture, with a particular focus on reducing the use of pesticides in farming and integrating more harmonious between land, people, environment, and resources. We provide some background on each below to situate our findings.

Pinglin, a rural town in Taiwan, is located in the mountainous area in the south of Taipei City. Here, 80% of its residents are involved with tea-related activities on a daily basis, including growing, processing, managing, and trading (S. Huang and Kuo 2010). Tea trees are prone to pest attack, so conventional tea cultivation relies heavily on pesticides and fertilizers to ensure the beauty and juiciness of tea leaves, and the quantity of tea that can be harvested in any given season; however, because of Pinglin's unique geological location, local tea farmers work closely with government administrations (e.g., Agriculture department in New Taipei City government, tea research and extension station under Executive Yuan), research institutions (e.g., National Taiwan University Graduate Institute of Building Planning), and non-profit organizations (e.g., Tse-Xin Organic Agriculture Foundation) to experiment with different ways of cultivation (Chang 2013; Tse-Xin Organic Agriculture Foundation n.d.; Taiwan Bluemagpie Tea n.d.). While less than 1% of farms in Taiwan are certified organic, 6% of these in Pinglin are (黃仲杰 2016).

The second site is Shengou Village (深溝村) in the rural Yuanshan township of Taiwan's Yilan County. In recent years, Yuanshan township has seen a surge of new generation of farmers, many of whom are young (20s-40s), former city dwellers and professionals (e.g., lawyers, engineers, biologists, cultural anthropologists, media producers, designers, and architects) with advanced degrees. Shengou Village is especially known for "小農群聚" (small farmer collectives) who express a desire for a different kind of human-land relationship: they practice and experiment with alternative farming techniques and principles to address ever-increasing deleterious environmental impacts (J. Bardzell, Bardzell, and Lindtner 2019).

Data Collection. Our data included fieldnotes, photos, audio recordings, and artifact collections from farmlands which included flyers, catalogs, and booklets farmers created to promote their products, community-building activities and events among others. Interviews were conducted

in Mandarin Chinese, and the English quotes in this paper were all translated by the authors. Two of the authors are native of Taiwan and native speakers of Chinese; the other, born in the US, has conversational competence in Mandarin. Our interlocutors include farmers, residents of farmlands we visited, agricultural policy makers in Taiwan, and more. Since Taiwanese farmers engage in activities and practices both off line in person and online virtually (e.g., announcing events, exchanging how-to tips, and documenting and sharing farming activities in forums and social media such as Facebook), it was necessary to engage with subjects in their own terms, so we also employed a set of digital ethnographic approaches (Boellstorff et al. 2012; Horst and Miller 2012; Miller and Slater 2000; Nardi 2010) to examine how experimental agricultural activities and interaction unfolds virtually and how farmers interface with others outside of the farming communities, including other farmers and consumers. We developed a customized scraper tool to automate the collection of posts and comment threads from Facebook, with individual items numbering in the tens of thousands.

Interpretive Procedures. The research team conducted data analysis through a procedure known as *explication de texte* (Ogden and Richards 1923), or close reading, an analytical method originating in the humanities (J. Bardzell and Bardzell 2015a). Two of the three researchers involved in the analysis have doctoral training in the humanities and are experienced with this analytical practice; the third is a design ethnographer who is also experienced at critical interpretation. Broadly, the *explication de texte* proceeded as follows: initially, the analyst seeks to build a literacy with the main contents of the texts. This literacy, which might be characterized as knowledge that any other reader would also share, gradually develops into a sensitivity for the particular data set. Developing it, we examined our interlocutors's use of diction, metaphor, narrative structures, allusive resonances, and connotation, etc. This phase followed an iterative and dialogic process, alternating between reading alone and reading together, and between

reading theory and analyzing textual data—mutually informing one another until a picture emerged that seemed to fit with participant discourses and activities, our inquiry goals, theoretical resources, and our own experiences.

5.4 Three Experiments in Symbiotic Encounters

In this section, we offer three accounts from our ethnographic work focusing on symbiotic encounters. As is common in critical intellectual traditions, we move from relatively descriptive accounts of our inquiry (to establish a basis of mutual understanding) towards increasingly interpretative ones (to develop our original contribution). Thus, each of our vignettes is initially descriptive, while more interpretative claims are offered later, particularly in the Discussion (§5.5).

5.4.1 Oriental Beauty and the Frog King's Beast

The fieldwork took us to organic tea farms in Pinglin in the summer of 2017. Tea farmer Chen Lu-He (陳陸合), a Pinglin native, spent much of his career at Panasonic before retiring and returning to his hometown to take up farming. Chen was financially stable at this phase of his life, so he wanted to experiment with ways that he can give back. Chen is known for being a pioneer in organic farming in Pinglin, nicknamed the "frog king" for his dedication to preserving local environment and wildlife (新北市政府農業局 2017). We visited Chen's Green Light tea farm, which sits on top of the mountains overlooking Beishi River, one of the water sources of the Feitsui Dam that a quarter of the total population in Taiwan relies on (Figure 14, left).

Previous research (Scott 2016; Sakata 2010; Chang 2013; 吳聲舜 2016) has shown that Taiwan's world-famous Oriental Beauty (東方美人茶) and honey scented tea (蜜香茶) are the a result of tea farmers having an effective relationship with non-human actors (in this case, bugs) in tea

cultivation. In fact, Oriental Beauty and honey scented tea become popular because of a distinctive fruity and sweet-like-honey aroma during brewing. These aromas are triggered by Jacobiasca Formosana (小綠葉蟬), a small leaf hopper that feeds on tea buds and leaves. Chen showed us how to recognize the "infected" leaves (Figure 14, right); he said,

Figure 14: Chen's organic tea farm. Left: Green Light tea farm sits on top of the mountains overlooking Beishi River. Right: the yellow and stunted foliage in the back was infected by leafhoppers; the rolled up tea leaves are the nests of the tea tortrix; and those with burning dots have been attacked by stink bugs.

This leaf has been stung by the leafhoppers, that is why it's yellow and stunted… if you don't use spray pesticide you will see these leafhoppers in the tea farm.

The leafhoppers are extremely small, measuring just 0.1-inch-long, making it hard to be detected through naked eyes. Farmers in Taiwan often call them (in the Taiwanese dialect) ian-a (蝘仔) or fuchenzi (浮塵子, written as "floating dust" in Chinese) to illustrate their diminutive size and prevalence during summer and autumn when their population peak (Writer 2016). Chen pulled out his phone to show us a close-up of this insect. He also showed us the needle-like proboscis of the leafhoppers, which penetrates the tissues of the tea leaves for its juice. The insect-bitten tea leaves produce two kinds of chemicals: one is the so-called ian-a smell, which attracts

spiders that eat the leafhoppers; meanwhile the plant produces another chemical repair the damage to its leaves, causing a chemical change in the leaf that results in the natural honey scent during tea brewing.

Recent biochemical studies indicate that the damage done by the leafhopper activates a defensive response and significantly increases a fragrant compound, which contributes to the sweet note of the tea (Sakata 2010; “Dongfang Meiren” n.d.). It is worth noting that the quality and quantity of tea depends heavily on the leafhoppers—the damage has to be done in the right amount and at the right time, because tea leaves of different ages react differently to the same bite, and too much damage increases the bitterness of the tea (Scott 2016). Cultivating oriental beauty and honey scented tea thus involves an intricate interaction between farmer and the non-human world, where leafhoppers are key actors. While leafhoppers cause physical damage to the foliage and reduce the yield of the season, they also contribute to the production of the distinct honey aroma, making the tea a highly sought-after commodity. They also attract the spiders that prevent their overpopulation—solving two difficult and unrelated problems at once.

Organic tea farmers in Pingling actively facilitate an alternative engagement with the natural environment by relinquishing control, including the use of both fertilizers and pesticides. In her exploration of permaculture movement as an alter-biopolitical intervention, Puig de la Bellacasa (2010) describes permaculture ethics as the engagement with the consequences of living in naturecultures, recognizing the interdependency of all forms of life – humans and their technologies, animals, plants, microorganisms, elemental resources such as air and water, as well as the soil we feed on. It thus decenters human ethical subjectivity by not considering humans as masters nor even as protectors of, but as part of earth’s living beings.

In the case of tea farmers and leafhoppers in Taiwanese tea farms, by decentering the needs of the human (i.e., maintaining bugs-free tea farms), a different relationship between the non-human and human emerges, one that is based on appreciation, affection, and responsibility as opposed to interspecies conflict and competition.

A skeptical reader might consider Chen's tea farm as yet another example of control—one that is carefully arranged to attract leafhoppers to consume the foliage, triggering the defensive mechanism in the leaves to release a unique honey scented aroma and elevate the value of the tea. A recent agriculture research project attempted to generate the unique honey aroma and mass produce Oriental Beauty by injecting tea leaves with identical chemical compounds that are original produced by the leafhoppers (Sakata 2010). In this counter scenario, humans replicate and take full control of the production of honey aroma mechanism in a lab setting, taking the leafhoppers and spiders out of the equation completely. The distinction between the two models is clear: while the latter focuses on *instrumentality*, requiring less time, and thus ensuring greater and more reliable availability of the honey scented teas, the former is about *cultivation* and sustainable collective caring, an aspect of permaculture we shall turn to in the next section. It is a feature—not a bug [sic]—that humans derive immediate benefit as well as the non-human participants.

5.4.2 The Weed Hacker

Moving back to Shengou Village in Yialn, we worked with Chen Xing-Yan (陳幸延), a 30-year old engineer-turned-farmer who settled in the village four years ago. Xing-Yan is the founder of Open Hack Farm, a group of farmers and technologists dedicated to leveraging open source and LASS (location aware sensor systems) to innovate on agricultural productivity in a sustainable way. For example, he developed "Farmer's Helper," a chat bot to help farmers obtain information about

the weather and suitable crops to grow in a given season. The chat bot also offers alerts on extreme weather conditions (e.g., thunderstorm) and possible pest attack. The Facebook group for Open Hack Farm has 1400+ members, and similar AgTech groups in Taiwan such as Smart Agri, AgriHarvest, Data-driving Farming, and Agricultural Technology Research Institute have combined followers measuring over 75,000.

Sitting by the ditch of a countryside road, Xing-Yan's field appeared to us more like a wasteland than a farmland: hundreds of crops, flower, trees, and weeds all jammed together in a 0.24 acres space, and it was hard for us to distinguish the wild from the cultivated (Figure 15, top left). Xing-Yan's field creates a sharp contrast to the ones surrounding his: those feature rows of crops, demarcated walkways, wooden scaffolds that support the climbing plants, and screens covering the crops that are vulnerable to pests. One might easily mistake Xing-Yan's field as an abandoned land with little sign of human attention. Xing-Yan nicknamed his garden 草草瞭事 (cao cao liao shi), which sounds like the Chinese idiom 草草了事 (literally doing things hastily and carelessly). The play on the words is significant: Xing-Yan did not use the character 了 for "do" or "act" originally used in the idiom; instead, he substituted in the character 瞭 that sounds like (and almost rhymes with) "understand," but suggests appreciation—notions of intention and care, the exact opposite of what the idiom connotes. Indeed, by working alongside Xing-Yan during our multiple visits to Shengou Village, we came to understand Xing-Yan's unique farming practice, including how he understands what constitutes "harmful" plants in his field and how he responds through special practices of weeding and composting.

We joined his weeding routine in a hot and humid summer afternoon in 2018. Weeding to Xing-Yan is not about removing all the non-crop plants from his field, only the ones in the Poaceae and Cyperaceae families in plant taxonomy, because they reproduce in a fast pace and can

easily dominate the farmland. Plants in the Poaceae are easily recognized because of their prickly leaves (Figure 15, bottom left). Xing-Yan explains,

> *these plants produce thousands of seeds in a single plant, making it extremely difficult to remove […] I prioritize the Poaceae family when I weed. And of course, it is not enough to be selective in weeding, you also need to refine the soil to make it suitable for more advanced plants to grow, so they can compete against the Poaceae family.*

He made a comparison between his and surrounding fields:

> *If you compare my field to the ones next to mine, you can see all the weeds in those are the prickly kinds […] I've already done several rounds of weeding, so there are not so many Poaceae plants in my field. Although it's pretty messy right now and needs more work to clean it up, the remaining weeds are the ones with broad leaves, even ferns.*

These weeds, in Xing-Yan's eyes, are companions to the crops he is growing (the word he uses is 共伴, literally "to accompany" or "to be a companion"). The practice of "companion planting" in agriculture traditionally refers to the planting of different crops in proximity for a variety of different reasons, including maximizing the space, pest control, pollination among others. Native Americans, for example, planted corn, beans, and squash together, referring to them as the "three sisters," because they complement and enhance each other (Landon 2008). Companion planting is a common strategy in polyculture (defined as the use of multiple crops in the same space) and permaculture (an agricultural philosophy that aims to leverage patterns seen in the ecosystem) as a way to cultivate and maintain biodiversity. Here, Xing-Yan extends that logic to weeds, instead of planting other crops in his field to increase yield, he regards weeds as "companion crops" to his rice because they cover the soil to maintain its moisture, offer shelter

to the critters in his field, help compete against the invasive weeds, and provide sugar glucose through photosynthesis to feed the microorganisms in the soil. It might not, on first glance, be much to look at, but as (Tsing et al. 2017) argue, “Co-species survival requires arts of imagination as much as scientific specifications.”

Figure 15: Xing-Yan’s polyculture garden. Top left: hundreds of species of crops, flowers, weeds, and trees growing harmoniously together in Xing-Yan’s garden. At first glance, it was hard to tell apart the cultivated from the wild. Top right: weeds removed from the garden were piled on the black tarp. Bottom left: Xing Yan is very selective when it comes to weeding: he only targets weeds in the Poaceae family. Bottom right: underneath the tarp is dark, moist, and fine compost soil made from the fast-growing weeds. The haphazard appearance of Xing-Yan’s farm belies its sophisticated arrangement of recycling and care.

Another time we returned to find Xing-Yan weeding and composting. Xing-Yan insisted on using his own hands rather than machines to ensure that the roots of these plants are cleared, and the

damage done to the soil are minimized. He compressed the weeds he removed from the field into many bundles. Two days later we returned to Xing-Yan's field to observe and participate in his composting practice. In the front of the field sits a large area covered by black tarps. He had placed wood planks, tree branches, and farming tools on top of the tarps to prevent them from being blown away by the wind. The weed bundles he removed from the field a few days ago—most of them were now brittle due to the burning sun—also sat on top of the tarps (Figure 15, top right). Underneath the tarps was a large pile of compost soil—black, moist, fine, and abundance of living lives such as ants, earthworms, and centipedes (Figure 15, bottom right). The soil was made from weeds that Xing-Yan previously removed from his field: the ones belong to the Poaceae and Cyperaceae family. We transported some of the old compost soil to a plastic bin for storage. The plastic bin was divided into two separate storage spaces, measuring approximately 30 inches wide and 60 inches long each. Xing-Yan then plowed the leftover compost with the rake to let it breathe; the weeds that we collected two days ago were then added to the pile, creating a fluffy texture.

Xing-Yan told us that water is an essential ingredient in facilitating the composting process but not the most important. He headed toward a blue bucket resting at end of the compost by the ditch. The liquid inside the bucket was dark, and it immediately filled the air with a nasty, rotten odor when cover was removed. Xing-Yan poured a scoop of the dark liquid to the weeds on the compost pile. Sensing our puzzlement about the liquid, Xing-Yan told us it included *"all kinds of fermented fluids… I just dump everything expired into the bucket… it doesn't really matter… I also put some rice and bread in the liquid because it needs flour… I mean they need vitamins."* The "they" Xing-Yan referred to are microorganisms in the rotting liquid, and the "vitamin" is the nutrient which they feed on. Characteristic of all of Xing-Yan's practice is a dialectic between apparent haphazardness and a sophisticated arrangement of care. His farm looks messy to the

eye, and yet its weed management is superior to that of its neighbors. Even its name is based on an idiomatic expression for carelessness, with a pun that inverts its meaning. Harmful and even threatening weeds are bundled with care, then layered with fermented expired foods, which become vitamins that nourish his crops and heal his soil.

5.4.3 Toppling the Scales

Tucked away in Shengou village（深溝村), the Yilan-based Land Dyke Family Farm is an experimental farming collective founded in 2012 by social activist Shawn Wu. The name Land Dyke was coined by American eco-feminists in the 1970s at the height of returning-to-the-land movement (A. Lin 2017). Its Chinese name is “Tulake” (土拉客). The name in Mandarin Chinese means “using land to greet people,” but when pronounced in Taiwanese dialect, it shares the same sound as the words for farm trucks. Unlike the separatist ideal celebrated by early lesbian farmers in the US fighting against patriarchy, the six feminist queer farmers take inspiration from its principles of collective cooperation in order to create a more community-based agriculture. They learned how to grow vegetables from 73-year-old Zhu Mei-chiao, a female veteran vegetable farmer and decided to live and work together in Shengou village with rice cultivation as the primary crop and fruit and vegetables as supplement. Like other small-scale friendly farmers (“友善小農” or “youshan xiaonong”) in Yuanshan township, Land Dyke is committed to eco-friendly farming and follows the sustainability principles established by the “Yilan Eco-friendly Smallholder Farmers’ Alliance”: it forbids pesticides, chemical fertilizers, and harming lives if they do not harm the crops, and the use of imported supplies (Y.-X. (NaiNai) Huang 2018). In practice, Land Dyke insists that after the grains have been harvested and dried, they will not be treated with chemical preservatives. They also hand-collect golden treasure snails (福壽螺), a major pest of rice agriculture across Asia, as opposed to killing them with pesticides.

On July 20th, 2018, Land Dyke released a long post on their blog and Facebook page documenting their ongoing struggles with scales[28]—tiny insects that suck sap from the citrus trees and then secret honeydew, a sticky and sugary substance, onto the leaves and branches. Ant colonies are attracted by the honeydew and feast on it, further damaging the trees. The honeydew also attracts a sooty mold that grows on the leaves of the affected plants, interfering the photosynthesis process.

Figure 16: Land Dyke's citrus trees. Left: healthy citrus trees. Right: scale-infested citrus trees with sooty mold covering the leaves and interfering the photosynthesis process. Image credit: Land Dyke.

The two farmers tell the story of their eventual and heart-breaking decision to go against their eco-farming principles and use pesticides in order to save the citrus crops. They witnessed the gradual decline of the affected citrus trees over a period of four months in the spring of 2018, first with falling twigs and branches, followed by the development of sooty mold covering all over the plants. They tell of their anguished decision to use pesticides in an attempt to save the orchard. But the use of chemical pesticides proved to be too little too late: after Land Dyke

[28] The original post, titling "土拉客柑橘園用藥說明" was written in traditional Chinese. http://landdykecsa.blogspot.com/2018/07/2018.html?view=timeslide

applied chemical pesticides in the citrus orchard in July, the scale infestation continued, and they caused further damage when the wasps who used to reside in the orchard abandoned it the day after the chemical spray (see Figure 16). They did eventually save the trees; however, they later disclosed on a blog that the harvested citrus fruits had 0.01ppm of pesticide residue, leaving it up to consumers to determine if they wanted to purchase them (Land Dyke CSA 2018).

NaiNai and GuaGua (the two Land Dyke farmers who cared for the orchard) first noticed the presence of scale insects in March when the citrus trees started to bloom. Scale insects feed on the sap of citrus trees and secrete honeydew, which accumulate on the foliage, fruits, and branches. When the insect infestation is severe, it can wipe out the entire orchard. Between March and June, NaiNai, GuoGuo, and other Land Dyke members had done what they could with all the non-chemical control methods, such as wiping and washing affected leaves with lukewarm water and soap, flushing the infected part of the orchid with water, physically destroying ant nests on the trees, and spraying the infested plants with neem oil (an organic and biodegradable broad-spectrum pesticide). Nothing seemed to work, and the scale insects gained more ground, in part because of the unusually high temperature in the region, the delay of the monsoon season, and the low quantity of ladybugs, the scale insects' natural predators (and thus beneficial insects to the citrus tree) were not enough in quantity to combat scale insects.

After four months of battle and struggle, the farmers made the painful decision to use non-natural pesticides for scale eradication. NaiNai motivated their decision thus, "*we can no longer bear to watch these fruit trees die… we love them, we lack the strength and the courage to watch them die.*" At the same time, they were also concerned about their livelihood and felt responsible for their neighbors':

It usually takes 6 years of nurturing before fruit trees can start having stable yield… we did not have enough capital to survive 6 years with no income. Further, if we don't act now, what happens when scale infestation spreads to the nearby orchards, affecting our neighboring farmers' livelihood?

They were stricken with guilt for not acting sooner; at the same time, they wondered about the timing when natural measures stop working and chemical pesticides need to take over:

If we could have made the decision earlier, could we have only had to spray once and reduce the harms that chemical compounds have posted to the land to its minimum?

She continued, reflecting on the challenges of practicing eco-farming:

Does eco-friendly farming simply mean the eradication of all chemical fertilizers and pesticides? To me, there is no standard definition to eco-friendly farming. [Instead,] it is all based on the trust the consumers have on the farmers and the goodwill the farmers invest in the land.

In describing the condition of the Anthropocene, Swanson et al. relates it to the "suffering from the hills of another species" for humans and nonhumans alike (Tsing et al. 2017). The Land Dyke account shows the vulnerability of their encounter where the fate of one species change the entire ecosystem with no clear "winners" because "entanglement with others makes life possible, but when one relationship goes awry, the repercussions ripple" (Tsing et al. 2017). The Land Dyke example does not have a magical twist nor a happy ending, reminding us that being Eco-Friendly sometimes simply fails. But there is a silver lining, because in its failure, it can clarify tradeoffs and support future decision making.

5.5 Discussion: Multispecies Interaction Design

HCI researchers focusing on climate change, sustainability, and the Anthropocene are seeking paradigms and models by which humans can better harmonize with nature. They have introduced a rich vocabulary from posthumanism—collaborative survival, natureculture, companion species, noticing differently, etc.—to decenter humans from our thinking; and they have begun to identify and propose new designs that reflect posthumanist values. Yet the scope of the problem is almost incomprehensibly large, and the role of HCI in it remains nebulous.

We have offered three accounts of ethnographic encounters which, we believe, exemplify contemporary efforts with affinities for posthumanist thinking. Part of their attraction to us is their connection to the land—soil, bugs, secretions, fermentation—and to the posthumanist theory. Many of the connections were surprising. For example, tea farmers depended on a pest whose crop destruction can, under the right circumstances, elevate the crops to a gourmet status. Or Xing-Yan's ability to see weeds as companion crops, leading to a conceptual and physical re-composition of his farm plot and his practices. We also showed failure—the scales who destroyed the orchard and the environmentalist farmers who tragically acted too late—and how it nonetheless produced useful knowledge.

What our ethnographic work has not yet shown is a role for technology or for a research community that focuses on the human side of technology—from its innovation through to its end users and their consequences. Although we do not (nor is it our intention to) offer concrete answers as to how technology might address issues in both environmental sustainability and food crisis, we recognize HCI's long-standing commitment to understanding use and users as foundational to technology design, and we position this study as doing so in two ways. First, our ethnography helps HCI researchers understand emerging sustainable farming practices,

including who is engaging with them and what technologies/approaches they are using. Second, unpacking our ethnography with a theoretical lens has helped us look to non-human "users" and the interactions between human and other species, which then helps to define a space of possibility for technological interventions. In the following sections, we reflect on what we've seen in relation to HCI research and practice, without any particular orders.

5.5.1 The Earth as Lab

HCI, like many other fields, tends to define "the lab" and "in the wild" as if they are opposites, sites that produce different kinds of knowledge, that demand different sorts of methods, and so forth (Rogers 2012). Yet "the wild" was one of humanity's earliest labs; experiments in food production—and the origins of the scientific method itself—go back to ancient times.

The farm functions well as a lab for many reasons. Its spatial organization accommodates different kinds of experiments simply by dividing it into sub-plots. Its cycles—day and night, alternations of dry and rainy stretches, seasonal, annual, and beyond—accommodate replication and variation (e.g., crop rotation). Natural processes such as decomposition and the effects of animal and vegetable life happen on their own, often rapidly. What IT developers today call a "minimum viable prototype"—a rapid effort to concretize and test an idea with the intention to learn and iterate—finds analogues throughout the sites and stories we heard. Experiments in soil optimization, seed hybridization, and creative recycling go back millennia, and they come with considerable knowledge and a technical vocabulary that are as worn as an old almanac.

Perhaps the most obvious question is how emerging technologies map onto this. Obviously, sensors, AI, and IoT are already finding applications in AgTech. Industrial farming and cutting-edge IT research and development are already collaborating. Yet all over the world there are also

smaller collectives like the ones we've studied, inventing and testing practices that blend new technologies, biological and agricultural knowledge, and agricultural philosophy (e.g., that of permaculture). As with other forms of bottom-up innovation, or long-tail innovation, much of it won't succeed, let alone be transformative. Yet as many of our interlocutors over the years have pointed out, even one Facebook or Google out of a million other efforts is a notable payoff.

A role for HCI, then, is to use its resources to increase participation in these forms of innovation. It can accomplish this in several straightforward ways. One is the development of tools and toolkits that encourage participation; the success of the maker movement was in part based on the availability of digital fabrication tools that were reasonably affordable, easy to learn, and efficacious. How can technologies help more people learn to see and to act on the potential of symbiotic encounters? Automated camera traps have given scientists and the general public non-invasive yet scientifically important glimpses into the behaviors of some of the world's most elusive and endangered species, such as snow leopards and jaguars. What could technologies such as sensors, micro-robotics, and cameras help the public learn to see about the soil? How might HCI facilitate the public's motivation and ability to rehabilitate soil? Given the rise of urban farming and the availability of small garden plots in suburban and rural settings, the possibility of popular garden labs and experiments in precision farming seems like an achievable goal.

Another HCI contribution could be technologies that aid in the dissemination of methods and results. Again, the maker movement, DIY and repair movements, ham radio, craft e-commerce platforms, and amateur animation and video platforms like Newgrounds and YouTube all provide models that offer technologies that both disseminate the most promising ideas and onboard new participants and help them grow their skills.

5.5.2 Intimacy with the Biosphere

We have outlined how this work might join the ongoing research threads in HCI in developing tools and technologies to support amateur farming and environmental sustainability. However, we believe that HCI has something more profound to offer than technological intervention. In the following section, we reflect on our own transformations as design researchers. In all three of our ethnographic engagements, the farmers expressed a care for the land that was emotionally charged. In this paper, we shared Land Dyke's narrative about the near destruction of their orchard—a costly and painful threat that they could have easily prevented with pesticides, made worse by the fact that they eventually did use pesticides but at the cost of contaminating their crops. The story is told in a tragic style, and the anguish of the teller, as much as events in the orchard, propels the narrative forward.

It might be tempting to dismiss this as some kind of romanticized, touchy-feely nostalgia for the land. Instead, we interpret it as a reflection of their intimacy with the biosphere, which also entails a deep understanding of the effects of pesticides and other forms of toxicity. This intimacy is based in identifying with the other lifeforms inhabiting the same ecosystem, at times competitors, at times companions, and at other times unconcerned with one another.

We know this because we underwent such a transformation ourselves. Our embodied understanding of the earth—bacteria, bugs, worms, secretions, rot, fermentation—changed as we worked it. Prior to this research, we saw worms and bugs as disgusting pests, dirt as something to vacuum up and remove. But our time spent shoulder to shoulder with a farmer and former software engineer trying to heal the soil has changed how we see the soil, how it sustains itself, and how it sustains life—including our own. We now notice differently, both in the ordinary sense that we notice different things, but also in Tsing's more specific sense of the word: we see

the soil now as an assemblage of different processes, structures, meanings unfolding dynamically over time. In certain moments, the interests of humans (as farmers, as consumers of food) and the interests of aphids or spiders or bacteria align; it's good for all of us, and this good outweighs (in the best case) or at least partly offsets (in the worst case) the subsequent misalignments. The ability to see that way is theorized in Tsing's work, but it just might be how farmers have seen all along. How technology will aid that vision, and how that vision will place demands on technology, remains to be seen.

HCI research has long championed users (Goodman, Kuniavsky, and Moed 2012), even represented them (Cooper and Bowers 1995). It has expanded the notion of user satisfaction into the thriving research and practice domain of user experience (Hassenzahl and Tractinsky 2006; McCarthy and Wright 2004). It has advocated for empathy for users (Wright and McCarthy 2008), developed methodologies to achieve it (S. Bardzell and Bardzell 2011), and proposed moving from a user centered approach to consider a wider range of stakeholders (Forlizzi 2018; Baumer and Brubaker 2017). Posthumanist HCI is advocating a non-human-centered approach to computing, one that views nonhumans as stakeholders. We propose that just as HCI researchers decades ago called for championing the user, and the field responded with a richer and more powerful multidisciplinary base of theory and methods than those who called for it could have hoped for, so now there is a role for HCI to do the same for nonhuman stakeholders. As user experience research outcomes now shape organizational strategy, so knowledge of and empathy towards nonhuman life must shape organizational strategy in the future. HCI has tools—theories and methods—that could help further the goal of improving interspecies relationality. HCI has already developed tools for cats (Noz and An 2011) and fungi (Liu, Byrne, and Devendorf 2018). Next up: gut bacteria.

5.5.3 Ode to Soil: Reimaging Data Processing and Representation[29]

So far, we have written a lot about Tsing's "arts of noticing" (2015), but how might these "arts" look like when we embody it in material forms that help us notice differently? Citizen scientist and community artist Deanna Pindell (2015, 43) has some thoughts,

> A post-humanist, postanthropocentric art requires an ethical aesthetics of deeply empathetic listening and responsive co-creation of the world; of mutuality in fertile relationships, and a determination to decompose intra-actively.

In Chapter 4, we have explored the space of "responsive co-creation" through the notion of scaffolding and its accompanying design tactics. In this chapter, after working alongside with the farmers, the concept of "empathetic listening" becomes particularly intriguing for a few reasons. First, the act of listening offers an opportunity to de-privilege the dominating sense (i.e., visual) and communicative act (i.e., language) that are both very anthropocentric and might not be accessible to social actors with various physical and functional limitations (Heywood 2017). Second, engaging in alternative ways of noticing defamiliarizes our senses, perceptions, and reasoning, which encourages speculation—another aspect that is crucial to "noticing differently." Finally, through listening, we are able to not only perceive languages but also the tone, sound, and spatial environment, which in turn evokes other senses, memories, and emotions (Heywood 2017). Simply considering how a mother is able to decode her baby's crying—simply through sounds and without and linguistic aids—to understand the baby's needs and emotions.

[29] I came up with the Ode to Soil design concept myself after the ethnographic fieldwork. However, to actually build the interactive prototype, Matthew Francisco has provided me enormous support, both on a technical and a material level; the name "Ode to Soil" was an idea proposed by Paul Johns, who also helped me creating a demo sound clip. I also thank Shaowen Bardzell and Jeffrey Bardzell for their feedback on the initial concept and prototype. Although the analysis and synthesis I include in §5.5.3 and §5.5.4 were conducted independently by myself, I use the pronoun "we" for reading consistency.

Inspired by multisensory design practices and Xing-Yan, the polyculture farmer who cultivated and attuned his bodily senses to attentively care for his soil, we created “Ode to Soil,” an interactive prototype that tracks the temperature, humidity, and biometric movement of the soil to narrate its condition and healthiness through acoustic outputs[30] (Figure 17).

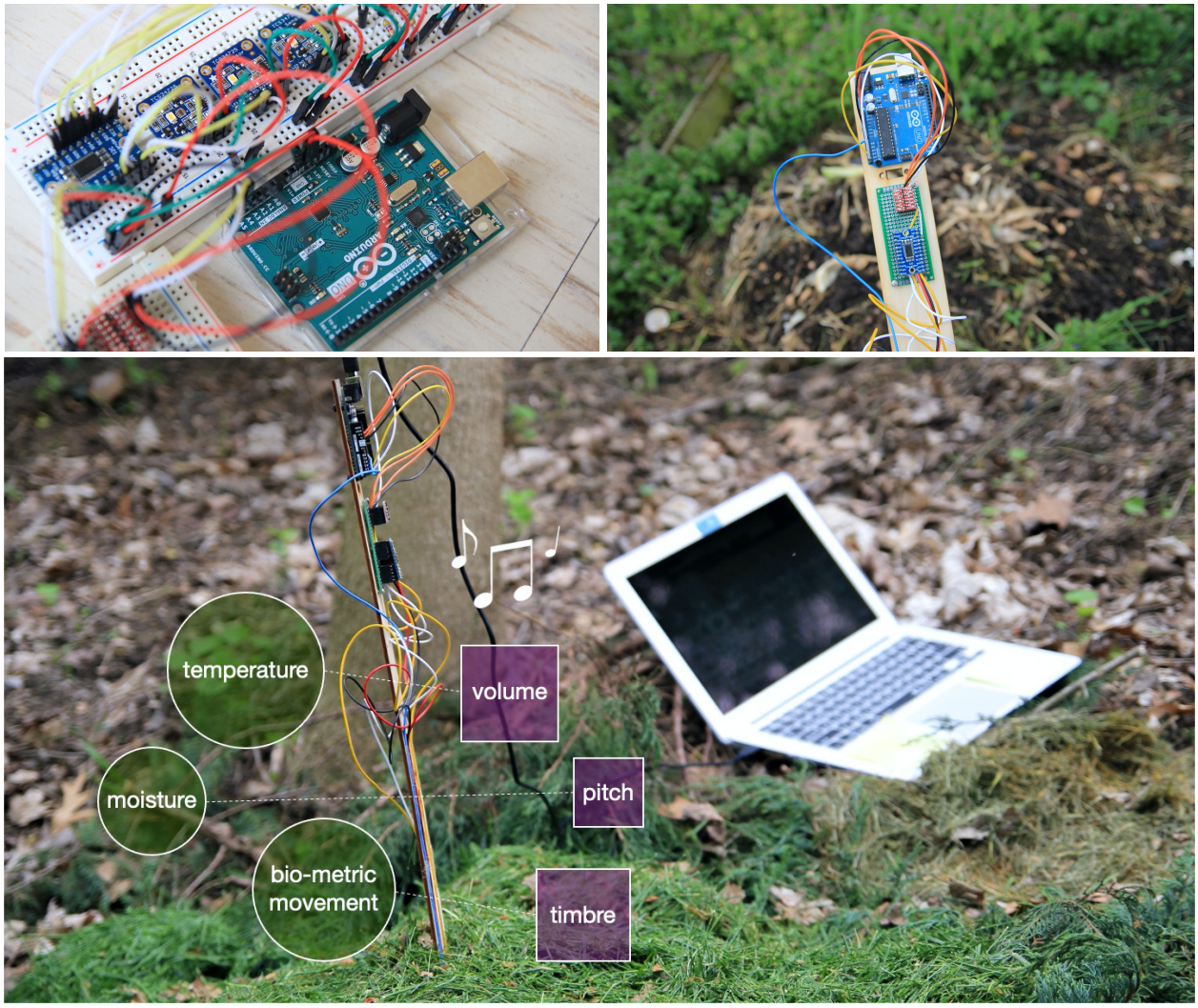

Figure 17: Ode to Soil working prototype. Top left: first prototype on breadboards. Top right: close shot of Ode to Soil in its first field deployment. Bottom: a schematic diagram that demonstrates the data processing model of sonifying soil data.

[30] For the limitation of presenting my dissertation in a paper format, interested listeners please refer to my website to access to the demo sound clips of both “good soil” and “bad soil.” https://www.szuyuliu.com/ode-to-soil

On a technical perspective Ode to Soil is not new, but an example of data sonification, which is about mapping and representing data into properties of sound, including pitch, volume, timbre, rhythm, location and so on (Wilson and Lodha 1996). However, as we reflect on Tsing's (2015) notion of "noticing differently", the design focuses directly on defamiliarizing dominating human senses to cultivate attentiveness towards nonhuman life forms, with whom the "language is less significant" (L. Hamilton and Taylor 2017, 112). Ultimately, what Ode to Soil embodies is an alternative data processing and representation model that replaces "a set of numbers" (as in computational models) with a "set of qualities" to encourage a more intimate, attentive, and sensorial form of human-nature interaction (Barone and Eisner 2012).

5.5.4 Interspecies Symbiosis as Non-Innocent Care

Illustrated through stories such as caring for leafhoppers to cultivate honey-scented tea (§5.4.1) and working with weeds to heal the soil (§5.4.2), the ethnographic accounts we offered in this chapter illustrate the collaborative, harmonious, and sometimes surprisingly pleasing kind of relationships between farmers, their crops, and the land. It is easy to mistake farming as romantic and nostalgia ways of living and imagine farm life simple as breathing fresh air, finding tranquilly in the midst of crisis, and being emotionally charged working alongside with flora and fauna. Surly, there are some parts about farming that is calming: we remember sitting by the ditch with the farmers we work with after a long day of weeding to wash away the dirt on our feet; we remember the cold water with tiny fishes running in between our toes; we remember feasting a full course lunch made from the freshly picked farm crops, casually chatting with people in the village while helping to bottle up fermented bean curb for sale, or enjoying a home-made popsicle in a hot summer. However, we also remember our arms full of bug bites and stalk cuts after working in the rice paddy for a day. We remember waking up the next day with aches and pains all over our body, not wanting to move, but still have a full day of work ahead of us. And

finally, we would never forget about the uneasiness we felt in the stomach knowing that a severe typhoon[31] was going to hit the village—the land that we became emotionally attached to—just one week before the summer harvest (Figure 18).

Figure 18: Ethnographic fieldwork in rural Taiwan. Different parts of my farm life.

The time working alongside with the farmers in rural Taiwan has taught us that farming is not at all easy, and that eco-friendly farming (or its similar practices such as permaculture and organic farming) can be particularly risky: just think about how the Land Dyke farmers almost had their entire citrus orchard eradicated by scale insects because they were reluctant to use chemical pesticides (§5.4.3). In Pinglin, the tea-farming village in rural Taipei, we heard stories about how one eco-friendly tea farmer had to give up after trying it for couple years: he only had 5 taijins[32] (about 6.6 pounds, or 3 kilograms) of harvest in an entire year, which is not enough even to sustain a single person's living sustenance. Back in Shengou Village in rural Yilan, many farmers I met with were half farmers who worked multiple jobs to minimize their personal economic risks. Many of them were (relatively) financially stable in the first place, with successful careers as big city architects, university professors, documentary directors, policy makers, software engineers,

[31] A typhoon is a tropical storm in the Northwest Pacific Ocean; it is equivalent to a hurricane in the North Atlantic Ocean and Northeast Pacific. Summer is the typhoon season in Taiwan when we have at least 3-4 typhoons between July to September; note that June to July is also the harvest season.

[32] Taijin (台斤) is a common Taiwanese unit of weight. 1 taijin equals to 600 grams.

and managers retired from international technology firms; the additional savings, income, and professional expertise they have all help support their farming experiments.

So, what implications does eco-friendly farming has to offer for some of the most pressing socio-environmental challenges associated with agriculture? In the previous section, we have written about developing tools to encourage public participation on alternative farming (§5.1.1), creating platforms to aid the dissemination of methods and results (§5.1.1), incorporating or designing specifically for nonhuman users (§5.1.2), and reimagining data processing and representation models to support intimacy and care with the biosphere (§5.1.3). Drawing from Xing-Yan's selective weeding practice and the lesson learned from the Land Dyke farmers tragic story, we see an opportunity for HCI researchers and practitioners to introduce sensing networks, machine learning techniques, and computer vision applications to make experimental farming more precise, less risky, and if not more, at least equally sustainable. For example, scientists work on computer vision and deep learning have some successes in identifying and classifying plants using images of the leaves (Olsen et al. 2019)—just as how Xing-Yan showed us how to target weeds in the Poaceae family by focusing on the ones prickly leaves.

In the past, we usually have negative connotations about precision farming, picturing it as energy intensive, purely instrumental, sometimes cruel (e.g., factory farming that traps animals in cages so tiny that they cannot turn), and focuses on nothing but profit maximization. However, we can also utilize the technologies developed in precision farming practices to help Xing-Yan with selective weeding; or in the instance of Land Dyke's citrus orchard, we can implement sensing networks to track pest clusters and use artificial intelligence to notify the farmers to take actions before it is too late. With the convergence of global environmental awareness, sensing networks,

and computational models, we look forward to seeing more tools supporting interspecies symbiosis and helping us replace “intention” with “attention” (Ingold 2015).

5.5.5 Concluding Thoughts

Reflecting on his farming practice, Xing-Yan explained, “the foundation of farming lays on the soil, and the healthiness of the crops have a lot to do with the microorganisms within it, so the most important task for me is to cultivate soil with compost.” He paused for a few seconds and continued,

> *I think I’m probably not even thinking about growing crops but about taking care of the microorganisms in my soil… if you provide a good cultivation environment the crops naturally will grow well, it’s not even my task to worry about the pests.*

In his playful way of repurposing idioms, Xing-Yan summarizes his practice as follows: “*to understand the world through weeds*.” His soil is his product, in other words, not his produce.

At the beginning of my PhD research, I went to farms in Taiwan in hopes of learning about innovation in the sustainability domain. We did, of course, learn about innovation, e.g., how a software engineer and open source advocate translates that discipline onto the (“Open Hack”) farm, or (in another case) how a former Manhattan architect moved his family to rural Taiwan to apply and develop the permaculture agricultural philosophy.

Yet over the course of such encounters, we reflexively wondered if we—city-raised technologists bearing laptops and mud-spattered boots—were also a metaphorical companion species. At times, we felt as if we had entered a different world; we worked with the farmers, weeding, hauling equipment, and helping to compost. Yet we believe we were useful to them, not only

because of the extra hands we provided in the field, but also because of the questions we asked from our other world: questions from design research, possible applications of research through design, the co-construction during tea-time breaks of What-If scenarios. These questions sometimes intrigued them, prompting new ways of thinking about their work. In those moments of walking alongside one another, we had glimpses of what might be. So it was that our well vetted and carefully crafted research questions, printed on clean white sheets of paper and nestled in binders as we made the journey from the city to the country, would come to be soiled.

5.6 Conclusion: Design (through) Human-Nature Interaction

Recent work in sustainable HCI advocates “working with nature” as a potentially efficacious alternative to human efforts to control it: yet it is less clear how to do so. We contribute to the theoretical aspect of this research by presenting an ethnographic study on alternative farming practices, in which the farm is not so much a system, but an assemblage characterized by multiple systems or rationalities always evolving and changing. In them, relationships among species alternate between mutually beneficial in one moment (or season), and harmful in the next. If HCI is to participate in and to support working with nature, we believe that it will have to situate itself within such assemblages and temporalities. In this work, we look into nontraditional users (e.g., nonhumans) and emerging forms of uses (e.g., interactions between human and other species) to help open a design space for technological interventions. We offer three ethnographic accounts in which farmers—and ourselves as researchers—learn to notice, respond, and engage in symbiotic encounters with companion species and the living soil itself.

Chapter 6.

Designing (for) Environmental Data [33]

> There are many other examples of non-human animals who challenge their oppression: non-human animal workers refuse to work, captive wild animals use violence against their captors, farm animals escape on their way to slaughterhouses, laboratory animals turn their heads away. Other non-human animals seek out human company, either becoming members of human households or taking up residence in their gardens, cities, or fields. Non-human animals may also care for humans or work side by side with them; human and non-human animals can have meaningful encounters, develop friendships, or simply co-exist as neighbors.
>
> – Eva Meijer[34]

The previous two chapters—co-creating with nature through decomposition in a design studio and cultivating care with weeds and pests in eco-friendly farms—illustrated the process in which

[33] The majority of this chapter was previously published as a peer-reviewed archival paper at ACM DIS 2020 titling "Making Air Quality Data Meaningful: Coupling Objective Measurement with Subjective Experience through Narration." This chapter has been lightly edited from the previous published by adding an introductory paragraph and providing more images to situate the readers. Additionally, while I led the fieldwork and analysis, Justin Cranshaw helped refining my inquiry, research questions, and contribute to the writing; Asta Roseway contributed to refining the design of the cognitive mapping toolkit. The research included in this chapter was conducted during my summer 2019 internship at Microsoft Research. I credit my colleagues at Microsoft Research Urban Innovation Initiative for their meaningful conversations throughout the study.

[34] Eva Meijer, 2019. *When Animals Speak: Toward an Interspecies Democracy.* New York University Press.

human and nonhuman stakeholders negotiate to reach a state of coexistence, collaboration, and cohabitation. I have shown through concrete examples that the act of negotiation is neither easy nor straight-forward; in fact, it is full of ambiguity (e.g., the unpredictability and irreproducibility of design outcomes produced through the process of scaffolding), surprise (e.g., the strange and counter-intuitive companion species in the farmlands), and setbacks (e.g., the incidence when a citrus orchard was almost eradicated by scale insects.) Considering Anthropocene, the geological epoch when the negotiations between humans and nonhumans failed, we are now living in a time when we have to face the consequences compounded of human dominance and unsustainable behaviors of ourselves and of the generations of people that came before us.

To identify ways of designing in the Anthropocene, this chapter investigates instances when the negotiation failed—and when such a failure put human survival into question. In particular, I focus on air pollution, one of the most detrimental forms of pollution that causes several million deaths every year[35] and does not stop at any kinds of cultural or territorial boarder. I ask, "how might HCI facilitate public engagement with the environment to promote environmental sustainability, justice, and resilience through design?" To find answers to this question, I worked with residents in the greater Seattle area, a region that receives increasing episodes of unhealthy air incidences due to more frequent and devastating wildfires on the US West Coast[36] in the past decade. Through a two-phase design fieldwork, I identify the strengths and limitations regarding our current environmental sensing technologies and data representation techniques. I conclude this

[35] According to the World Health Organization (WHO), air pollution causes about 4.2 million of premature deaths every year; additionally, 91% of the world population live in areas where air quality exceeds WHO guideline limits.

[36] A study conducted by New York Times suggests that major wildfires on the West Coast has made 2020 (when this dissertation is written) a record year for wildfire outbreaks. Original source: https://www.nytimes.com/interactive/2020/09/24/climate/fires-worst-year-california-oregon-washington.html

chapter by outlining strategies to facilitate community engagement with data, increase data transparency and accountability, and support public health decision.

6.1 Unbreathable Air

The World Health Organization estimates that outdoor air pollution causes over 4.2 million premature deaths each year worldwide, and that 91% of the global population lives in places where the air quality is worse than recommended standards (World Health Organization 2018). Over the past decade, a convergence of low-cost sensing technologies and mobile networks presents opportunities for capturing air quality data to facilitate better monitoring of environmental change, promote public health, and assist efforts in sustainable urban planning (Aoki et al. 2009; Chakraborty et al. 2016; X. Chen et al. 2018; Gongora et al. 2018; Hsu et al. 2019; Kuznetsov, Davis, Paulos, et al. 2011). Building on this opportunity, researchers have explored strategies for collecting real-time data at high spatial resolutions revealing variations in air quality at the neighborhood or block level (G. Lin et al. 2014; Mayer 1999; Patel et al. 2009; Szpiro et al. 2010); examples include grass-root pollution tracking (L.-J. Chen et al. 2016; Dutta et al. 2009; Hsu et al. 2019; “Tackle Air Quality in Neighbourhoods Together” 2020), sensor-enabled mobile phones (Y. Kim et al. 2013), hand-held monitors (Kuznetsov and Paulos 2010; Kuznetsov, Davis, Cheung, et al. 2011; Tian et al. 2016), sensing wearables (Hu et al. 2014; S. Kim, Paulos, and Gross 2010; Maag, Zhou, and Thiele 2018), sensor modules on vehicles (Aoki et al. 2009; Chakraborty et al. 2016; Lanza et al. 2015; Paulos, Honicky, and Hooker 2009; Shirai et al. 2016), or computational models (X. Chen et al. 2018; Gongora et al. 2018; Zheng et al. 2015). The future is pointing towards a world where high-quality, high-resolution data on air quality will be increasingly available and accessible.

However, there is a gap between our ability to generate fine-grained measurements of environmental realities, and our comparative lack of understanding of how people subjectively make sense of the air through their day-to-day experiences. In other words, while a new wave of technologies may reveal peoples' exposure to air pollutants at increasingly hyperlocal scales, few works have investigated the full spectrum of peoples' lived-experiences with air pollution, and how these personal experiences affect and are influenced by individuals' subjective perceptions, histories, imaginations, and the sociopolitical context in which they live.

To paraphrase Dourish and Cruz, data do not speak for themselves; they must be narrated (Dourish and Cruz 2018). This work addresses the under-explored question of how to narrate environmental data to make them more meaningful. Inspired by previous work (Aoki et al. 2009; D'Ignazio and Klein 2020; DiSalvo, Sengers, and Brynjarsdóttir 2010; Dourish and Cruz 2018; Liu, Bardzell, and Bardzell 2018b), we believe that to encourage pro-environmental behaviors through data, we must engage with peoples' lived experiences in our designs, incorporating the nuanced, contextual, subjective, political, and social experiences people have with the air. While we recognize that the boundary between objectivity and subjectivity may be blurry with each lying at one end of a continuum, and that environmental measurement can be subjective when it is narrated in service of political or economic interests, in this work we take a simplified view, treating environmental measurements as objective and peoples' lived experiences as subjective, as they typically fall at the opposite ends of an objectivity spectrum.

We turn to a fundamental question: what does air quality mean to everyday citizens, and how do we make air quality data more meaningful through design? In pursuit of this inquiry, we conducted two phases of design fieldwork with residents in the greater Seattle area. In the first phase, we combined cognitive mapping with semi-structured interviews to establish an empirical

understanding of the full spectrum of experiences people have with the air. We then moved on to explore possible strategies of making air quality data more meaningful through community co-design workshops. Our results reveal that individuals have different modality preferences, and some rely on multiple modes of perception simultaneously (e.g., drawing on the look, feel, temperature, and smell of the air) to perceive air quality. Reflecting on this, we suggest coupling objective measurements with subjective experiences to make environmental data more meaningful. We conclude by outlining possible design strategies for achieving so, including engaging with the sociotechnical context, encouraging reflection and speculation, and incorporating nonhuman stakeholders.

6.2 Air Quality Sensing, Data Narration, and Persuasive Sustainability

Air pollution is a major public health concern that impacts billions of people and causes millions of premature deaths each year (World Health Organization 2018). Potential health effects of air pollution include increased risk of asthma, cardiovascular damage, impacts to the nervous system, and developmental risks to unborn children (Kampa and Castanas 2008; Pope, Dockery, and Schwartz 1995; Pope III and Dockery 2006; Seaton et al. 1995). High concentrations of air pollution around schools has been linked to increased child absence and poor academic performance (Currie et al. 2009; Mohai et al. 2011). In addition, air pollution also threatens our fragile ecosystem (Bobbink, Hornung, and Roelofs 1998; Bytnerowicz, Omasa, and Paoletti 2007; Heagle, Body, and Heck 1973; McLaughlin 1985). Sources of air pollution are both natural and artificial, including combustion, industrial and agricultural activities, wildfires, geological processes, and gasses from decomposing waste (European Environment Agency 2019; Liu et al. 2016; National Park Service 2019). In urban environments, air quality varies significantly by

location and time, influenced by factors such as terrain, traffic flow, human activity, land use, and weather (G. Lin et al. 2014; Patel et al. 2009; Szpiro et al. 2010).

Governments around the world have adopted scientific standards to measure pollutant concentrations in the air and communicate the associated health risks to the public. Such indices vary by countries in terms of how they are computed and which pollutants are taken into account (Gulia et al. 2015; Kuklinska, Wolska, and Namiesnik 2015). The Air Quality Index (AQI) in the US tracks the concentration of ground level ozone (O3), carbon monoxide (CO), sulfur dioxide (SO2), nitrogen dioxide (NO2), coarse particulates (PM10), fine particulates (PM2:5), and aggregates their respective concentrations into one numeric index representing the degree of public health risk (US Environmental Protection Agency 2014). Guidelines from the U.S. Environmental Protection Agency on AQI divide the full numeric scale into six coarse-grained, yet easy to interpret levels of risk: “good” (0–50), “moderate” (51–100), “unhealthy for sensitive groups” (101-150), “unhealthy” (151–200), “very unhealthy” (201–300), and “hazardous” (301–500).

The proliferation of personal devices, the expansion of wireless networks, the emergence of low-cost pollution sensors, and the rise of bottom-up initiatives have created a new paradigm in environmental sensing where city dwellers and the urban infrastructure can be activated to gather real-time data. Tactics for increasing the granularity of air quality data include leveraging existing network of mobile and wearable devices (Devarakonda et al. 2013; Lanza et al. 2015; L. Liu et al. 2018; Maag, Zhou, and Thiele 2018), involving communities of actors (L.-J. Chen et al. 2016; Dutta et al. 2009; Hsu et al. 2019; Kuznetsov, Davis, Paulos, et al. 2011), mounting sensors on vehicles and animals (“The Copenhagen Wheel” 2019; Aoki et al. 2009; Chakraborty et al. 2016; Vaughan 2016), building low-cost personal sensors (Kuznetsov, Hudson, and Paulos 2014;

Tian et al. 2016), combining various sources of data (Zheng et al. 2014; Hsu et al. 2017), and developing computational algorithms and models (X. Chen et al. 2018; Zheng et al. 2015).

Following this thread, HCI researchers have also explored a wide range of strategies for visualizing air quality data, such as maps, heatmaps, graphs, charts, and numeric scales (Hsu et al. 2019; Hu et al. 2014; Y. Kim et al. 2013; Kuznetsov, Davis, Cheung, et al. 2011; Lanza et al. 2015; L. Liu et al. 2018; Zheng et al. 2015). While data visualization renders environmental data legible to everyday citizens, there is still an enormous gap between the measured data and the felt life of individuals. The purely numeric scale of AQI, for example, exhibits little connection to our embodied experiences with the air. As Barone and Eisner argue, "what is hard to experience is a set of numbers. What is comparatively easy to experience is a set of qualities" (Barone and Eisner 2012, xi), we believe that overly reductive, arbitrary representations of rich environmental phenomena de-contextualizes users from real-life scenarios and obscure the relationship between personal behavior and environmental consequences (D'Ignazio and Klein 2020; DiSalvo, Sengers, and Brynjarsdóttir 2010; Kuznetsov, Hudson, and Paulos 2014; Lockton et al. 2017; McLean 2019; Rapp, Tirassa, and Tirabeni 2019; Wargocki and Wyon 2017; Zhang et al. 2017).

More recently, HCI researchers have explored more tangible forms of air quality representation to better connect real-world experiences with tracked results. For example, Hsu et al. recorded time-lapse videos to visualize temporal changes in smoke emissions from a coke plant. A thumbnail generator is embedded in the design to help local residents create animated smoke images as visual evidence of air quality violations for filing petitions to the government (Hsu et al. 2017). To increase community awareness and facilitate public discussions, Kim et al.'s design communicates concentrations of polluted gases through patterns displayed on a sensor-integrated t-shirt (Kim, Paulos, and Gross 2010). Following the strategy of broadcasting

environmental data through expressive media, Kuznetsov et al.'s balloon installation changes colors to represents different levels of air pollution (Kuznetsov, Davis, Paulos, et al. 2011). Very recently, Torres and Campbell used augmented reality to simulate contaminates in the air; their design helps bring awareness to the public by mapping pollutants that are invisible to naked eyes onto the real-world (Torres and Campbell 2019). Common across these explorations is that instead of offering a singular, prescribed representation of the environment, subjective experiences and personal goals play a major part in how an individual go about interpreting the data. In this way, data is democratized to support science discovery, civic participation, community advocacy, policy reform, and artistic expressions.

Inspired by these works, we break new ground in engaging with air quality by following Dourish and Cruz's theoretical framing that data "must be narrated—put to work in particular contexts, sunk into narratives that give them shape and meaning, and mobilized as part of broader processes of interpretation and meaning-making" (Dourish and Cruz 2018). Focusing on sense-making, they note that data "makes sense only to the extent that we have frames for making sense of it," emphasizing the trajectories, temporalities, and cultural grounding within which data are embedded and must be interpreted. Our work employs ethnographic methods to explore these dimensions, and the question of how to narrate environmental data to promote public awareness, civic engagement, and sustainability (Dourish and Cruz 2018).

In response to concerns about climate change, public health, and social equality, HCI researchers have committed to promote sustainability in (reducing the material impacts of products) and through design (encouraging sustainable behaviors and decisions) (Blevis 2007; Mankoff et al. 2007). Within the discourse of sustainable HCI, one major thread focuses on persuasive sustainability, which "involves efforts such as monitoring the state of the physical

world; managing the direct and indirect impacts of large-scale human enterprises such as agriculture, transport, and manufacturing; and informing individuals' personal choices in consumption and behavior" (Mankoff et al. 2007, 19). While curating and analyzing environmental and behavioral data provide useful insights to raise awareness and assist decision making, many have observed that persuasive sustainability holds the false assumption that "people are rational actors seeking to optimize activity based on what they know" (Rapp, Tirassa, and Tirabeni 2019, 20). Along this line, many have argued that works in persuasive sustainability often disconnect individual behaviors with the politics of space and infrastructure (Brynjarsdottir et al. 2012; Cuff, Hansen, and Kang 2008; DiSalvo, Sengers, and Brynjarsdóttir 2010; Dourish 2010; Liu, Bardzell, and Bardzell 2019b; Pierce and Paulos 2012).

In addressing these concerns, Brynjarsdottir et al. (2012) suggest supporting open-ended interpretation and reflection, allowing users to better establish the connection between data and their lived experiences. In the context of sustainable agriculture, Liu, Bardzell, and Bardzell (2018b) propose using the model of "working with" to replace the paradigm of control posed by persuasive sustainability. Dourish (2010, 7) suggests shifting the focus from "connecting people to their actions and their consequences" towards "connecting people through their actions and consequences" to support meaning making. Recently, Rapp et al. propose looking beyond the quantified, behavioral manifestations of change to focus on changes that are internal and subjectively defined by the individuals (Schön 1983). Collectively, these works surface the need to account for subjective values, experiences, and felt lives to design for persuasion.

In the context of motivating pro-environmental behaviors, we see that challenges lay in representing environmental data in a way that is meaningful to everyday citizens. By meaningful air quality data, we suggest moving away from abstracting and discounting the heterogeneous

day-to-day experiences people have with the air to a singular and arbitrary representation of the environment (e.g., AQI). Instead, we propose narrating environmental data by unpacking peoples' meaning-laden experiences with the air.

6.3 Understanding the Spectrum of Subjective Experiences with Air

Figure 19: One participant annotating on her cognitive map. This participant mapping and annotating her map responding to the question, "where would you place the sensors if we give you 3-5 of them?"

Over the summer of 2019, we conducted two phases of design fieldwork in the greater Seattle area aimed at better understanding the contour of lived experiences people have with the air and air pollution. Our work is inspired by the tradition of ethnography to render the ordinariness "extraordinary and yet, recognizable" (Anderson 1997, 158). In the first phase, we conducted individual interviews and cognitive mapping sessions to establish an empirical understanding of peoples' firsthand perceptions with the air. Informed by these sessions, we moved on to conduct

community co-design workshops to explore design considerations on making air quality data more meaningful (Figure 19).

This work differs from previous studies on participatory sensing in the way that we did not have a fixed design embodiment or probe while engaging with the participants. Instead, to avoid imposing a priori beliefs or values of the researchers, we took an open-ended approach with the researchers being the "window to individual subjectivity and collective belonging" (Madison 2020, 35): the people whom we engaged with were not passive objects to be investigated but interlocutors who actively shape our understanding or air and air quality (A. S. Taylor 2018).

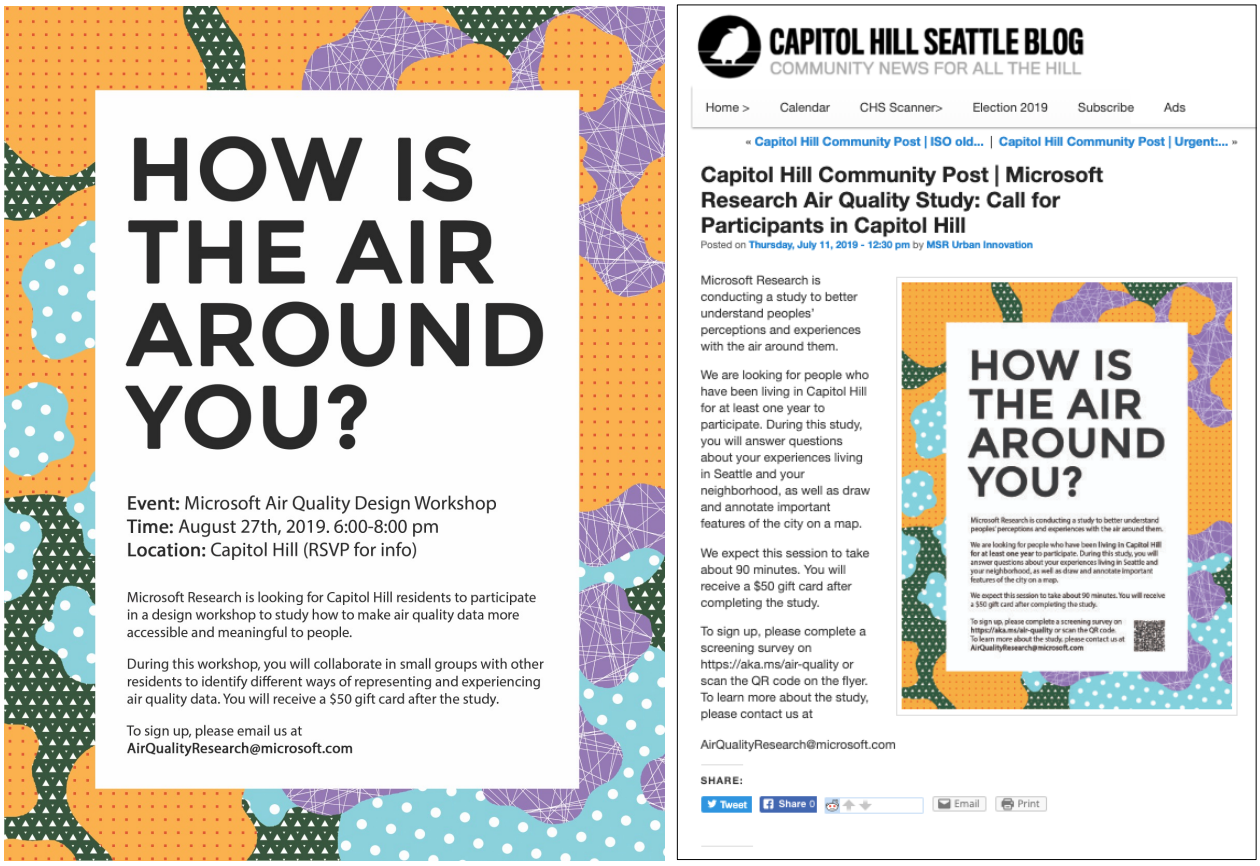

Figure 20. Examples of recruitment materials. Left: flyer design of the study. Flyers were posted on community boards and street posts in dense public areas. Right: our call for participants posted on the Capitol Hill Seattle Blog.

In considering how people might make sense of neighborhood scale air quality data, we recruited participants who live in the same parts of the city so their geographic experiences would overlap. We targeted two different areas of Seattle to also gather diverse perspectives—Capitol Hill, a dense and vibrant urban neighborhood in central Seattle, and Kenmore, a smaller suburban municipality just outside of Seattle.

In both locations, we posted on local civic forums and neighborhood social media groups; our recruitment strategy also varied slightly depending on the geography of the neighborhood. In Capitol Hill, we put flyers on community boards and street posts in dense public areas (Figure 20). In Kenmore, since there were few dense areas to post flyers, we worked with the local government who shared our study information to an email list of residents who were engaged about civic issues. Interested participants were directed to an online screening survey that collected their background information. In total, 179 participants responded to this screening survey, 116 of whom were from Kenmore and 37 were from Capitol Hill (others lived outside our two targeted area). Participants were selected based on their availability and to balance age and gender as much as possible. To mitigate sampling biases, the participants were subsampled to balance different degrees of awareness/concern about the air, which was self-reported in the screening survey. In each session, people were given a $50 gift card for their participation. To situate our discussions closer to the community, interviews and workshops were conducted in public spaces within the participants' neighborhoods. This study was approved by Microsoft Research's Institutional Review Board.

6.3.1 Cognitive Mapping and Participant Interview

We developed a semi-structured interview protocol and cognitive mapping toolkit to probe into the experiences, perceptions, memories, and folk-theories our participants might have about air

quality. Each session lasted 90-120 minutes. The interview began with a discussion of the participant's background, including where they come from, how long they have lived in the neighborhood, and what other places they have lived in the past. Next, we conducted several rounds of cognitive mapping to sensitize the participants' tacit knowledge about the environment, including the built environment, their experience with natural spaces, and their perceptions about air quality in their neighborhood and beyond (Figure 21).

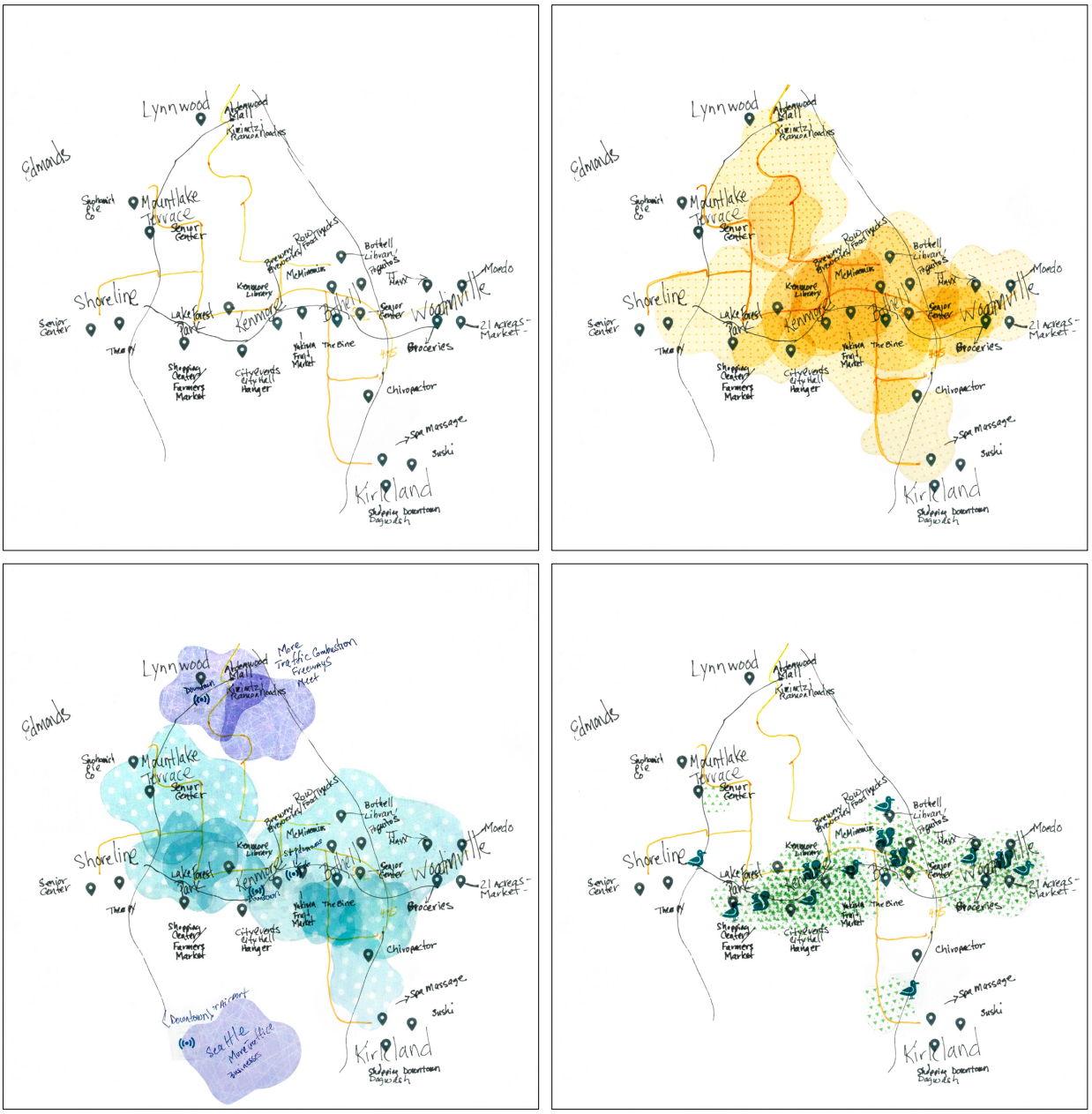

Figure 21. A cognitive map made by the participant depicting four experiential layers. Top left: a base map showing major roads, important places, landmarks, overlaid with common routes. Top right: a familiarity layer (yellow), where darker regions indicate areas the participant was more familiar with. Bottom left: an air quality layer, showing areas where they perceived there to be “good air” (blue) and “bad air” (purple), where darker regions indicate a higher intensity of perceived goodness or badness. Bottom right: a nature layer (green), indicating areas where the participant has observed “natural” areas, where darker regions again reflect the intensity of perception.

In using cognitive mapping, we were motivated by its strength in externalizing and visualizing aspects of non-verbal or spatial experiences that our participants may not be fully cognizant of a priori (Bentley et al. 2012; Cranshaw et al. 2012; Kuznetsov, Davis, Paulos, et al. 2011; Lynch 1992; Milgram 2010). As Stanley Milgram writes, “a person may know many things about a city while not being aware that he possesses such knowledge” (2010, 96). Such is the case with perceptions of the air. On the one hand, air is a vital resource essential our very existence; on the other, air is such a ubiquitous part of life that people can be totally oblivious to it. In our study, cognitive mapping activities helped extract narratives that are “more personal and more closely tied to direct experience” (Milgram 2010, 77). To tease apart the complex web of relationships between people and their felt lives with the air and the environment around them, we created a tangible mapping toolkit that allowed us to visualize and explore different dimensions of peoples’ experiences simultaneously, through a layered mapping technique.

First, participants were asked to draw the contours and boundaries of their neighborhood as they perceive it on a piece of 12" x 12" white card stock, mirroring traditional cognitive mapping methods (Lynch 1992). We then augmented this base map with four additional layers that explore different dimensions of their experiences with their neighborhood: (1) common routes they take, (2) their familiarity with different parts of the city, (3) their perceptions of air quality, and (4) their experience with nature. Participants constructed and annotated each of these layers on transparent sheets of 12" x 12" acetate using markers, tape, icons, and translucent colored patterns printed in acetate in various shapes and sizes. These colored shapes were designed to be stackable to create splotches of varying opacity, which we used to create experiential “heat maps” that express the intensity of their perceptions. We used four colored patterns to map their *familiarity* with different areas (yellow), their perceptions of *good* (blue) and *bad* (purple) air, and their experiences with *nature* (green) (Figure 21). Participants were instructed not to “force” any

of these relationships; for example, if they did not perceive any bad air in the region, it was perfectly fine to leave this layer blank.

Our interest was not in the particular details of maps people made, though they may be valuable artifacts for visual analysis in future work. Rather, we used the mapping to structure our conversation on subjective experiences with the air—discussions that may be difficult to approach purely verbally. By layering these semi-translucent maps on top of each other, we bring to the surface any relationships between the air and the environment that may have been latent. The maps also served as a boundary object (Henderson 1991), helping researchers and participants form a stronger connection over subtle concepts through our shared understanding of the local geography.

Throughout the mapping exercises, we guided the conversation with questions designed to provoke noticing through reflection. For example, to nudge the participants to reflect on their past and other people, we asked "*do you recall a time when yourself or the people around you were bothered by the air?*" Calling their attention towards their senses, we asked "*how do you come to notice the bad air? Do you see, smell, or feel anything different than usual?*" We also provoked reflection and speculation by making explicit comparisons, both spatially (e.g., "*If you had three to five air quality sensors, where would you place them on your map and why?*") and temporally (e.g., "*Do you think the air quality in your neighborhood changes throughout different times of a day or different seasons of a year? Is there any pattern that you noticed?*"). As many of the largest contributors to air pollution are a direct result of the day-to-day activities, we also tried to shift the participants' attention between environmental catastrophes and mundane experiences. We did so by going back and forth between interviewing and mapping to facilitate the participants engage in different modes of thinking and reflecting.

6.3.2 Community Co-Design Workshop

Participants of the workshop worked in groups of 3-4 to respond to our two prompts: (1) creating an image collage accompanied by short descriptions responding to the question, "*what does air quality mean to you?*", and (2) selecting a target user and propose a design that makes air quality data "*meaningful*" to the user. Both prompts are designed to be opened, with no definitions given to encourage reflection and discussion. Each workshop session lasted 2 hours.

Figure 22: Workshop materials and group exercises. Top left: workshop materials and tools. Top right: a workshop introduction was given to the participants. Bottom left: one group from our workshops in a co-design session exploring design scenarios for their target profiles. Bottom right: one workshop participant working on filling out the questions on the worksheet after group discussions.

A variety of materials were given, including 52 images manifesting the various hypotheses people have with the air (both good and bad) we learned at the first study, 10 user profiles for the participants to choose as the target user of their design (they can also choose to create a new profile), 4 design inspirations representing different embodiment of environmental data (e.g., physical, digital, wearable, and system), pile of magazines rich in imaginary but varies in genre, and crafting supplies such as pens, glues, and scissors (Figure 22). We also created a worksheet with questions that the participants answer to brainstorm and refine design ideas. Questions include: "*what is it*," "*how does it work*," and "*what scenario best explains how the user interact with it*." (Figure 22). The participants also answered a post-workshop online survey which encourages reflection on the design proposed by their own groups. This survey aims to capture individual values and concerns that might be backgrounded during group exercises.

In phase one, we interviewed 12 participants: 6 from Capitol Hill and 6 from Kenmore. There were 7 females and 5 males, and their ages were approximately uniformly distributed across age groups, with two people in their 20s, two in their 30s, two in their 40s, three in their 50s, two in their 60s, and one in their 70s. In the second phase, we conducted two workshop sessions of 19 participants, with 8 people in the Capitol Hill session, and 12 people in the Kenmore session. There were 9 females and 10 males, and ages were diverse, skewing slightly older, with four people in their 20s, one in their 30s, three in their 40s, four in their 50s, six in their 60s, and one in their 70s. Cognitive mapping interview sessions were conducted in pairs by either Liu and Cranshaw or by Liu and Roseway, and workshops were collaboratively led by Liu and Cranshaw.

We audio recorded the interviews and the independent group discussions at each table in the workshops. The 29 hours of audio were transcribed using an automated service,1 and the transcriptions were reviewed and corrected collaboratively by Liu and Cranshaw. Following other

works that engage with each participant's individual (possibly idiosyncratic) perceptions and experiential observations of a collective phenomenon, we analyzed the data through an Interpretative Phenomenological Analysis (IPA) (Rapp, Tirassa, and Tirabeni 2019; J. A. Smith and Shinebourne 2012). IPA offers us a framework for documenting and understanding a diversity of approaches and strategies people take to form meaning about the air, given their own personal life experiences. Transcriptions were reviewed independently by Liu and Cranshaw, and relevant quotations were thematically interpreted and coded. Liu, Cranshaw, and Roseway met frequently during this process to continually refine our understandings of relevant concepts as we made sense of the data, and the participants' experiences. Sampling people from a variety of age groups and sensitivities towards air quality enabled us to document a wide spectrum of backgrounds, experiences, and personal stories, that helped us contextualize each person's relationship with air and pollution.

6.4 Lived Experiences with Air

To explore how technological interventions might make air quality data more meaningful, we focused on the lived experiences, tacit knowledge, and any folk-theories individuals have with the air and air pollution. In what follows, we present four themes that emerged from our empirical data. To highlight critical reflection, below we are more interested in how people make sense of air and air quality than how representative our participants are; we recognize that larger scale studies are needed to avoid faulty generalizations (Madison 2020).

6.4.1 Sensory and Emotional Encounters

When asked to describe a moment when they or the people around them were bothered by the air, several referred to the regional wildfires in 2017 and 2018: "*I work on the 20th floor and I can*

see the smoke coming towards me, it's quite scary" (P1), "*it was just grey and orange. it really was pretty thick and stagnant*" (P10), "*it was like apocalypse. You can't see the sky and you can smell the smoke. I feel like you're inhaling 10 cigarettes per minute. I can't really breath, the air is not coming in and out of my lungs... it feels like you're being suffocated in the city*" (P6).

The physicality of the air—its color, weight, taste, smell, and thickness—plays a major role in how people perceive pollution. Speaking of negative encounters with the air, one mentioned, "*it smells terrible, it's kind of sour, it's not smoky. It's a smell that kinda passes down your nose and launches into your... kinda your vocal cords and your throat... it is a... um, pungent smell and taste. I guess it's a combination, you can almost taste it* (P8)". Presence of air pollution is often perceived by unpleasant physical reactions such as watery eyes, running nose, headaches, chest pain, coughing, sneezing, and breathing difficulties. For participants with asthma or allergies, contaminants in the air can have serious physical impacts. One participant (P12) recalled smelling marijuana while at a traffic light:

> *We stopped at the light and the smell just came in... and I couldn't... like... I couldn't function... I had to pull into a parking lot and then I closed all the windows and put on the air conditioner. And then, um, I use my inhaler until I felt better so that I could drive.*

Compared to bad air, good air seems to have less visual, tactile, and olfactory qualities; instead, participants described fresh air as something that just *feels* good: "*where I can walk and not be wheezing" (P12), "I can't feel it in my throat... it feels like it's clear in my head... it feels healthy*" (P10), "*it takes over your mind and then it brings all that peace... Peace is a mental thing but it is also a physical thing, and you don't notice it as much as you normally would*" (P8).

While all participants rely on sensory cues and physical reactions to detect the presence of air pollutants, some noticed that not all air pollutants are perceivable by human senses; some even spoke of an "*invisible danger*" of such toxins: "*you could stand on the street and be exposed to asbestos and not even know it. You know? cuz it doesn't have any... there is no taste, there's no odor, there's nothing... I can put a board with lead paint on it and you wouldn't know what it was*" (P11). Analogously, P8 described the danger of not being aware of air pollution using diabetes as a metaphor:

> *It's kind of like diabetes, you know. It'll kill you unless you take care of it... that's the same way with air quality. It'll kill you unless you're able to... and you might not even notice that it's happening.*

While everyone may hold different subjective definitions about what should be considered an air pollutant—wildfire, traffic, marijuana, pollen, cigarettes, pet hair, car exhaust, bug spray, perfume—people's sensory perceptions play an important role in their overall awareness of the air. A person who pays little attention to the air under ordinary circumstances, may in an instant become acutely aware of it upon sensing something that feels "wrong." When it comes to air quality, put simply, lack of sensory perception contributes to lack of awareness. Here we see both the potential and limitation of human sensory perceptions and subjective experiences.

6.4.2 The Relativity of Space and Time

We noticed that air quality is a relative concept with respect to space and time, and this relativity drives peoples' perceptions, awareness, and concerns about pollution. A workshop participant compared the air quality in Seattle with northern Italy where he grew up smelling pollution in the air, "I'm actually glad that I'm here. Yes, we had the fires. The fires are bad, but I feel that it was

still much better." Another remembered forest fire being an annual routine while he was living in Los Angeles: "*You get used to it... you wake up, you have ash on your car and everything. It's just like, oh, it's LA snow.*" Also, another former resident of LA, P6 remembered how bad the air was and blamed it as the cause of her dog's illness:

> *He had this horrible disease, Aspergillosis, he almost died. He was living with my parents in LA, and that's where he got the disease. I wonder if the air had something to do with it because I asked my vet in Seattle and they told me that they don't see a lot of that.*

For those who have been living in the same neighborhood for an extended period of time, many observed that air quality worsened due to an increase in traffic, construction, and wildfire: "*When I first moved here... I can hike and walk and... not wheezing, I didn't have to use my rescue inhaler. Really wasn't that long ago when you think about it. Seven years, there's big, big changes*" (P12). A workshop participant resonated with this experience saying that she has witnessed a "*total change*" in Capitol Hill over the past 45 years. However, for some, the perspective of time revealed drastic improvements to the reginal air, largely driven by environmental regulations:

> *The air quality in the Seattle area is way better now than when it was prior to 1970. In 1970 at the base of Madison at 1st Ave in Seattle the asbestos in the air from car breaking exceeded the EPA standards at the time. Smell from the pulp mills in Tacoma, Everett and Puyallup was unbearable. Lake Washington, in 1970, was where all the raw sewerage from the Eastside was drained to. I could go on and on, but the bottom line is was have very good air quality (P11).*

Because air is ubiquitous and omnipresent, not everyone is sensitized to stay alert: "it's just something you live with... in levels of air contamination, I don't think people notice it because we

live in the city with the toxins anyway" (P8). Along this line, P6 recalled visiting her families in Hong Kong and Macau; even though her eyes constantly teared up because of polluted air, locals seemed to be desensitized to her:

> *It seems like they're used to it and only the visitors are talking about how bad air the air quality is. And it seems like people there, the main thing they say is it's fog. But I googled it and I found that it's actually air pollution.*

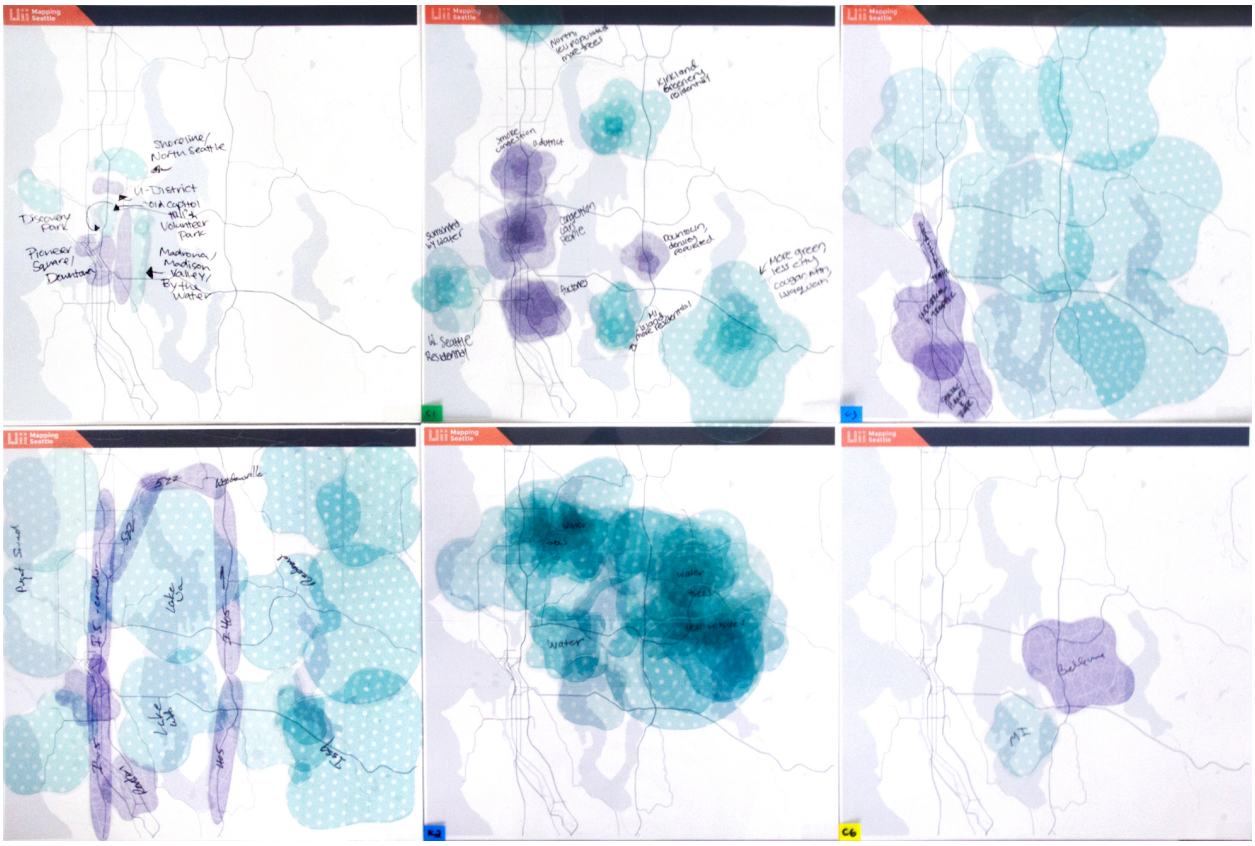

Figure 23. Six cognitive maps of the greater Seattle area. Different participants' cognitive maps of the same geological area show that the perceived air quality vary among individuals. Additionally, people hold idiosyncratic hypotheses concerning what contribute to good/bad air.

When being asked to visually represent how air quality varies in the greater Seattle area using our cognitive mapping kit, two participants did not map any bad air, choosing only positive gradients within their mappings (see Figure 23, map on the bottom middle). Among them, P6 was comparing Seattle air with air in the other places where she has lived or visited. The other participant described how challenging going outdoors was for someone who was born with asthma, "*I've been in this area since 67... I can tell you that when I first moved here... you had to be careful where you went if you had asthma because it was bad*" (P11). He continued, "*from my point of view, the air, even with all those things going on, it was way better than it was in other places. In Los Angeles, you can't see across the street, I mean it was bad.*"

These narratives highlight both the importance of reflection in driving awareness and perceptions of the air, and the subjectivity inherent in reflection, as each person's subjective comparison between space and time colors their perceptions of the present in unique and biased ways.

6.4.3 United We Stand

To understand what air quality means to people, as a warming up exercise, we asked all workshop participants to create a visual representation and a short description to communicate their perception of air quality. One participant cut out a black and white image showing people standing hand-in-hand by a bonfire (Figure 24, top left). Her idea was that if humans made air pollution together, we could fix it together. In her words:

> *I feel like we can make a bigger impact when we work together. When I see this image, I see that these people, they probably make the bonfire... you know? like they gathered the woods as a group and then they're gonna get rid of the fire as a group. So it's kind of like a teamwork.*

Figure 24. Four collages made by workshop participant groups. All collages were made to answer the probing question "what does air quality mean to you?"

There is a strong sense of "togetherness" in her narrative which, brings hope to a dark time. To others, the concept of togetherness is further extended to the relationship between humans, animals, and plants. One made a collage by gluing several images together, including a house, a castle in the forest, a windmill, a dog, a hawk, a pig family, and a lynx (Figure 24, top right). The description: "*having an abundance of greenery + offering alternative solutions for energy (i.e., windmill) has an impact on overall air quality which affects all members of wildlife, birds, farm animals, and humans.*" Here, the sense of togetherness evokes both hope and responsibility.

Similarly, one workshop group had prolonged conversations on how humans and nature are interdependent. Starting from a photo of a vineyard: "*this is technology working with nature. I mean you can't grow crops without technology and being mindful of nature if it is for the long term*." He continued,

How are bananas grown? Bees and birds do not pollinate bananas. Bats do, so you need bats, so you can't destroy the bats and their habitat and what they're eating, because other than that, you're not going to have bananas. It's like I grew a lot of vegetables and other plants. I grow things to bring in beneficial insects so they can pollinate my other plants... Everything has to work together. You just can't take one piece and say that's it.

The collage this group made captured different aspects of air quality and exemplified (Figure 24, bottom left), in their words, how everything has "*to work as a whole*." They chose a photo that depicts a forest because it was "*emblematic of the complexity of air quality*." They also included a photo of an EPA document: "*I like the idea of including the EPA because they have established science-based standards.... well, as the minimum standards for government is to keep us safe.*"

The image collages and narratives from our participants illustrate the notion of collaboration as an important pathway to address environmental crisis. Bringing the conversation back to the forest fires in the past two years, participants recollected how the fires in Oregon and British Columbia had drastic impacts on the air quality in the greater Seattle area, they said, "*you really can't put a blanket at the border and stop it... they [the fires] have no respect for borders anyway*."

6.4.4 Science as The Bottom Line

When avoiding dirty air is not always an option for urban dwellers, many participants turn to science and technology to stay alert of what is happening in the environment. The value of equipping air quality sensors is specifically highlighted when pollutants are not perceivable by human senses: "*unless you up your little machines around and identify it, it's just something you live with*" (P8). P11 recalled that soldiers were all rationed cigarettes during World War Two and

the Korean War until the 70s when scientists finally recognized that cigarettes were hazardous to human health. As a big advocate of science, he said,

> *Science is... helped us become more aware of what all these issues are. And you know, it takes people time to make this all happen. And then they start doing more research and find out things like creosote. Nobody knew that was hazardous. Asbestos—didn't know that was hazardous... all kinds of things like that. We just didn't know, and they'd been around forever.*

Many who took part in the co-design workshop believed that more scientific data is needed to help us identify and avoid the unknown dangers. To do so, two groups of participants brainstormed strategies to help increase the granularity of air quality sensors. Among them, one group came up with the concept of a portable "array of sensors" that can be turned into a clip, a bracelet, or a docking station. Another group proposed an app that incentivizes users to deploy air quality sensors through a points reward system.

While everyone holds positive attitudes toward science and technology, a few brought up that science can be limited in some scenarios. For example, complex issues like social justice and behavior change might not be answered just by putting a few sensors out in the environment. One participant wrote in his post-workshop survey, "*being aware, is one thing. Doing somethings that might change the situation, is an emotional response to that stimulation*" (P8). Another workshop participant took it to the extreme by role playing a volcano. He said, "*what about like... like a volcano, like a volcano doesn't care. And a volcano is going to make air pollution, but it doesn't see it as poor air quality...*" While this is a puzzling and unusual narrative, we interpret his use of volcano as an analogy for those who do not care whether the air quality is good or

bad. To paraphrase, this statement conveys that data is only relevant to people who care; for the rest, data is meaningless.

Our data suggest changing behavior requires more than awareness: some might simply have no means to choose between different options. For example, P5 told us that he won't change his commute route just to avoid air pollution, despite being concerned: "*I mean, air is just... I can't do anything about it... maybe I'll wear a mask? well, you just accept the reality... convenience of getting from point A to point B as fast as possible usually outweighs everything else... it's a sad but true.*" When asked to imagine a time when hyper-local air quality data is commonly available, he paused, telling us that he doesn't know what to do about that information:

> *If data starts coming out in the neighborhoods... um, I don't know... that could be a weird thing... Let's say you live in south Seattle and the air is bad... I'm not sure how that would affect that sort of stuff. (P5)*

These narratives suggest that while objective environmental data is imperative for improving air quality, designers must also embrace subjectivity in order to better understand people, their life experiences, and world views, if we ever hope to address such complex and "wicked problems" (Dombrowski, Harmon, and Fox 2016; Buchanan 1992).

6.5 Designing (for) Meaningful Environmental Data

There is rising world-wide concern regarding air pollution and other forms of environmental crises, to the point where civilization collapse and global extinction are plausible outcomes (Light, Powell, and Shklovski 2017; Liu, Byrne, and Devendorf 2018; Tomlinson et al. 2013). In response, an on-going body of research focuses on motivating sustainable behaviors through persuasive technology. In this section, we connect our findings to suggest opportunities and considerations

for future research in sustainable HCI and environmental sensing, and to guide critical re-imaginings of environmental data representation to support sustainable behaviors through technological interventions.

6.5.1 Coupling Measurements and Experiences

In the context of measuring and communicating air quality, we have argued that *environmental data is not enough*, referring specifically to the data generated by electronic sensors that show objective (but possibly meaningless) representation of the air. First, such environmental data reduce the complexity of urban environment to a limited set of predetermined parameters according to the sensors' tracking capabilities. As our results suggest, such reductive measures fail to capture the contours of personal experiences with the air. In addition, environmental data needs to be situated and narrated to have meaning, but a purely numeric representation of air quality does not offer much for sense-making on its own.

While subjective experience plays a major role in constructing meaning about air and air pollution, subjectivity can also be limiting and misleading. For example, our study showed that while people often rely on sensory cues to detect pollution, toxins such as carbon monoxide, asbestos, or lead cannot be perceived by the human senses. Additionally, almost all participants explicitly associated good air with nature while describing pollution as being entirely human in origin.

> *[air pollution is] anything that doesn't come from quote un-quote "nature." Um... so like pollen and things like that, I wouldn't consider pollution. Like that's normal. That's fine. I don't know if I would consider wildfires pollution cuz I do think they're natural that we do need a certain amount of that. (P2)*

However, poor air quality can have natural origins (e.g., smoke, pollen), revealing a disconnection between objective measurement and subjective experience. On the other hand, while objective measurements provide a ground truth that renders “invisible dangers” visible, purely objective designs may lack opportunities for meaning making that is essential for behavior change (J. Bardzell and Bardzell 2015b; Wright and McCarthy 2004; Rapp, Tirassa, and Tirabeni 2019; Sengers and Gaver 2006). Following this, we suggest coupling objective measurement and subjective experience to narrate air quality data. Our empirical data contains rich verbal and visual vocabularies people use to depict air. Some narratives and descriptions of wildfire included: “*smelt like burnt barbeque*” (P6), “*smelt like a campfire*” (P9), “*haze over*” (P7), “*thick and stagnant*” (P12), “*smoke rolling around*” (P1), “*grey and orange*” (P10), “*sky is red*” (P11), “*see lots of patients coming*” (P2), “*lung tightened*” (P3), “*tired and sluggish*” (P1).

For example, Pan, Cheong, and Blevis (2010) proposed “Climate Change Habitability Index” (or “CCHI”) that translates large-scale environmental data into five categories of risks—water, food, ecosystem, coasts, and health—associated with the habitability of a specific place to increase data accessibility and legibility. In doing so, CCHI connects device-centric measurements with human-centered experiences to democratize environmental knowledge, guide environmental planning initiatives, and facilitate public health decisions. Another example of coupling objective measurements with subjective descriptions of air is to create a crowd-sourced system that collects verbal narratives or image collages to provide a more contextualized representation and embodied understanding of air quality. Conversely, future work might focus on understanding how the subjective experience of the air might be informed by objective data from sensors. With rapid technological and design innovations in this space combining large-scale air quality data with corresponding fieldwork, we believe that we are not too far from answering this question.

6.5.2 Engaging with the Sociopolitical Context

Air quality is an immensely complex concern that touches on numerous facets of society including urban planning, transportation, economic development, policy, public health, socio-demographics, environmental sustainability, and others. These intricate, sociopolitical dimensions of air quality present a web of challenges that designers must grapple with if we are to push towards positive changes through design. For example, during our study, we observed that while many participants believed that having high spatial resolution air quality data might help guide them to take protective actions, several participants noted that having the choice to avoid polluted air is a privilege. During the cognitive mapping activity, P1 nicknamed a bucolic area near a conservatory with its old growth tree-covered streets as the "*old Capitol Hill*." To her, this is an area with "*rich people air*," out of reach to the underprivileged. In fact, this idea of clean air as a luxury was pervasive throughout our interviews; in P5's words,

> *I'm inclined to believe that people who are much more economically challenged, this is going to be the last thing they're gonna think about. I know a lot of people that are homeless... um, they're not gonna think about this... they have other issues going on.*

These discussions emphasize the inherent spatiality of air quality, and the underlying politics and power dynamics that shape and control that spatiality (Featherstone and Painter 2013; Massey 1992). As the above examples illustrate, air quality is a "wicked problem" that is unlikely to be resolved through technical means alone (Buchanan 1992), as there is no simple solution to improve the air, but rather a series of negotiations, trade-offs, and conflicts. During a co-design workshop, one participant reflected on her horrifying experiences with wildfire in previous years,

> *I was just dreading this upcoming Summer thinking that it would happen again. And then you feel sort of selfish because we're not having the fires, right, and I'm only seeing it from*

my little viewpoint. What about all those people losing their homes and who are closer to the fire?

This narrative provides a glimpse into the opposite side of the tracks from areas of "*rich people air*." Many people don't have a choice but sleep on the streets during forest fires. Speaking to this, P2 recalled seeing a drastic increase in patients who suffered from home insecurity visiting the hospital during the wildfire period, "*because they can't crash in their cars*."

Following Dombrowski, Harmon, and Fox, we argue that air quality is a social justice issue that requires a new "mode of knowing and relating, and sensitivities to inequality and marginalized voices" (2016, 657). While there is no easy answer considering the equity of having access to clean air, this did not stop our participants from designing for the underprivileged. During the co-design workshop in Kenmore, one group chose to design for "*an 'everyday person' who may not have the time and/or resources to pursue air quality technology on her own but should have access nevertheless."* To design for someone who they considered to be "*busy and perhaps not affluent*", and "*maybe hearing impaired*" due to aging, they believed that the design should be affordable and effortless to use.

We call to shift our attention from an emphasis on technological progress towards strengthening commitments to ethics and politics (Dombrowski, Harmon, and Fox 2016; Dourish 2010). Attending to the sociopolitical context of air quality means to acknowledge the inherent tension and power differences both in society and in the technologies we build. For example, instead of showing AQI levels on a map without context, we can surface the inequalities in the production or and exposure to pollutants or reveal how certain populations are more vulnerable to environmental realities while highlighting how changes in individual behaviors might have strong

impacts to others. By enabling activism through design and designing for those who do not have a voice or the means to participate, all of humanity can benefit.

6.5.3 Encouraging Reflection and Speculation

We have argued that purely objective measurements of a quantified environment abstracts and decontextualizes air quality from the embodied, lived, and felt experiences people have with air, creating a barrier to forming meaning from data. One way of bridging this gap is to create systems that work *with* users by creating designs that encourage self-reflection and open interpretation, instead of offering prescriptive views that might not reflect individuals' worlds (Brynjarsdottir et al. 2012). But how exactly might we achieve that through design?

To begin, it is difficult to study implicit knowledge that an individual might not even be aware of, let alone be able to explicitly communicate. One of the main challenges we faced in understanding and unpacking the perceptions people have with the air was getting our participants to reflect and externalize— "to move through very vague, holistic, and bodily felt forms outward toward delineated and explicit symbols" (Carspecken 1996, 168). Informed by critical qualitative methods and literature on reflection, our entire research protocol is designed to get people to reflect about the air (Baumer et al. 2014; Carspecken 1996; Schön 1983). During the interview, when our participants were asked to describe a moment when they or the people around them were bothered by the air, most started by talking about the regional wildfires happened in the past two years. With wildfires being such a catastrophic and alienating encounter for Seattle residents, this was not too surprising; but such extraordinary events are insufficient for understanding how perceptions and subjectivity are formed through every day, mundane interactions with the air.

To elicit reflections on the seemly trivial incidences, our research protocol involved a wide range of stimulus as probing materials. We went back and forth between textual (survey, design descriptions, annotations), verbal (interview, group discussions), tactile (drawing, mapping, annotating, and designing), and visual (layering maps, narrating images, making collages, and sketching ideas) forms of communication, each medium serving as prompt shifting experiences in scale, time, location, meaning, and interpretation. During the study, many participants had an "aha" moment, in realizing their own hypotheses, biases, and (un)awareness: "*come to think about it, I think sometimes just the noise quality makes me perceive that air quality is worse*" (P2), "*I noticed that it felt fresher down there. I didn't notice that... come to think of it, but wasn't like I thought about it much while I was there*" (P10). The cognitive maps, image collages, and design worksheets were simultaneously boundary objects that help establish a shared understanding of the local geography and material enactments that encourage reflection-in-action.

In addition, our interview protocol also prompted participants to imagine and to speculate on air. During the interviews, we asked our participants hypothetical questions such as "*where would you place the sensors if we give you 3-5 of them?*", "*what if the data tells you that the air quality in the forest is no better than in the city center?*", and "*how does it make you feel if you learn that rich people have better air quality?*" These questions often made our participants pause and appreciate the complexity of air quality. In other words, our study showed that speculation plays a critical role in reimaging what a meaningful environmental representation might be.

Taking into account individual subjectivity, one strategy to design for speculation is to design for open interpretation. For example, inspired by the correlation between noise quality and air quality mentioned by our participant (P2), we can create designs that communicate air quality through acoustic representations, varying in tempo, timber, pitch, and volume. We suspect, designs that

encourage multiplicity in meaning-making will make the user pause and puzzle; and it is through the process of speculation, attunement, and making connections between personal experiences and environmental representation that an individual form meaning from the data. Designs that employ an artistic representation of the environmental data help "evoking meanings, rather than denoting them" (Leavy 2015, 34). If we avoid forcing a prescribed definition or authoritative claim onto how data should be understood, we might better engage people to form meaning from data in a personal way.

6.5.4 Incorporating Nonhuman Stakeholders

While many discussions centered around how air quality might affect the health of themselves and the people around them, several groups voiced concerns for the less-privileged, who "might be unable to voice their concern and need for care" (Puig de la Bellacasa 2017, 52). In thinking of who is left in the current landscape of technological interventions, our participants reminded us to look around. Describing how she was bothered by the dusts generated from an on-going construction, P12 noticed that animals seem to suffer even more:

> *There's like bears running around on the golf course. There's coyotes, there's bobcats... there's all kinds of animals that I never saw seven years ago. You've got to go out to the woods if you wanted to see them. right? But they're being driven from their habitats.*

Within the community of sustainable HCI, there is an emergent thread of research that draws concepts in posthumanism, suggesting "de-centering humans" in design as a response to rising concern of climate change and environmental crisis (R. Clarke et al. 2019; DiSalvo and Lukens 2011; Forlano 2016; Light, Powell, and Shklovski 2017; Liu, Byrne, and Devendorf 2018; Liu, Bardzell, and Bardzell 2019b; N. Smith, Bardzell, and Bardzell 2017). By de-centering humans,

the discourse of nonanthropocentric HCI does not suggest to simply negate humans; on the contrary, it is about foregrounding the sense of "togetherness," using our participants' words. We see observations reflecting the interdependency between human and nature throughout our empirical data. For example, almost all participants drew connections between good air and the presence of nature; arguing that protecting ecosystems and natural environment is necessary in bettering air quality. A group of workshop participants further brought out the notion of "*technology working with nature*" as the key for achieving long-term sustainability and well-being (see previous section). The notion of working with is important, pointing at symbiotic relationships aiming towards mutual beneficial ends.

So how might we incorporate nonhuman stakeholders in reimagining environmental sensing? Of course, we can design *for* nonhuman animals and plants such as improving air quality in wildlife habitats or providing alerts to warn and evacuate fauna when forest fire occurs. However, feminist STS scholar Maria Puig de la Bellacasa reminds us that caring for the others is more than just an ethical concern but also involves interspecies relationship building and the transformation of the self. She writes, "thinking-with nonhumans should always be a living-with, ware of troubling relations and seeking a significant otherness that transforms those involved in the relation and the world we live in" (Puig de la Bellacasa 2017, 83).

Following Puig de la Bellacasa, the effort of thinking-with can be supported through the practice of defamiliarization, which involves shifting our attention to notice what matters to our nonhuman significant others (Haraway 2008; Dooren, Kirksey, and Münster 2016). One way of doing so is through disengaging from our dominate model of knowledge production (Bell, Blythe, and Sengers 2005; Braidotti 2017). For example, we can build cross species environmental sensing platforms that animals and plants are involved "in the creation and representation of our

environmental commons" (Hannah and Jeremijenko 2017, 219). We have seen initiatives that leverage the mobility of birds to gather air quality data (Vaughan 2016), designs that integrate mussels' high sensitivity to water pollutants to make legible environmental parameters that we have not known or could not yet measured (Hannah and Jeremijenko 2017), and works that couple biosensing and natural language processing techniques to enable two-way conversation between humans and plants (Steiner et al. 2017). Following this thread, we are no longer design *for* but design *with* nonhuman stakeholders. In fact, there is perhaps more for us to learn than to service. For example, to avoid oversimplifying the complex and ever-changing urban ecosystem to a few parameters, we can build computational models that learn from "natural intelligence" by observing, tracking, and understating how environmental data affect animals, plants, and microorganisms in the biosphere (Hannah and Jeremijenko 2017).

6.6 Conclusion: Designing (for) Human-Nature Interaction

Through semi-structured interviews, cognitive mappings sessions, and community co-design workshops, we ground our research on the concept of data narration to reimagine environmental data representation and support meaning making. We build on previous work in environmental sensing but take an open-ended approach to studying how people perceive air quality using the full spectrum of their perceptions. We illustrate limitations of overemphasizing objective measurements or subjective experiences and outline strategies for making environmental data meaningful. The design directions include engaging with the sociopolitical context (to attend to issues of social justice and advocate change through design), encouraging reflection and speculation (to support open-interpretation and cultivate new sensory engagements), and integrating nonhuman stakeholders (to expand our current understanding of the environment). While we are still far from solving the environmental crisis, our study provides a critical re-

interpretation of environmental representation and persuasive sustainability which helps us see challenges in a new light and ask better questions considering ways of moving forward.

Chapter 7.

Posthumanism for HCI: A Discussion Thread

> For me, the question 'Who should speak?' is less crucial than 'Who will listen?'. 'I will speak for myself as a Third World person' is an important position for political mobilization today. But the real demand is that, when I speak from that position, I should be listened to seriously; not with that kind of benevolent imperialism….
>
> - Gayatri Chakravorty Spivak[37]

Tracing back to 2016, as a confused junior designer who loved nature (and still does) but constantly felt guilty about the electronic waste I created in practicing and distributing products, I decided to leave a corporate position to embark on my PhD. In starting this new journey, I strived to understand whether there was a space to create designs that both takes the environment (and all kinds of species who call the Earth home) seriously without having to compromise on making a living. Consequently, I undertook my dissertation research seeking to answer the question: how might technological intervention amplify the agency of different species to support more sustainable, inclusive, and aesthetic forms of human-nature interaction? This was the question I wish that there was someone to engage in a conversation with and seek guidance from when I was a defeated designer. I did not meet that person back then, but today

[37] Gayatri Chakravorty Spivak, 1990. Questions of Multiculturalism, *The Post-Colonial Critic: Interviews, Strategies, Dialogues.* Sarah Harasym (Ed.). Routledge, New York.

I will pretend to be that someone, sharing implications of PID on HCI. This discussion is not only deliciated to my former self but to the HCI researchers and designer of today.

7.1 Implications HCI Theories

In Part II of this dissertation, I introduced several posthuman concepts—arts of noticing (Tsing 2015), natureculture (Haraway 2003), companion species (Haraway 2008), and non-normative care for nonhumans (Puig de la Bellacasa 2017)— as theoretical foundations for me to trace, analyze, and illustrate three different field encounters I had with nonhuman stakeholders. In the following sections, I describe how I—through cultivating an embodied understanding with insects, weeds, soil, and pollution—translate posthuman concepts into HCI theories which guide PID practice to pursue more sustainable, inclusive, and resilient futures.

Starting this discussion thread by reflecting on the theoretical implications that PID offers to HCI is not accidental but deliberate: I believe that the epistemological groundings in which HCI researchers, designers, and engineers are taught or surrounded by fundamentally guide the methods we choose, the systems we build, and the actions we take. Let us begin this section by exploring the alternative, not so human-centered paradigms that HCI can build upon.

7.1.1 Designing as Scaffolding Assemblages

Through a series of design critique and ceramic-making experiments, I have proposed replacing the industrial fabrication process of molding with scaffolding to cultivate a space of human-nature co-creation, which offers opportunities for nonhuman stakeholders to add characteristics, value, and aesthetics into design. In addition, I have introduced alternative farming practices in Taiwan to depict instances when the farm is not so much a controlled system, but an assemblage characterized by multiple rationalities always evolving and changing. Produces that come from

these experimental farms, including honey-scented tea and the fertile soil made from weeds, are not only commodities of high-demand but also embodiments of equitable food cultures.

Both examples involve human actors restraining from acts of control; and resisting control helps reveal nonhuman agency to enable interspecies participation, collaboration, and cohabitation. Sociologist Alexis Shotwell (2016, 8–9) describes control as "a bad approach because it shuts down precisely the field of possibility that might allow us to take better collective action against the destruction of the world in all its strange, delightful, impure frolic." To a certain extent, we may consider control as a manifestation of power, which jeopardizes diversity, social justice, and ultimately distorts truth (D'Ignazio and Klein 2020; Carspecken 1996).

However, the notion of control has a long-standing tradition in HCI. One of the most prominent examples related to this dissertation is the paradigm of persuasive and prescriptive technologies: systems that have a pre-determined vision of what "good" or "desirable" behaviors ought to be (e.g., sustainable, healthy, efficient) and are designed specifically to convince users to behave in certain ways that help them achieve the prescribed preferred state (Fogg 2009). In advocating PID as an alternative design orientation that resists actions to control, my intention is not to criticize that the control model as intrinsically bad, nor do I attempt to dispute the usefulness of persuasive technologies. Instead, my goal is to show instances when the control model falls short or fails in creating flourishing futures. Specifically, I have demonstrated how resisting control creates new design opportunities for humans to "be both actively involved and passively fascinated," (Hitchings 2006, 376) both in the ceramic-making experiments (i.e., considering design as an act of scaffolding instead of molding) and in alternative agricultural practices (i.e., treating farming as facilitating assemblages as opposed to building systems). Next, I will share

three concepts that have helped me to understand what it means to resist the impulse of being in control—I hope these concepts will be useful to readers of this work as well.

First, resisting control involves the recognition of relationality and interdependence: the fate of one stakeholder can change the entire ecosystem. One of the most recent examples is the COVID-19 global pandemic: since its initial outbreak, the virus has fundamentally disrupted our day-to-day life across the globe and created a set of "new normal" (Lichfield 2020). Realizing that *Homo sapiens* are nothing but one of the 8.7 million species on Earth[38] and the fact that we have never been in total control essentially challenges the concept of human dominance.

Second, resisting control also requires the acknowledgement that there are various ways of being; some of them might be fundamentally distinctive, even contradictory from one another, but the distinctions and/or conflicts do not essentially make one way of being more superior, authentic, or correct than others. As a design practitioner, I acknowledge that all technologies are inherently political as the act of designing requires one to constantly make choices. Taking it to the extreme, "you have to make up your mind either to make sense or to make money, if you want to be a designer" (Papanek 1972, 86). Personally, I do not consider making profits and creating meaning as an either-or question but a spectrum capturing different sets of values and design ethics. Nevertheless, this question brings the different values and facts that co-exist in our lived world. For Haraway, "multispecies flourishing requires a robust nonanthropomorphic sensibility that is accountable to irreducible differences" (Haraway 2008, 90); similarly, following

[38] The Census of Marine Life estimates that there are about 8.7 million species on Earth. The number varies among different sources and analytical techniques; what I wish to emphasis here is the concept of specie interdependency.

critical theorist Jürgen Habermas, I argue that to orientate toward mutual understanding, then, is to resist the impulse to control but to engage in communicative acts (Habermas 1984).

Finally, giving up control includes embracing uncertainty and allowing vulnerability—perhaps not a single individual wants to be perceived as chaotic, confused, clueless, and weak—and this is why resisting control is challenging both on a personal and on a social level. For me, realizing the fact that I have never been in total control was in fact quite relieving, because all of a sudden, all I have to do is to be peace with ambiguity. It is worth mentioning that resisting control does not mean to abandon one's own agency, nor does it mean to do things in a careless manner; rather, it is about reorienting attention from ourselves to the world, following Tsing (2015), "the modern human conceit is not the only plan for making worlds: we are surrounded by many world-making projects, human and not human. World-making projects emerge from practical activities of making lives; in the process these projects alter our planet. To see them, in the shadow of the Anthropocene's 'anthropo-,' we must reorient our attention."

In sum, if HCI were to pursue more sustainable, inclusive, and resilient futures, I believe it can benefit from consciously resisting the impulse to control: moving away from "molding systems" towards "scaffolding assemblages" for a wider range of stakeholders.

7.1.2 Reimagining Stakeholders: from Other to Kin

> Species interdependence is the name of the worlding game on earth, and that game must be one of response and respect. That is the play of companion species learning to pay attention. Not much is excluded from the needed play, not technologies, commerce, organisms, landscapes, peoples, practices. (Haraway 2008, 19)

In the previous section, I have argued that the control model of design (as embodied in forms of persuasive technologies) reinforces imbalanced power structure, intensifies species isolation, and prohibits interspecies collaboration. I have also demonstrated how rethinking the process and the act of design through a posthuman lens (considering designing as scaffolding assemblages) provides an alternative mode of engagement that decenters human agency and problematizes the paradigm of human-centered design. In this section, I focus on another important component in HCI research and design practice—the user. In particular, I describe how a PID orientation reconceptualizes the user in terms that resists the trap of anthropocentrism.

In HCI and interaction design, we tend to portray users who have different needs, abilities, limitations, cultures, and experiences compare to a typical user as the "other;" and the "other" are usually illustrated as either distinctive or distant from the majority of users. However, recent work have argued that the needs of the other might not be so distinct in certain cases. For example, literature on inclusive design and disability studies have demonstrated that designing for individuals who have permanent disabilities can in fact benefit everyone as a whole (Holmes 2018); similarly, feminist studies scholars and user experience researchers have noted that the "marginal" or "extreme" users can be inspiring "resources for design solutions" (S. Bardzell 2010; Strachan 2017; Halpin 1989). In other cases when the users we are designing for do exhibit very distinctive characteristics, behaviors, and needs from us—for example, as I have illustrated in Part II of this dissertation—we are still part of world-making project where the fate of one stakeholder can change the entire ecosystem. That is, regardless of the biogenetic and sociotechnical differences, we are in fact not so distant from our earthy partners: pests, weeds, soil, and pollutants.

In the previous chapters, I used the term “strange companions” to describe stakeholders who are “unfamiliar (outside what we thought was family or gens), uncanny, haunting, active” to human stakeholders, echoing Donna Haraway’s notion of “kin” (2016):

> *Kin* is a wild category that all sorts of people do their best to domesticate. Making kin as oddkin rather than, or at least in addition to, godkin and genealogical and biogenetic family troubles important matters, like to whom one is actually responsible.

Haraway’s definition of kin is useful term for helping us to reimagine the notion of users through a posthuman lens. In particular, the concept of kin foregrounds relationality, interdependence, and the sense of togetherness. In other words, when thinking about the users, PID includes considerations of design ethics but goes far beyond it; similar to how Karen Barad’s description on responsibility: “responsibility is not an obligation that the subject chooses but rather an incarnate relation that precedes the intentionality of consciousness. Responsibility is not a calculation to be performed. It is a relation always already integral to the world’s ongoing intra-active becoming and not-becoming.” (Barad 2010, 265). When I spoke with Seattle residents who participated in the air quality study, many narratives centered around descriptions on how air pollution is a result of collective behaviors, and thus it also requires global efforts and actions to tackle (§6.4.3). Similarly, back in Shengou Village in rural Yilan, the eco-friendly farmers I interacted with have, in their own unique ways, tried to make kin with companions whom we may find strange or malicious at the first glimpse. Another intriguing human-nature encounter I

observed in Shengou Village involves how Jeff and Sophia, an ex-architect now permaculture farming couple, practice threading, a process of separating grains from straws and husks[39].

I first met Jeff and Sophia at their rice paddy on a scorching hot and humid summer morning. There are hundreds of rice paddies in the village, and while most of the paddy fields look very similar, theirs stand out because of the triangular-shaped racks that are lined up nearly in the rice paddy. These racks are made by using bamboo as the main frame and metal tubes as the hanging structure, secured with cotton ropes. These racks are one of a kind and are used to hang harvested stalks prior to threshing and hold the straws after threshing. Jeff and Sophia showed me how to thresh: we collected the straws, removed the weeds, spread the stalks evenly, put them into the threshing machine to collect grains, and then put the straws back onto the triangular racks. By closely handling the crops, I soon noticed that there were many "leftover" grains on the straws. Jeff explained that this is because the threshing machine can only function within a certain range, so the grains outside of the range will stay intact. I asked if they want to put the straws back into the threshing machine to collect remaining grains, they declined, "*we want to protect the ecosystem, so it's okay to leave some grains on the straws for the birds to eat.*" This statement illustrates the permaculture philosophy of working with nature.

What one might consider as a wasteful behavior at the first blush turns out to be a deliberate consideration, an act of care of the rice farmers. Specifically, Jeff and Sophia chose not to collect the remaining grains, nor did they decide to burn the straw (which is a fast, low-cost practice among many farmers to dispose straws and clear the land in preparation for seeding); instead, they fabricated aesthetic and sturdy racks that prop up the straws so birds can feed on the

[39] The ethnographic encounter I had with Jeff and Sophia was originally published as a peer-reviewed archival paper at ACM LIMITS 2018 titling "Out of Control: Reframing Sustainable HCI Using Permaculture." The description I include here has been greatly abbreviated from the original publication.

remaining grains. As a permaculture evangelist and practitioner, Jeff referred this practice to the permaculture ethic of "return of the surplus" (Mollison 1988). He explained, "*in a narrow sense, permaculture is about social justice, but in a broader sense, it is about how you keep the engine running. What you want to create is a loop rather than a linear process*." To Jeff, Sophia, and many others in Shengou Village, sharing what they do not need contributes directly to regeneration of resources.

We might read Jeff and Sophia's act of intentionally leaving rice in the field to feed birds as an instrumental choice—a belief that only by returning the surplus, we can maintain the environment sustainable and keep the resources unexhausted. Embedded in this rationale is that "we are nature working" (Starhawk 2004, 9) and that our "personal actions have consequences for more than ourselves and our kin" (Puig de la Bellacasa 2010, 160). Reimagining and representing the users not as "other" but as our "kin" foregrounds the interdependency and entanglement between different entities, humans or nonhumans; this reimagination also pushes the ethics of care and responsibility from a moral disposition to a quest of searching for alternatives. In the next section, I will outline a few methodological strategies I explored in this work to guide interested readers in joining the journey of reconsidering other as kin.

7.2 Implications for HCI Methods

I grounded my research on critical epistemology and took an interdisciplinary approach with the goal to mobilize Tsing's "arts of noticing" (2015), which, at its core, refers to "the ability to acknowledge and simultaneously step in and out of multiple simultaneous frames of references" (Liu, Bardzell, and Bardzell 2019b). To resist habitual perceptions, reorient myself and to engage in alternative modes of knowing, and move from seeing "what is" to speculating "what can be" (Blevis 2018), I bring together arts-and-design, ethnographic, and humanistic inquiry methods.

In the following sections, I reflect on my methodological experiments and focus this discussion on how HCI researchers and design partitioners might mobilize “arts of noticing” in our study.

I note that the methods that I include in the following sections are inspired by or rooted from critical methodologies, and thus they are not entirely new (nor should they be treated as an exhaustive list). My goal, however, is to introduce an number of initial and actionable strategies for members in the HCI community to practice, explore, and develop our own “arts of noticing” (Tsing 2015). Overall, I suggest the HCI and interaction design pedagogy to focus more on community engagement, interdisciplinary training, the recognition and mitigation of power, as well as the development of experimental and speculative methods.

7.2.1 Reorienting Attention to The Margins

The first strategy for embodying “arts of noticing” is to shift our attention from the center to the margins. The “margins” might have very different meanings depend on the context, but it refers to entities, artifacts, activities, and values that are being neglected, oppressed, or excluded. For human-centered-design, the marginalized stakeholders are individuals who are not humans—such as animals, plants, and microorganisms. HCI has a long tradition in designing technologies for non-expert everyday users, and interaction design researchers and practitioners have already attended to a wide range of marginalized groups: women, people of color, older adults, LGBTQ+ groups, individuals with disabilities, lower income households, rural communities, or the Global South, just to name a few. Reorienting attention to the margins means to be resist habitual thinking, be aware of unconscious biases, challenge power, and promote inclusion.

Bardzell argues that reorienting attention to the margins simultaneously creates more inclusive and ethical futures and offers opportunities for creativity and innovation; she noted that the

practice of decentering "encourages an alternative sensibility to design, foregrounding questions of cultural difference, encouraging a constructive engagement with diversity." (S. Bardzell 2010, 1309). Similarly, anthropologist Arturo Escobar cited Colombian designer Alfredo Gutiérrez Borrero's work[40] to call for more focus on "designing with," and ultimately "letting ourselves be designed by" values, practices, and stakeholders in the Global South (Escobar 2018):

> What happens, then, when we design on the basis of design thinking based on other notions and by other names, of sciences which are not such, in order to create alternatives to development with technologies and industries that are something else? We are confronted by older idioms that we are just beginning to hear anew, and by epistemologies in search of aliases. Designs from the south were always there, albeit with other names, we are just starting to perceive them. It takes time to recognize them. Now we need to begin the task of designing with them and of letting ourselves be designed by them. (Gutiérrez Borrero 2015, 126)

The passage above directly describes how the marginals can become a resource for innovation. Google, for example, has a team that specializes in creating technologies for emerging markets and developing countries in Asia; they call it is the "Next Billion Users" (NBU) team[41]. The reason why I am including Google's NBU team here is not to argue whether their initiative on reorienting to the margins is ethical or colonial—that will be a whole separate conversation, but rather, I use this on-going project as an example to emphasize the resourcefulness of the margins.

[40] The text was originally published in Spanish. The English version provided here is translated by Arturo Escobar.
[41] The manifesto put by Google's Next Billion Users team goes, "Everyone — no matter their location, language or digital literacy — deserves an internet that was made for them." For more info visit https://nextbillionusers.google/

I encourage readers who are interested in practicing shifting attention to the margins to look into nontraditional and underserved users (e.g., nonhumans), as well as emerging forms of use (e.g., multispecies interactions). This suggestion resonates with the common user research technique on focusing on extreme users to deliver good user experiences, and the rationale is that extreme users often have extreme behaviors, and by addressing these extreme scenarios, we can both address most issues that a typical user might have and identify innovative design features[42].

7.2.2 Tracing Conflicts and Sufferings

Tracing is a common method for HCI researchers. Instances include following and investigating a task flow using contextual inquiry methods, tracing an actor, tracing an activity, or an artifact using ethnographic approaches (Halse 2013; R. C. Smith et al. 2016; Nippert-Eng 2015). Critical environmentalist Robin W. Kimmerer (2014) writes, "paying attention to suffering sharpens our ability to respond. To be responsible." Similarly, Light, Powell, and Shklovski (2017) argue that "paying attention to things that we do not wish to see and that make us uncomfortable" offers the opportunity to resist self-centeredness. To create more flourishing and inclusive future, I suggest tracing conflicts and sufferings as they often surface moments when opposing values collide or when unbalanced power relationships enacted in tangible forms. Examples that I have previously illustrated included scale insects that almost destroy the entire citrus orchard and urban air pollution that post environmental and public health threats to local residents.

A recent example is Casa De Carne (2019)[43], a two-minute film directed by Dustin Brown and produced by Last Chance for Animals, a nonprofit organization. Casa De Carne means "Meat

[42] I credit Lesliu Liu for having several informative private conversations with me on conducing user experience research in industry settings; these conversations have inspired several parts of this dissertation.
[43] Please visit director Dustin Brown's webpage for the film. https://www.dustintoddfilms.com/

House" and the clip is set at a high-end fictional restaurant that takes "the dining experience full circle." In the film, the main character ordered a baby back ribs for dinner before he was escorted to a room in the back of the restaurant, given a knife and being locked inside the room with a pig, whom he was supposed to slaughter himself. Perhaps not too surprisingly, he could not kill the pig; he dropped the knife and petted the animal instead. The next second, the restaurant staff rushed inside the room, yelled, "another one!" and slaughtered the pig in front of him before he could have stopped it. Director Brown (2019) writes in a blog post, "I'd like this film to make people think and question their everyday reality." Indeed, by guiding our attention to moments of suffering and things that make us uncomfortable, the film foregrounds how disconnect humans are with our food sources and fosters critical reflections on our dietary choices.

My intension of sharing the film Casa De Carne is not to criticize our meat-eating culture—I am not a vegetarian myself either—that will be a different discussion. Instead, I wish to demonstrate how tracing conflicts and sufferings can help HCI researchers and designers cultivate intimacy towards marginalized users and create equitable food cultures. Luckily, we do not need to travel too far to notice the conflicts: similar to the concepts of "kill your own animal," conflicts and sufferings are everywhere: on the land we stand, the food we consume, the product we purchase, and the waste we dispose—all we need is not to turn our attention away from them.

7.2.3 Challenging Assumptions and Making Speculations

A related strategy to attending to the moments that make us uncomfortable is to challenge the assumptions, hypotheses, and folk theories that we take for granted. My PhD research, for example, has on many different levels contested my presumptions and urged me to engage in critical and speculative reflections. In Part II of this dissertation, I have described how getting my hands dirty to engage in the seemingly disorganized ceramic-making experiments allowed me

to reconsider the value of decomposition—a natural phenomenon that is often associated with negative connotations such as decay, rotting, aging, and death—as a design tactic that involves nonhuman agency to create opportunities for growth, renewal, transformation, and rebirth (DeSilvey 2006). I have shared how the time I spent in the field working alongside with eco-friendly farmers has taught me to consider pests and weeds not as something to be removed but as companion species to the farmers and their crops. I have described how cultivating an embodied understanding of the Earth led me to appreciate the (seemly messy and dirty) visual representation of eco-friendly farms—they are in no ways similar to the aesthetics in industrial agriculture—and yet the eco-friendly farms represent a different and more equitable kind of care. I have also illustrated how asking hypothetical questions about the air challenged the assumptions we take for granted. For example, questions like, "*what if the data tells you that the air quality in the forest is no better than in the city center?*" and "*how does it make you feel if you learn that rich people have better air quality?*" often made the participants pause and came to realize the implicit (and idiosyncratic at times) assumptions they hold.

HCI literature on design futuring and design fiction offers rich and diverse methods to engage in critical and reflexive reflections. For example, Bell, Blythe, and Sengers (2005) proposed strategies such as "make strange" or "defamiliarize" the status quo to "see our own design practices in a new light." Brown et al. (2016) mobilized the concept of "equivocality" by creating a furniture catalogue that visualizes "ideas that have multiple meanings" to encourage open and playful interpretations. Ballard, Chappell, and Kennedy's board game design (2019) engages stakeholder perspective taking by prompting members in a product team to write fictional reviews for technological products. The proposed strategies in encouraging reflection and speculation can be used both as research methods and for creating designs that challenge the status quo—critical design and speculative design are two of the most evident examples. On an

applied level, we might utilize the tactic of "equivocality" and intentionally introduce contradictory perspectives to create search engines and social media platforms that help us see the other side of the story. I am aware that most technology companies might be relucent embrace this idea for the time being since most of their algorithms are designed to support addiction[44]. However, with the public become more and more aware of the social responsibilities that tech giants hold, hopefully we are not too far away from demanding internet platforms for displaying less biased views but more diversified perspectives. And when that day finally comes, it will then be our own responsibility to reorient "attention to things that we do not wish to see and that make us uncomfortable" (Light, Powell, and Shklovski 2017).

7.2.4 Practicing Listening with Interlocuters

To mobilize "arts of noticing" (Tsing 2015), the fourth actionable methodological strategy I offer is to practice attentive listening by working alongside with interlocuters. The Cambridge Dictionary[45] defines an interlocuter as an individual "who is involved in a conversation" or "who is representing someone else." In comparison, in natural science and traditional social science, researchers tend to treat their participants as "objects of scientific study" or as "lower (inferior) forms of life towards which the scientist need not feel compassion or respect" (Halpin 1989). I am among the feminist scholars who consider individuals with whom we engage with as "participants" or "interlocuters." Over the course of conducting my PhD research, I am fortunate enough to have read, encountered, or worked with many generous and intelligent interlocuters who helped me to see the world in a new light. In the previous chapters, I have introduced various

[44] For example, in 2019, Chamath Palihapitiya, former Vice President of User Growth at Facebook, gave a public speech on how many algorithms behind social media platforms are designed to optimize addiction. https://datascienceathome.com/the-dark-side-of-ai-social-media-and-the-optimization-of-addiction/
[45] https://dictionary.cambridge.org/us/

scholars whose work have inspired this dissertation; in this section, I focus on reflecting my experience interacting and learning from the interlocuters in my fieldwork.

To begin with, one of the biggest challenges I have faced in doing research with nonhumans is that we do not have a shared language. However, just as Donna Haraway was able to relate to and write about her dog Cayenne (2008; 2003) or as Anna Tsing as able to tell stories through mushrooms (2012; 2015; 2014), I turned to those who have prolonged histories and first-hand experiences interacting, collaborating, caring, or negotiating with nonhuman stakeholders. As I embarked on this research, I worked alongside with ceramic artists, eco-friendly farmers, and urban dwellers—let me call them my "translators"—to try to understand their lived experiences with materials, crops, and pollution through (anthro-) communicative acts (Habermas 1984; Carspecken 1996). Gradually, I noticed that I began to pick up nonhuman communicative cues not replying on my "translators" but through the embodied understanding I cultivated overtime. This is not at all a superpower I am born with, but a hard-earned sensitivity[46]. In the context of supporting cultures of making through, Bardzell, Bardzell, and Ng (2017) described a similar kind of sensitivity and appreciation as a form of "scholarly rigor." In particular, they encouraged HCI researchers and design practitioner not only seek to "*represent*" the culture we engage with, "but also to *appreciate* it with scholarly rigor, to open oneself up to become more fully alive to it" (S. Bardzell, Bardzell, and Ng 2017, 6524). In the next section, I will describe in more details how I seek to cultivate this scholarly sensitivity in my own work.

7.2.5 Cultivating Bodily Ways of Knowing

[46] The Chinese idiom "庖丁解牛" (pao ding jie niu) offers similar meanings. The term originally comes from Zhuangzi (莊子) in a fable that describes how a butcher was able to perfectly cut a cattle through years of practice and reflection—until he and his craft becomes one.

Body and its sensory experiences—or even more generally, different communicative acts other than language—plays an important part when we try to understand and respond to nonhuman stakeholders. Multispecies ethnographers argue that "tuning into our own senses equips us better for the sort of posthuman, species-inclusive ethnography we advocate" (Hamilton and Taylor 2017, 112). Similarly, Karan Barad describes knowing as "a direct material engagement, a practice of intra-acting with the world as part of the world in its dynamic material configuring, its ongoing articulation." (Barad 2007, 379). In this view, knowing is not a cognitive activity happening in the head but a practice and process that involves direct engagements with the world. The media of engagement varies—ranging from tangible materials to bodily movements, perceptions, and reflections—as how Maurice Merleau-Ponty (1945) saw it:

> Rather than a self-sufficient consciousness or even a self-contained body, Merleau-Ponty offers us a view of the body as an open system of dynamic exchanges with the world, exchanges that, in their habituality, ground the body ever more firmly within the world, and, in the process, offer us new ways of engaging and transforming it. (Weiss 2008, 236)

Our bodies—including our eyes, ears, tongue, skin, and nostrils—have always played a big part in shaping how we understand and respond to the world. For example, I have noted in the Part II of this dissertation that lack of sensory perception contributes to people's lack of awareness on air pollution; I have also argued in the previous section that an embodied understanding of Earth is a form of scholarly rigor. In HCI, a wide range of quantitative methods involve tracking bodily movements (e.g., bio-sensing, eye tracking, motion tracking) to measure product usability and user behavior. Similarly, in qualitative and design research, we often use the term life-world to describe the lived experience of individuals, with the body (as opposed to the language or the cognition) being a key "field of experience" (Abram 1997, 44); a few examples include research

through design (Zimmerman and Forlizzi 2014), visual thinking (Blevis 2016; Pink 2013), (multi-)sensory ethnography (L. Hamilton and Taylor 2017; Daniele et al. 2015; Pons, Carter, and Jaen 2016; Crivellaro et al. 2015), and somaesthetic design (Höök 2018; Metcalfe n.d.). I suggest we build upon these existing methods to further expand and cultivate more bodily ways of knowing for HCI and interaction design research.

7.2.6 Methodological Reflections

In Part I of this dissertation (§3.1 and §3.2), I have illustrated the interdisciplinary methodological approach I took in this work; I have described how I arrived at the configuration that combines arts-and-design approaches, ethnographic fieldwork, and humanistic methods. Additionally, I have argued how this interdisciplinary approach helped me develop the multi-faced perspective that is necessary in exploring an alternative design paradigm that builds upon but expands conditions of human-centered design. In this section, I reflect on the specificities regarding the methodological arrangement as well as their strengths and limitations. Specifically, I describe the ways in which the "arts of noticing" (Tsing 2015) I seek to explore in this dissertation differ from a conventional human-centered orientation and incorporate nonhuman stakeholders.

To being with, one the most challenging issues that I faced early on in my inquiry is that the existing methods in HCI were too human-centered; they focus on studying human behaviors and social interactions while nonhuman stakeholders were rarely part of the scenario. For the goal of "being alongside" (Latimer 2013) and "becoming-with" (Haraway 2008) participants who do not use human language to communicate (e.g., pests, weeds, and soil), I needed to better engage with communicative actions that does not simply reduce to speech or linguistic cues (L. Hamilton and Taylor 2017; Carspecken 1996). In the previous section, I have argued that cultivating bodily ways of knowing helps deprivilege language. Here, I note that the method of knowing through

the senses I propose in this work differs from an empiricist's approach. Specifically, I seek to engage with senses in a way that does not set me apart from the world but to better locate and illustrate the kind of connectiveness I always had with the various world-making projects.

However, as I have stated earlier (§1.1), I am also aware that as a human myself, I am limited to the languages and senses that are accessible to human beings; as a result, the approaches we develop will always be colored by human experiences, perceptions, and imaginations. While this is an inherent limitation for PID, I suggest HCI researchers and designers who are interested in incorporating nonhuman stakeholders in design to experiment and develop more methods that help us relate and respond to different species.

7.3 Implications for HCI Systems

The Interaction Design Foundation[47] defines human-computer interaction (HCI) as a field of study that focuses on "the design of computer technology and, in particular, the interaction between humans (the users) and computers." Made explicit in this definition is that HCI is an applied field with design being an important component to it. Alongside with Dourish (2006; 2007), I believe that "ethnographic contributions should not be judged on the inclusion of delimited implications for design" (2007); as a result, I focused the previous two sections on reflecting the theoretical and methodological implications this dissertation can offer to HCI. However, to demonstrate that "ethnography is, in fact, deeply relevant for design" (Dourish 2007), in this section, I shift the discussion back to directly focus on the act of design and the product of designing. Additionally,

[47] The Interaction Design Foundation (https://www.interaction-design.org/) is an online educational platform that provides open access educational materials for interaction design professionals.

to concretize the design strategies I offer, I reference and show existing examples as physical and conceptual embodiments of the design strategies.

7.3.1 Servicing Nonhuman "Clients"

Let me start this discussion by sharing an anecdote. I was in Southern California for conference trip during a "super bloom" in late March 2019, so I decided to go on a day trip to Lake Elsinore where I was absolutely stunned by the fields of poppies and their vibrant orange colors that lied in front of my eyes. For those who are not familiar with a "super bloom," it is a rare natural phenomenon that happens on an average of once every decade; the colloquial term super bloom is "used to define an explosion of wildflowers that exceeds typical spring blooms" (Gibbens 2019). Not for long, this marvelous show arranged by Mother Nature soon turned into a "poppy apocalypse"[48] where tens of thousands of visitors went off the hiking trial, trampled over the poppies to find a perfect patch to pose for a photograph, or cut down the flowers to bring home as souvenirs[49]. Despite the science community sending out constant message warnings possible ecological catastrophes that might arise from these unsustainable behaviors, the apocalypse continued. I remember sitting inside of my hotel room, checking hashtags related to the California super bloom (e.g., #superbloom, #superbloom2019), and reporting to Instagram each photograph showing people trampling the flowers.

[48] The term "poppy apocalypse" was coined by the Mayor Steve Manos to describe a series of disastrous events—unbearable traffic, people fighting over parking spaces, and visitors trampling the field to capture picturesque photos—that happened to the local community as a consequence of the super bloom.

[49] I prefer not to get myself into trouble by sharing this anecdote, so I refrain myself from pointing toward any particular individuals who held questionable ethics. Interested readers please read this public report from Los Angeles Times at https://www.latimes.com/local/lanow/la-me-ln-superbloom-lake-elsinore-20190314-story.html.

Figure 25 shows two screenshots concerning the reporting function on Instagram. The image on the right shows all reasons when a post might be considered as “inappropriate.” One might notice that there is no reason that is designed specifically for problematizing unethical behaviors when it does not involve a human or its properties being harmed. I was left with no choice but to mark these posts as either as “violence” or “bullying”; at the end, Instagram rejected all my reports, saying that they do not see anything concerning in the posts.

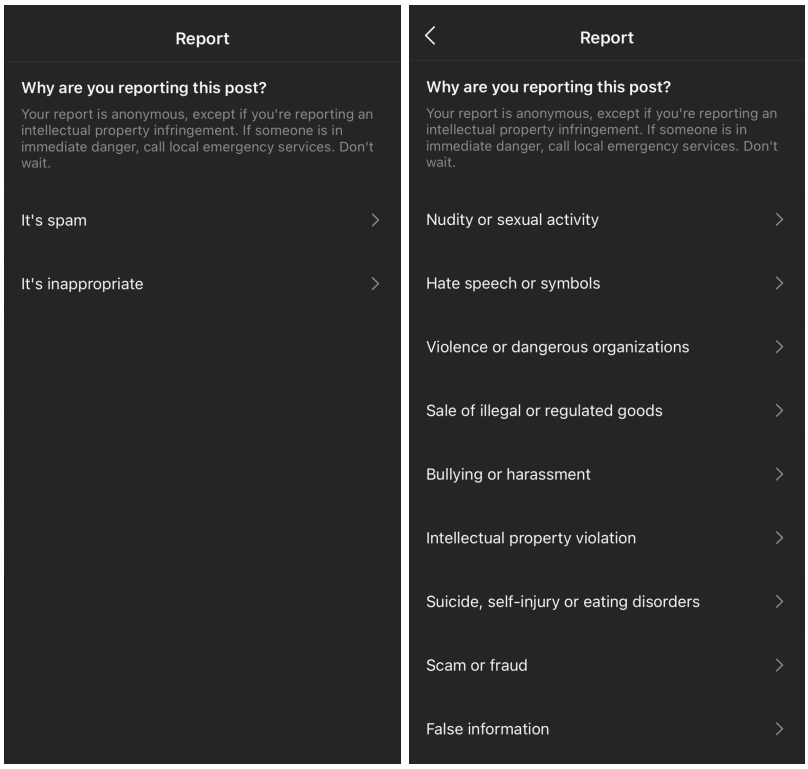

Figure 25. The reporting function on Instagram. Left: to report a specific post, one needs to first choose whether post is a spam, or it contains inappropriate contents. Right: a list of reasons one could from when reporting inappropriate contents.

Drawing from this upsetting (at least on a personal level) anecdote, perhaps one of the most straight-forward design implications that dissertation can offer for HCI is to expand the stakeholders we are engaging with and designing for to include nonhumans. Animal-computer

interaction (ACI), for example, is a sub-field in HCI that focuses on designing technology for inter-species (human-animal) interactions. However, although ACI offers a refreshing perspective for HCI researchers and designers to start incorporating nonhuman stakeholders into technological developments, the field of ACI itself remains rather human-centered in practice:

> The study of the interactions between animals and computing technology has never entered mainstream computer science, and the animal perspective has seldom informed the design of animal computing applications […]. The design of these technologies remains fundamentally human centered, and the study of how they are adopted by or affect their users remains fundamentally outside the remit of user-computer interaction research. (Mancini 2011, 69)

More specifically, the current corpus of ACI tends to focus on domesticated animals (i.e., pets, service animals, farm animals). There are, for example, digital devices for pet owners to track or play with their pet dogs, cats, birds, and fishes (Noz and An 2011; Ko et al. 2018; Nelson and Shih 2017); systems that evaluate the workability of service animals (Cleghern et al. 2019; Melody Moore Jackson et al. 2018), or designs that aim to improve welfare and enrichment for farm animals (Rault, Webber, and Carter 2015; French et al. 2017). Although these are important areas of research, I believe that if HCI were to pursue more equitable futures and support inclusion for nonhuman stakeholders, we need to overcome the shadow of the anthro- (as in the paradigm of human-centered design) and take more seriously the perspectives of species who might be outside of our immediate reach.

Figure 26. Two design examples that involve bees as stakeholders. Left: "Insectology: Food for Buzz" is an artificial flower that turns rainwater into surgery water for urban pollinators to consume © Atelier Boelhouwer. Right: "Living IoT" utilizes flying insects to expand wireless connectivity by attaching sensors to bumblebees © Iyer et al.

For example, multispecies design researcher Daniel Metcalfe advocates shifting our design focus from domesticated animals toward wild species and "treating animals as clients of design." He designed a set of cards for those who are interested in incorporating wild species into their design practice[50]. To me, the strategy of "treating animals as clients of design" signifies a critical move—a manifestation that nonhumans should no longer be treated as tertiary stakeholders for design or as utilities that service human needs, but the center of our design focus. For instance, if interaction designers were to create systems consider city-dwelling bees as our clients, we are more likely to create artificial flowers that provide sugary water for bees as emergency foods (Boelhouwer n.d., Figure 26, Left), pave pollinator friendly pathways in dense urban areas (Matthews n.d.), or produce building blocks that provide safe nesting spaces for solitary bees (Green&Blue 2015). On the contrary, we are less likely to, for example, attach sensing devices or wireless modules on bees to expand our sensing networks (Iyer et al. 2019, Figure 26, Right) or

[50] The design card set—and more descriptions on how to use the card—are made for public access on Metcalfe's personal website. http://www.danimetcalfe.com/index.php/md/

manufacture robotic bees who serves the purpose of pollination but does not benefit or communicate to living bees (Jafferis et al. 2019).

In the previous section (§7.2), I have offered actionable strategies—such as tracing conflicts and sufferings, practicing attentive listening with interlocuters, and cultivating bodily ways of knowing for HCI researchers and design partitioners to cultivate attentiveness towards supporting justice for nontraditional users. I hope that by illustrating these methodological strategies through concrete and contrasting design embodiments, this section provides a more tangible imagery regarding what attentiveness and care means in practice.

When we talk about including nonhumans in design, let us mean it: let us stop exploiting nonhumans to service anthropocentric technological explorations but to treat nonhumans as our respected clients and beloved kin. Let us also use this opportunity to reflect on ways in which the quest of servicing nonhuman clients might affect HCI's design evaluation criteria and peer review processes. For example, echoing Haraway (2016), "it matters what stories we tell to tell other stories with […] It matters what stories make worlds, what worlds make stories," many HCI venues now welcome various forms of submission (e.g., academic papers without page limits, arts and installations, pictorials, demos, posters, workshops) and recognize the values and rigors offered in these different forms of submission. Can we extend the model to further diversify the various kinds of contributions a research/design might offer? Similarly, a few HCI venues now honor submissions with diversity awards if the work helps with efforts in diversity and inclusion. How might we evaluate the contribution of the submissions if HCI were serious about servicing for nonhuman clients? Should (and how might) we invite animals and plants to the paper review committee? Furthermore, federal and industry grant applications often require a description on

the broader impacts the research can offer beyond the academic community[51]. What might happen if we implement a similar requirement to conference and journal submissions? Obviously, I do not have answers to all these questions. However, I do wish to use this opportunity to encourage my readers to reflect on some of evaluation criteria that we have been taken for granted as some of them might be enhancing structural power relations and systematic oppressions that we try hard to address in our own work.

7.3.2 Strengthening Human-Nature Kinships

> In towns and cities, and increasing in rural areas, people live in a way that is divorced from natural rhythms of seasons or ecology, and from any direct economic link to land or water resources. […] People do not see, understand or relate to nature as they did. We relate to it at a distance, in bursts, or by remote control, in cyberspace, creating and consuming images of nature and countryside. (W. M. Adams 2003, 109)

In his book, geographer William Adams noted that a major challenge for environmental protection and restoration initiatives is that modern societies tend to consider nature and culture as two separated and distant entities. Urbanization certainly plays a big part of this human-nature estrangement, but as I see it, the design of our technological applications and systems further enhance the alienation. In Part II of this dissertation, I have argued that representing the environment as a set of numbers or datasets negatively takes away its liveness and agency,

[51] For example, the US National Science Foundation evaluates the broader impacts of the study by asking the following questions: “How well does the activity advance discovery and understanding while promoting teaching, training, and learning? How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)? To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks, and partnerships? Will the results be disseminated broadly to enhance scientific and technological understanding? What may be the benefits of the proposed activity to society?” (source: https://www.nsf.gov/pubs/2007/nsf07046/nsf07046.jsp)

which, in turn, posts difficulties for humans to relate and respond to environmental pollution. Additionally, I have described how the time I spent in the field has taught me to appreciate strange companion species and unruly materials. Building on these observations, I suggest the HCI community focus on exploring design strategies that foreground human-nature relationality to help cultivate responsibility, intimacy, and care.

One design strategy is to develop alternative, (multi-)sensory data representation models that allow humans to experience environmental data or interact with nonhuman beings using our bodily senses—mirroring (but enhancing) the sensory experiences we have while immersing ourselves in natural spaces without the disruption of technology. For example, the data sonification technique that I used in creating the Ode to Soil prototype (§5.5.3) has also inspired the development of augmented pentatonic chime, an air quality windchime that plays major tones when the air quality is good and switches to minor tones when the air quality goes bad[52].

Another actionable strategy is to create a space for human-nature collaboration by revealing the agency of nonhuman stakeholders. For example, in Chapter 4, I have illustrated through the ceramic making experiment how the theoretical concept of scaffolding helps cultivating a space for natureculture co-creation. A previous design embodiment that explored a similar strategy is designed by tangible and auditory artist Till Bovermann. Specifically, by installing "piezo-based microphones into beehives," he invited multiple sound artists to improvise live music with bee colonies, building upon the sound that come from beehives[53] (Figure 27, Left). Here, to compose harmonious melodies with bees, one must practice attentively listening and responding.

[52] In collaboration with Microsoft Research, the idea of displaying air quality data using sounds is implemented in Project Eclipse as a conceptual design. The design is publicized online to demonstrate Microsoft's effort in fusing arts and science. https://innovation.microsoft.com/en-us/fusing-art-and-science

[53] The "Hive Concerts" by Till Bovermann (2013, 2016). https://tai-studio.org/portfolio/hive-concerts.html

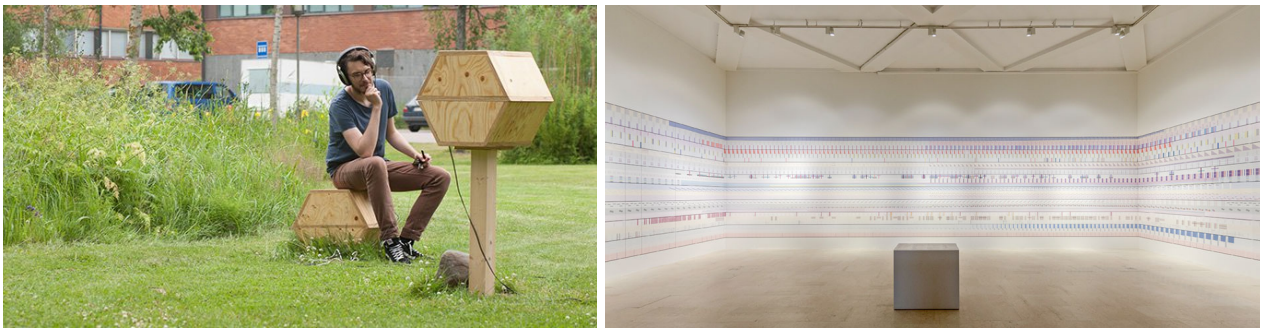

Figure 27. Two examples that help strengthen human-nature kinships through design. Left: “Hive Concert” © Till Bovermann. Right: “The Room of Change” © Accurat.

The third strategy for foregrounding human-nature relationality is to capture correlation between different datasets. Using the COVID-19 global pandemic as an example, studies have shown that face coverings can effectively reduce infection rates (Peeples 2020). In this case, we can employ data visualization techniques to highlight the relationality between human behaviors (i.e., wearing face covering) and nonhuman activities (i.e., virus spread). In a separate example, data visualization studio Accurat created “The Room of Change” exhibition with a “30-meters-long hand-crafted data-tapestry” that combines multiple datasets together (e.g., world population, average temperatures, energy consumption, etc.) to illustrate how our environment has changed overtime and the relationship between various activities[54] (Figure 27, Right).

Finally, if the previous strategy for strengthening human-nature kinships is by reveal the power and force of nature, a different but related strategy would involve showing “the beauty of the world” (Light, Powell, and Shklovski 2017). I have previously demonstrated through my observation that humans are not most comfortable or fulfilling living in isolation from nature; I have also illustrated that to see the beauty in our strange companions (e.g., weeds, pests, etc.)

[54] https://www.accurat.it/work/brokennature

requires a different kind of noticing and appreciation that differs from the aesthetics and order in industrial agriculture. I call for more engagements in public outreach and education.

Overall, I am in line with Barone and Eisner who argued that "what is hard to experience is a set of numbers. What is comparatively easy to experience is a set of qualities" (2012, xi). To reveal the liveness and agency of nonhuman stakeholders, to render natureculture interdependency, and to strengthen kinship between human and nature, I encourage HCI researchers and design practitioners to move away from data representation models that are overly reductive and to explore alternative strategies that better capture the richness of our bodily experiences.

7.3.3 Harvesting Natural Intelligence

The third design strategy I offer is to "look around" to learn from other world-making entities who reside with us, rather than looking ahead for constant technological progression (Tsing 2015). The strategy of harvesting natural intelligence is not at all a new idea; in fact, many modern innovations were inspired by nature. Biomimicry, for instance, is one of the notable and widely recognized techniques for building nature-inspired projects:

> Nature has evolved systems over billions of years that work in harmony with each other, that build from bare, rocky, thin soil to lush, green forests. Without human intervention the processes of nature have evolved self-regulating forces of beauty, grace, and efficiency. Our challenge is to learn how to honor them and be inspired by their truth to create new cultural values and systems. (Swan and Swan 1994)

However, my observation is that we tend to harvest nature's intelligence on a more superficial level, such as copying the mechanics of gecko feet to produce climbing pads, mirroring the hooks of the burrs to create Velcro, or mimicking the shape of a bird's beak to build highspeed

bullet trains. The design implication I propose here is both about learning the surface *mechanics* and the deep *mechanism* concerning how nature works and sustains as an ecosystem. To better illustrate the differences between these two approaches, let us review to the concept of a "structure-preserving transformation" (Alexander 2002) that I have discussed in Part II (§4.3.5) of this dissertation. In this case, architect Christopher Alexander was interested in creating a "living structure" that responds, evolves, and sustains itself. To achieve so, he turned to search for inspirational mechanisms and patterns in nature, a notable self-sustaining living entity. Through long-term empirical observations, he noticed that when changes take place in the natural environment (e.g., seasonal alternations), "nothing entirely new has been injected—the newness has been created by intensification of what exists" (Alexander 2002, 53). He then proposed design strategies for architects who are interested in creating architectures that are both "pervasive in nature and in deeply satisfying man-made things" (Alexander 2002, 442).

Figure 28. "MUSSELxCHOIR" water quality sensing installation by Natalie Jeremijenko. The design has been installed in New York Pier 35 EcoPark and at Venice Aechitecture Biennale (2012) © Natalie Jeremijenko.

Another design example that harvests natural intelligence on a deeper level is "MUSSELxCHOIR", a water quality monitoring installation that tracks the opening and closing of mussel shells with

sensors[55] (Figure 28). According to environmental scientist and artist Natalie Jeremijenko who designed the installation, mussels are commonly used in water quality monitoring projects because they are highly sensitive to zinc and copper, "they'll quite literally 'clam up' if the water quality is too bad" (Hannah and Jeremijenko 2017). In "MUSSELxCHOIR", the data that tracks mussel behaviors are converted into sound for public display. The design did not involve data sonification techniques; and Jeremijenko this conscious decision in an interview,

> […] there are issues about how a model represents and what it represents, because it can only represent what we already know. Whereas the idea of natural intelligence that I'm trying to iconify with the *MUSSELxCHOIR* is that the mussels themselves are integrating over many parameters that we know and don't know, that we can measure and can't measure. They are actually capturing a certain kind of knowledge through their behavior and making it legible. (Hannah and Jeremijenko 2017)

The idea behind the concept reveals the limitation of human knowledge and ultimately the potential weakness artificial intelligence: environmental sensors and computational models can only, at their best, capture the parameters that we have already known. To illustrate, she asked a simple question, "if an Environmental Protection Agency data set said the water quality was healthy and the mussels died, who would you believe?" To mitigate this knowledge gap, "MUSSELxCHOIR" avoids reducing complex and unpredictable ecological systems to a set of fixed and known parameters. Instead, the installation offers an opportunity for us to engage in

[55] Natalie Jeremijenko does not have a personal website, for more details regarding "MUSSELxCHOIR", please visit its description page on Carbon Arts, a platform that curates creative ideas to shape a more sustainable future. http://www.carbonarts.org/projects/melbourne-mussel-choir/

attentive listening and "to understand data in a biological meaningful way, in terms of how they affect organisms in the environment." (Hannah and Jeremijenko 2017, 209).

To conclude, I encourage HCI researchers and design practitioners to harvest natural intelligence on a deep level by embedding ourselves in the field and learning from nonhuman stakeholders. In Part II of this dissertation, I have proposed the idea of considering the Earth as a "lab" where innovations take place; I have discussed the possibility of building a cross-species environmental sensing platform that tracks how pollutions affect wild species; I have also advocated demystifying artificial intelligence decisions by incorporating machine teaching techniques. Similarly, the design implication of harvesting natural intelligence calls us to look around instead of looking ahead; let us practice attentive listening to discover the unknown patterns and rhythms in nature—let us pay attention to what already exists in the world.

7.3.4 Designing for Resistance and Social Activism

Finally, I would like to share a few thoughts concerning computing ethics and the responsibilities of HCI researchers and designers. To Karan Barad (2007, 384), "ethics is about mattering, about taking account of the entangled materializations of which we are a part, including new configurations, new subjectivities, new possibilities-even the smallest cuts matter." Ethics in a PID agenda is more important than ever, as it is as much as about our personal values as about how we relate to different stakeholders in the world, humans or nonhumans.

Studies have shown that data is never objective or neutral; in fact, according to Bowles, "the choice of what data to collect and what to omit, the technologies we use to collect and process it, and the techniques we use to analyse data are themselves laden with implicit assumptions and biases" (2018, 63). If us designers and technologists fail to handle data with care, they often

end up intensifying social oppression and structural injustice (D'Ignazio and Klein 2020; Noble 2018; Myers West, Whittaker, and Crawford 2019; Hong 2020).

Previously, I have discussed a number of on-going explorations that aim at mitigating unintended biases in big data and AI by facilitating public participation with data (e.g., the "MUSSELxCHOIR" example in the earlier section) or by increasing algorithmic accountability (e.g., explainable AI, machine teaching, etc.). I have also shared examples when big data help expose social injustice, such as revealing instances when certain demographic groups are more susceptible to pollution (i.e., the hypothetical question we asked participants in the air quality study project, "*how does it make you feel if you learn that rich people have better air quality?)*. We can employ analogous approaches toward supporting participation, inclusion, and justice for more nontraditional or marginalized populations, including those who are not humans. For example, how might a machine teaching model look like if we were to include animals and plants as teachers? How might microbes report internet trolls or inappropriate behaviors on social media?

In addition to resistance that happened within the academic community, social activist movements have also become increasing common in technology industry. For example, in 2020, major tech companies including Microsoft, Amazon, and IBM all publicly refused to sell facial recognition technology to the US police department, recognizing the potential harms the technology might cause to human rights (Brewster 2020); additionally, in 2017, many Google executives and employees boycotted the "antidiversity" manifesto which argued that female software engineers are psychologically inferior to their male colleagues[56] (Matsakis 2017). As we now recognize the fact that algorithmic bias is a result of the structural oppression that is deeply

[56] The software engineer James Damore who initiated the "antidiversity" manifesto was reported fired by Google as a result of "perpetuating gender stereotypes." Source: https://www.bloomberg.com/news/articles/2017-08-08/google-fires-employee-behind-controversial-diversity-memo

rooted in our society, the focus should no longer about *fixing* the problem but *surfacing* and *resisting* inequalities and injustice. We can use data to reveal systematic oppression and injustice; we can design tools to help organize social activist movements.

We need resistance in all dimensions—including implementing them into policies and regulations. A recent example includes Apple's decision on excluding earbuds and power adapter in their iPhone 12 packaging. Lisa Jackson, vice president of Apple's Environment, Policy, and Social initiatives explained this decision during the iPhone launch event, "there are also over 2 billion Apple power adapters out there in the world, and that's not counting the billions of third-party adapters. We're removing these items from the iPhone box, which reduces carbon emissions and avoids the mining and use of precious materials." She further claimed that by removing the power adapter, Apple can both significantly reduce the materials that went into producing the packages and the environmental impact of shipping (Chokkattu 2020).

On the surface level, excluding a power adapter seemed to be a sensible and environmentally friendly decision. However, the fact is that the charging cable that comes with iPhone 12 is a Lightning-to-USB-C cable (with the Lightning end plugged into iPhone and the USB-C side plugged into the power adapter), which is not compatible with any charger used by any previous iPhone model[57]. As a result, consumers who purchase the new iPhone model most likely will also have to purchase a compatible power adapter; the power adapter will come in a separate box and requires additional shipping—a result that goes the extreme opposite considering Apple's claim to be environmentally friendly[58].

[57] The previous models that came before iPhone 12 all used power adapters with a USB (instead of USB-C) outlet.
[58] Read more about Apple's environmental claims and plans at https://www.apple.com/environment/

There were resistances and public pushbacks. For example, the European Union (EU) pressured Apple to change the Lightning outlet on their iPhone 12 to a USB-C port to comply with the charging standard and to reduce electronic waste by ensuring "that EU consumers are no longer obliged to buy new chargers with each new device" (Hardwick 2020). Although Apple eventually went against EU's wish, the company was forced to include free earbuds for its France market to comply with its radiation law: "any object containing radio equipment cannot be distributed for payment or free of charge without a wired, solid and reliable headset" (Dent 2020).

Regardless of how my criticisms may seem, I do not intend to target Apple but to call for more regulatory and legislative enforcements. As climate change intensifies, almost all major tech companies—Apple, Google, Facebook, Amazon, Microsoft, and so on—have their sustainability claims in place and are now committed to achieve carbon neutral/negative within the next decade (Hern 2020). I believe that sustainability should not be a business slogan, nor should it be utilized as a marketing tool toward supporting profits. As HCI researchers and designers, we can design to raise public awareness toward demanding companies meeting their sustainable goals or advocate the installation of necessary laws and measurements for sustainability assessment. We need resistance from all directions to win this fight.

7.4 Concluding Remarks

> Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry human beings pursue in the world, with the world, and with each other. (Freire 1970, 72)

To explore strategies for HCI researchers and designers to integrate a broader range of species as stakeholders, I conducted three intertwined design and ethnographic fieldwork that traced different instances of human-nature encounters, ranged from collaborative to competitive and

conflicting ones. Posthumanism and its critique of anthropocentrism is the underlying theoretical foundation that drove the observation and analysis of this dissertation. In sum, this work explores and posthuman interaction design (PID) as an alternative paradigm that challenges the agenda of human-centered design and seeks to amplify the agency of different species to support more sustainable, inclusive, and aesthetic forms of human-nature interaction.

Through three intertwined ethnographic and design field studies, this dissertation contributes to the development of HCI theories and methods which offer implications for system development, design pedagogy, evaluation criteria, future research, design ethics, social activism, and policy reform—the various implications are outlined in the previous sections throughout this chapter. Ultimately, my goal is to demonstrate that posthumanism, regardless of how counter-intuitively it seems to align with the paradigm of human-centered design on the surface, is in fact deeply relevant and complementary to HCI and its long-term commitment to understand, represent, and support the "users." To conclude, I suggest HCI researchers and designers who are interested in attending to and incorporating nonhuman stakeholders in design to focus on cultivating a space for human-nature co-creation, collaboration, and cohabitation. This might be done in three different ways: using the alternative design process of scaffolding to support participatory design and democratize innovation; cultivating compassion, care, and respect towards nature by developing multisensory data processing models that represent nature as affectionate living entities rather than as a series of data points or numbers; and foregrounding human-nature interdependency by carefully consider the socioenvironmental impacts that our designs might have toward nonhuman stakeholders—and ultimately to ourselves as well.

7.5 Coda: Towards a Posthuman Design Orientation

As I left my former position as a hardware product designer in an international electronics firm, my goal was to explore a space where technological interventions are committed to the sustainment of different life forms and the creation of more inclusive and resilient futures. On a broader level, this dissertation is motivated by critique of anthropocentrism and capitalism, as well as concerns on climate change and technology obsolescence. As Architect R. Buckminster Fuller argued that to be a designer, "you have to make up your mind either to make sense or to make money" (Papanek 1972, 86), we seem to always being forced to choose between two opposing extremes: to support economic growth or to sustain the environment; to design for our own benefit or to design for social good; to be, or not to be? To me, this question very much resembles many economic-environmental dilemmas and conflicts we are currently facing, and I am inclined to believe that the choice between making money and making sense need not to be a "*either, or*" but a "*and, and*" question. Put it in mathematical terms, the choice should not be a dichotomy between 0 and 1 (although the computer only recognizes *either* 0 *or* 1), but a continuum that encompasses an infinite choices between the number 0 and 1. At the minimum, I would argue that to survive and thrive in the Anthropocene, we need to explore strategies when making a choice does not lead us to existential crisis that lay at both ends.

To illustrate, let me use the Land Dyke farmers' story as an example. As I have described in the previous sections, the Land Dyke farmers faced a hard decision where they had to choose between (1) losing their entire citrus orchard to scale insects, risking the nearby orchards and the livelihood of their neighboring farmers, or (2) apply chemical pesticides on to the citrus trees—which was deeply against their commitment towards eco-friendly farming—in order to control the infection. At the end, this tragic incidence led the Land Dyke farmers to reflect what eco-friendly farming really means to them. They concluded that one does not necessarily need

to jeopardize their livelihood, and that being eco-friendly is not a "*either, or*" question, but a constant process that involves the practice of attentive listening and the cultivation of intimacy toward Mother Nature.

Building on feminist STS scholar Maria Puig de la Bellacasa (2017, 189) who wote, "soil is not just a habitat or medium for plants and organisms; nor is it just decomposed material, the organic and mineral end product of organism activity. Organisms *are* soil. A lively soil can only exist with and through a multispecies community of biota that *makes* it, that contributes to its creation." My invitation to HCI researchers and designers, then, is to position ourselves as companion species (not as a dominator or a parasite) to Mother Nature, and to consider the act of designing as scaffolding assemblages or as composing soil (rather than drawing boundaries) with the animals, plants, and microbes who are always with us, whose contributions to this piece of scholarship have always been and will remain under-recognized until we are willing to listen.

References

Abram, David. 1997. *The Spell of the Sensuous: Perception and Language in a More-Than-Human World*. Twentieth. Vintage.

Adams, Catherine, and Terrie L. Thompson. 2016. *Researching a Posthuman World: Interviews with Digital Objects*. Springer Nature.

Adams, W. M. 2003. *Future Nature: A Vision for Conservation*. London: Earthscan Publications.

"Air Pollution Sources." 2019. *European Environmental Agency*. https://www.eea.europa.eu/themes/air/air-pollution-sources-1.

Alba-Lois, Luisa, and Claudia Segal-Kischinevzky. 2010. "Yeast Fermentation and the Making of Beer and Wine." *Nature Education* 3 (9): 17. https://www.nature.com/scitable/topicpage/yeast-fermentation-and-the-making-of-beer-14372813.

Alexander, Christopher. 2002. *The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*. 1st ed. Center for Environmental Structure.

Anderson, Bob. 1997. "Work, Ethnography and System Design." *The Encyclopedia of Microcomputing* 20: 159–83.

Aoki, Paul M, R J Honicky, Alan Mainwaring, Chris Myers, Eric Paulos, Sushmita Subramanian, and Allison Woodruff. 2009. "A Vehicle for Research: Using Street Sweepers to Explore the Landscape of Environmental Community Action." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '09*, 375–84.

Aoki, Paul, Allison Woodruff, Baladitya Yellapragada, and Wesley Willett. 2017. "Environmental Protection and Agency: Motivations, Capacity, and Goals in Participatory Sensing." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '17*, 3138–50.

Aspling, Fredrik, Jinyi Wang, and Oskar Juhlin. 2016. "Plant-Computer Interaction, Beauty and Dissemination." In *Proceedings of the Third International Conference on Animal-Computer Interaction - ACI '16*, 1–10.

Awori, Kagonya, Frank Vetere, and Wally Smith. 2015. "Transnationalism, Indigenous Knowledge and Technology: Insights from the Kenyan Diaspora." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '15*, 3759–68.

Bai, Xuemei, Sander Van Der Leeuw, Karen O Brien, Frans Berkhout, Frank Biermann, Eduardo S Brondizio, Christophe Cudennec, et al. 2016. “Plausible and Desirable Futures in the Anthropocene : A New Research Agenda.” *Global Environmental Change* 39: 351–62.

Ballard, Stephanie, Karen M. Chappell, and Kristen Kennedy. 2019. “Judgment Call the Game: Using Value Sensitive Design and Design Fiction to Surface Ethical Concerns Related to Technology.” In *Proceedings of the 2019 on Designing Interactive Systems Conference - DIS’19*, 421–33.

Barad, Karen. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Duke University Press.

———. 2010. “Quantum Entanglements and Hauntological Relations of Inheritance: Dis/Continuities, SpaceTime Enfoldings, and Justice-to-Come.” *Derrida Today* 3 (2): 240–68.

Bardzell, Jeffrey. 2011. “Interaction Criticism: An Introduction to the Practice.” *Interacting with Computers* 23 (6): 604–21.

Bardzell, Jeffrey, and Shaowen Bardzell. 2013. “What Is ‘Critical’ about Critical Design?” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’13*, 3297–3306.

———. 2015a. *Humanistic HCI*. Morgan and Claypool.

———. 2015b. “The User Reconfigured: On Subjectivities of Information.” In *Proceedings of The Fifth Decennial Aarhus Conference on Critical Alternatives*, 133–44.

Bardzell, Jeffrey, Shaowen Bardzell, and Mark Blythe, eds. 2018. *Critical Theory and Interaction Design*. Cambridge, MA; London, England: The MIT Press.

Bardzell, Jeffrey, Shaowen Bardzell, and Lone Koefoed Hansen. 2015. “Immodest Proposals: Research Through Design and Knowledge.” In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI ’15*, 1:2093–2102.

Bardzell, Jeffrey, Shaowen Bardzell, and Silvia Lindtner. 2019. “Some Things about Innovation.” In *Bauhaus Futures*, edited by Laura Forlano, Molly Wright Steenson, and Mike Ananny, 3:1. The MIT Press.

Bardzell, Shaowen. 2010. “Feminist HCI: Taking Stock and Outlining an Agenda for Design.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’10*, 2:1301–10.

———. 2018. “Utopias of Participation: Feminism, Design, and the Futures.” *ACM Transactions on Computer-Human Interaction - TOCHI* 25 (1): 6:1-6:24.

Bardzell, Shaowen, and Jeffrey Bardzell. 2011. “Towards a Feminist HCI Methodology: Social Science, Feminism, and HCI.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’11*, 675–84.

Bardzell, Shaowen, Jeffrey Bardzell, and Sarah Ng. 2017. “Supporting Cultures of Making: Technology, Policy, Visions , and Myths.” In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI ’17*, 6523–35.

Barone, Tom, and Elliot W Eisner. 2012. *Arts Based Research*. Sage.

Barricelli, Barbara Rita, Gerhard Fischer, Daniela Fogli, Anders Mørch, Antonio Piccinno, and Stefano Valtolina. 2016. “Cultures of Participation in the Digital Age: From ‘Have to’ to ‘Want to’ Participate.” In *Proceedings of the 9th Nordic Conference on Human-Computer Interaction - NordiCHI ’16*, 128:1-128:3.

Baskin, Sofya, and Anna Zamansky. 2015. “The Player Is Chewing the Tablet! Towards a Systematic Interpretation of User Behavior in Animal-Computer Interaction.” *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play - CHI PLAY 2015*, 463–68.

Baumer, Eric P. S., and Jed R. Brubaker. 2017. “Post-Userism.” In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI ’17*, 6291–6303.

Baumer, Eric P S. 2015. “Reflective Informatics: Conceptual Dimensions for Designing Technologies of Reflection.” In *Proceedings of the 2015 CHI Conference on Human Factors in Computing Systems - CHI ’15*, 585–94.

Baumer, Eric P S, Vera Khovanskaya, Mark Matthews, Lindsay Reynolds, Victoria Schwanda Sosik, and Geri Gay. 2014. “Reviewing Reflection: On the Use of Reflection in Interactive System Design.” In *Proceedings of the 2014 Conference on Designing Interactive Systems - DIS ’14*, 93–102.

Bell, Genevieve, Mark Blythe, and Phoebe Sengers. 2005. “Making by Making Strange: Defamiliarization and the Design of Domestic Technologies.” *ACM Transactions on Computer-Human Interaction* 12 (2): 149–73.

Bennett, Jane. 2011. *Vibrant Matter: A Political Ecology of Things*. Duke University Press.

Bentley, Frank, Henriette Cramer, William Hamilton, and Santosh Basapur. 2012. “Drawing the City: Differing Perceptions of the Urban Environment.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’12*, 1603–6.

Blevis, Eli. 2007. “Sustainable Interaction Design: Invention & Disposal, Renewal & Reuse.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems -*

CHI '07, 503–12.

———. 2016. "Being Photo-Visual in HCI and Design." In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems - DIS '16*, 983–95.

———. 2018. "Seeing What Is and What Can Be: On Sustainability, Respect for Work, and Design for Respect." In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*, 370:1-370:14.

Blevis, Eli, and Susan Coleman Morse. 2009. "Sustainably Ours: Food, Dude." *Interactions*, 2009.

Blevis, Eli, William Odom, and Sabrina Hauser. 2015. "Sharing The Hidden Treasure in Pictorials." *Interactions*, 32–43.

Bobbink, Roland, Michael Hornung, and Jan G M Roelofs. 1998. "The Effects of Air-Borne Nitrogen Pollutants on Species Diversity in Natural and Semi-Natural European Vegetation." *Journal of Ecology* 86 (5): 717–38.

Bødker, Susanne. 2006. "When Second Wave HCI Meets Third Wave Challenges." In *Proceedings of the 4th Nordic Conference on Human-Computer Interaction - NordiCHI '06*, 1–8.

Boelhouwer, Atelier. n.d. "Insectology Food for Buzz." Accessed October 30, 2020. http://www.matildeboelhouwer.com/insectology-food-for-buzz/.

Boellstorff, Tom, Bonnie Nardi, Celia Pearce, and T.L. Taylor. 2012. *Ethnography and Virtual Worlds: A Handbook of Method*. Princeton University Press.

Borning, Alan, and Michael Muller. 2012. "Next Steps for Value Sensitive Design." In *Proceedings of the 2012 CHI Conference on Human Factors in Computing Systems - CHI '12*, 1125–34.

Bowles, Cennydd. 2018. *Future Ethics*. NowNext Press.

Braidotti, Rosi. 2016. "Posthuman Critical Theory." In *Critical Posthumanism and Planetary Futures*, edited by Debashish Banerji and Makarand R. Paranjape, 13–32. Springer.

———. 2017. "Four Theses on Posthuman Feminism." In *Anthropocene Feminism*, edited by Richard Grusin, 21–48. University of Minnesota Press.

Brereton, Margot, Paul Roe, Ronald Schroeter, and Anita Lee Hong. 2014. "Beyond Ethnography: Engagement and Reciprocity as Foundations for Design Research Out Here." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '14*, 1183–86.

Brewster, Thomas. 2020. "Microsoft Won't Sell Facial Recognition To American Cops After

Protests." Forbes. 2020. https://www.forbes.com/sites/thomasbrewster/2020/06/11/microsoft-wont-sell-facial-recognition-to-american-cops-after-protests/?sh=53ec1db9bb15.

Brondizio, Eduardo S, Karen O Brien, Xuemei Bai, Frank Biermann, Will Steffen, Frans Berkhout, Christophe Cudennec, et al. 2016. "Re-Conceptualizing the Anthropocene: A Call for Collaboration." *Global Environmental Change* 39: 318–27.

Brown, Barry, Julian Bleecker, Marco D'Adamo, Pedro Ferreira, Joakim Formo, Mareike Glöss, Maria Holm, et al. 2016. "The IKEA Catalogue: Design Fiction in Academic and Industrial Collaborations." In *Proceedings of the 19th International Conference on Supporting Group Work - GROUP '16*, 335–44.

Brown, Dustin. 2019. "'Casa De Carne': My Short Film That Explores A Restaurant Where Customers Have To Kill Their Own Food." 2019. https://www.boredpanda.com/casa-de-carne-short-film-animal-rights-dustin-brown/?utm_source=google&utm_medium=organic&utm_campaign=organic.

Brown, Tim, and Barry Katz. 2011. "Change by Design." *The Journal of Product Innovation Management* 28: 381–83.

Brown, Tim, and Jocelyn Wyatt. 2010. "Design Thinking for Social Innovation." *Stanford Social Innovation Review*, July 2010.

Brummett, Barry S. 2009. *Techniques of Close Reading*. SAGE Publications.

Brynjarsdottir, Hronn, Maria Håkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. 2012. "Sustainably Unpersuaded: How Persuasion Narrows Our Vision of Sustainability." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '12*, 947–56.

Buchanan, Richard. 1992. "Wicked Problems in Design Thinking." In *Design Issues*, 8:5–21.

Burns, Brian. 2010. "Re-Evaluating Obsolescence and Planning for It." In *Longer Lasting Products: Alternatives to the Throwaway Society*, edited by Tim Cooper, 39–60. Gower Publishing Limited.

Bytnerowicz, Andrzej, Kenji Omasa, and Elena Paoletti. 2007. "Integrated Effects of Air Pollution and Climate Change on Forests: A Northern Hemisphere Perspective." *Environmental Pollution* 147 (3): 438–45.

Carson, Rachel. 2002. *Silent Spring*. Anniversar. Houghton Mifflin Company.

Carspecken, Francis Phil. 1996. *Critical Ethnography in Educational Research: A Theoretical and Practical Guide*. Routledge.

Chakraborty, Tusher, Taslim Arefin Khan, Mahmuda Naznin, Chowdhury Sayeed Hyder, and A B M Islam. 2016. “What We Breathe As We Commute: From the Perspective of a Developing Country.” In *Proceedings of the 7th Annual Symposium on Computing for Development - ACM DEV ’16*, 19:1-19:4.

Chang, Shenglin Elijah. 2013. “Blue Magpie TEAgriculture: Eco-Tea Cultivation and Participatory Farming in Pinglin Satoyama, Taiwan.” *Procedia - Social and Behavioral Sciences* 101: 14–22.

Chen, Ling-Jyh, Wuulong Hsu, Ming Wei Cheng, and Hu Cheng Lee. 2016. “Demo: LASS: A Location-Aware Sensing System for Participatory PM2. 5 Monitoring.” In *Proceedings of the 14th Annual International Conference on Mobile Systems, Applications, and Services Companion -MobiSys ’16 Companion*, 98.

Chen, Xinlei, Xiangxiang Xu, Xinyu Liu, Shijia Pan, Jiayou He, Hae Young Noh, Lin Zhang, and Pei Zhang. 2018. “PGA: Physics Guided and Adaptive Approach for Mobile Fine-Grained Air Pollution Estimation.” In *Proceedings of the 2018 ACM International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers - UbiComp ’18*, 1321–30.

Choi, Jaz Hee-jeong, and Eli Blevis. 2010. “HCI & Sustainable Food Culture: A Design Framework for Engagement.” In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction - NordiCHI ’10*, 112–117.

Choi, Jaz Hee-jeong, Marcus Foth, and Greg Hearn, eds. 2014. *Eat, Cook, Grow: Mixing Human-Computer Interactions with Human-Food Interactions*. The MIT Press.

Chokkattu, Julian. 2020. “The IPhone 12 Ships Without a Charger. Will It Curb E-Waste?” Wired. 2020. https://www.wired.com/story/apple-iphone-no-charger-gallium-nitride/.

Clarke, Alison J., ed. 2011. *Design Anthropology: Object Culture in the 21st Century*. Angewandte. Wien, NewYork: Springer.

Clarke, Rachel, Sara Heitlinger, Ann Light, Laura Forlano, Marcus Foth, and Carl DiSalvo. 2019. “More-Than-Human Participation: Design for Sustainable Smart City Futures.” *Interactions* 26 (3): 60–63.

Cleghern, Zach, Evan Williams, Sean Mealin, Marc Foster, Timothy Holder, Alper Bozkurt, and David L. Roberts. 2019. “An IoT and Analytics Platform for Characterizing Adolescent Dogs’ Suitability for Guide Work.” In *Proceedings of the Sixth International Conference on Animal-Computer Interaction - ACI’19*, 1:1-1:6.

Collier, Stephen J. 2006. “Global Assemblages.” *Theory, Culture & Society* 23 (2–3): 400.

Collier, Stephen J., and Aihwa Ong. 2008. “Global Assembladges, Anthropological Problems.” In *Global Assemblages: Technology, Politics, and Ethics as Anthropological Problems*, edited by Aihwa Ong and Stephen J. Collier. Wiley-Blackwell.

Comber, Rob, and Anja Thieme. 2013. “Designing beyond Habit: Opening Space for Improved Recycling and Food Waste Behaviors through Processes of Persuasion, Social Influence and Aversive Affect.” *Personal and Ubiquitous Computing* 17 (6): 1197–1210.

Cooper, Geoff, and John Bowers. 1995. “Representing the User: Notes on the Disciplinary Rhetoric of Human-Computer Interaction.” In *The Social and Interactional Dimensions of Human-Computer Interfaces*, 48–65. New York: Cambridge University Press.

Costanza, Enrico, Sarvapali D Ramchurn, and Nicholas R Jennings. 2012. “Understanding Domestic Energy Consumption through Interactive Visualisation: A Field Study.” In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing - UbiComp ’12*, 216–25.

Cranshaw, Justin, Raz Schwartz, Jason Hong, and Norman Sadeh. 2012. “The Livehoods Project: Utilizing Social Media to Understand the Dynamics of a City.” In *Sixth International AAAI Conference on Weblogs and Social Media - ICWSM’12*, 58–68.

Crivellaro, Clara, Rob Comber, Martyn Dade-Robertson, Simon J. Bowen, Peter Wright, and Patrick Olivier. 2015. “Contesting the City: Enacting the Political Through Digitally Supported Urban Walks.” In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI ’15*, 2853–62.

Cross, Nigel. 1982. “Designerly Ways of Knowing.” *Design Studies* 3 (4): 221–27.

———. 2006. *Designerly Ways of Knowing*. Springer.

Crutzen, Paul J. 2002. “Geology of Mankind.” *Nature* 415 (6867): 23.

Cuff, Dana, Mark Hansen, and Jerry Kang. 2008. “Urban Sensing: Out of the Woods.” *Communications of the ACM* 51 (3): 24–33.

Currie, Janet, Eric A Hanushek, E Megan Kahn, Matthew Neidell, and Steven G Rivkin. 2009. “Does Pollution Increase School Absences?” *The Review of Economics and Statistics* 91 (4): 682–94.

D’Ignazio, Catherine, Alexis Hope, Becky Michelson, Robyn Churchill, and Ethan Zuckerman. 2016. “A Feminist HCI Approach to Designing Postpartum Technologies: ”When I First Saw a Breast Pump I Was Wondering If It Was a Joke.”.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’16*, 2612–22.

D’Ignazio, Catherine, and Lauren F Klein. 2020. *Data Feminism*. MIT Press.

Daniele, Quercia, Rossano Schifanella, Luca Maria Aiello, Mclean Kate, and others. 2015. "Smelly Maps: The Digital Life of Urban Smellscapes." In *International Conference on Web and Social Media (ICWSM)*, 327–36.

David E. Williams. 2006. "Predators, Humans Sharing Habitats a Volatile Mix." CNN.Com. 2006. http://www.cnn.com/2006/TECH/science/05/30/animal.attacks/index.html.

Dell, Nicola, and Neha Kumar. 2016. "The Ins and Outs of HCI for Development." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '16*, 2220–32.

Dennis, Barbara. 2018. "Validity as Research Praxis: A Study of Self-Reflection and Engagement in Qualitative Inquiry." *Qualitative Inquiry* 24 (2): 109–18.

Dennis, Barbara, Suraj Uttamchandani, Spencer Biery, and Aubrie Blauvelt. 2019. "LGBTQIA+ Youth as Multicultural Educators." *Ethnography and Education* 14 (3): 360–76.

Dent, Steve. 2020. "IPhone 12 Comes with Free EarPods in France Thanks to Radiation Laws." *Engadget*. https://www.engadget.com/apple-iphone-12-france-earpods-included-122501246.html.

DeSilvey, Caitlin. 2006. "Observed Decay: Telling Stories with Mutable Things." *Journal of Material Culture* 11 (3): 318–38.

Despret, Vinciane. 2016. *What Would Animals Say If We Asked the Right Questions?* University of Minnesota Press.

Devarakonda, Srinivas, Parveen Sevusu, Hongzhang Liu, Ruilin Liu, Liviu Iftode, and Badri Nath. 2013. "Real-Time Air Quality Monitoring through Mobile Sensing in Metropolitan Areas." In *Proceedings of the 2nd ACM SIGKDD International Workshop on Urban Computing - UrbComp '13*, 15:1-15:8.

Devendorf, Laura, and Daniela K. Rosner. 2015. "Reimagining Digital Fabrication as Performance Art." In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '15*, 555–66.

Devendorf, Laura, and Daniela K Rosner. 2017. "Beyond Hybrids: Metaphors and Margins in Design." In *Proceedings of the 2017 Conference on Designing Interactive Systems - DIS '17*, 995–1000.

Devendorf, Laura, 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 - CHI '15*, 2477–86.

Dew, Kristin N., 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 - CHI '18*, 585:1-585:12.

Dewey, John. 1934. *Art as Experience*. Southern Illinois University Press.

Dillahunt, Tawanna R. 2014. "Fostering Social Capital in Economically Distressed Communities." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '14*, 531–40.

Disalvo, Carl, Kirsten Boehner, and Nicholas A Knouf. 2009. "Nourishing the Ground for Sustainable HCI: Considerations from Ecologically Engaged Art." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '09*, 385–94.

DiSalvo, Carl, Ann Light, Tad Hirsch, Christopher A. Le Dantec, Elizabeth Goodman, and Katie Hill. 2010. "HCI, Communities and Politics." In *CHI '10 Extended Abstracts on Human Factors in Computing Systems - CHI EA '10*, 3151–54.

DiSalvo, Carl, and Jonathan Lukens. 2009. "Seeing the City Through Machines: Non-Anthropocentric Design and Youth Robotics." In *Digital Cities 6: Concepts, Methods and Systems of Urban Informatics (Workshop)*, edited by Marcus Foth, Laura Forlano, and Hiromitsu Hattori. State College: Penn State University Press.

———. 2011. "Nonanthropocentrism and the Nonhuman in Design: Possibilities for Designing New Forms of Engagement with and through Technology." In *From Social Butterfly to Engaged Citizen: Urban Informatics, Social Media, Ubiquitous Computing, and Mobile Technology to Support Citizen Engagement*, edited by Marcus Foth, Judith Donath, and Laura Forlano, 421–36. MIT Press.

DiSalvo, Carl, Phoebe Sengers, and Hrönn Brynjarsdóttir. 2010. "Mapping the Landscape of Sustainable HCI." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '10*, 1975–84.

Dombrowski, Lynn, Ellie Harmon, and Sarah Fox. 2016. "Social Justice-Oriented Interaction Design: Outlining Key Design Strategies and Commitments." In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems - DIS '16*, 656–71.

"Dongfang Meiren." n.d. Wikipedia. Accessed January 28, 2018. https://en.wikipedia.org/wiki/Dongfang_Meiren.

Dooren, Thom van, Eben Kirksey, and Ursula Münster. 2016. "Multispecies Studies: Cultivating Arts of Attentiveness." *Environmental Humanities* 8 (1): 1–23.

Dourish, Paul. 2006. "Implications for Design." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '06*, 541–50.

———. 2007. “Responsibilities and Implications: Further Thoughts on Ethnography and Design.” In *Proceedings of the 2007 Conference on Designing for User EXperiences-DUX ’07*, 25:1-25:16.

———. 2010. “HCI and Environmental Sustainability: The Politics of Design and the Design of Politics.” In *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS ’10*, 1–10.

———. 2014. “Reading and Interpreting Ethnography.” In *Ways of Knowing in HCI*, edited by Judith S. Olson and Wendy A. Kellogg, 1–24. Springer.

Dourish, Paul, and Gómez Edgar Cruz. 2018. “Datafication and Data Fiction: Narrating Data and Narrating with Data.” *Big Data & Society* 5 (2): 1–10.

Dourish, Paul, Janet Finlay, Phoebe Sengers, and Peter Wright. 2004. “Reflective HCI: Towards a Critical Technical Practice.” In *CHI ’04 Extended Abstracts on Human Factors in Computing Systems - CHI EA ’04*, 1727–28.

Dourish, Paul, and Scott D Mainwaring. 2012. “Ubicomp’s Colonial Impulse.” In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing - UbiComp ’12*, 133–42.

Dunne, Anthony, and Fiona Raby. 2001. *Design Noir: The Secret Life of Electronic Objects*. Birkhauser.

———. 2013. *Speculative Everything: Design, Fiction, and Social Dreaming*. MIT press.

Dutta, Prabal, Paul M Aoki, Neil Kumar, Alan Mainwaring, Chris Myers, Wesley Willett, and Allison Woodruff. 2009. “Common Sense: Participatory Urban Sensing Using a Network of Handheld Air Quality Monitors.” In *Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems - SenSys ’09*, 349–50.

Erete, Sheena, and Jennifer O. Burrell. 2017. “Empowered Participation: How Citizens Use Technology in Local Governance.” In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI ’17*, 2307–19.

Erickson, Ingrid, Libby Hemphill, Amanda Menking, and Stephanie Steinhardt. 2016. *On the Production of the Spirit of Feminism*. *Interactions*. Vol. 23.

Escobar, Arturo. 2018. *Designs for the Pluriverse: Radical Interdependence, Autonomy, and the Making of Worlds*. Duke University Press.

Farris, Val Jon. 2014. “From Broken to Beautiful: The Power of ‘Kintsugi.’” The Huffington Post. 2014. http://www.huffingtonpost.com/val-jon-farris/from-broken-to-beautiful-_b_5903994.html.

Featherstone, David, and Joe Painter. 2013. “Spatial Politics.” *Essays for Doreen Massey*.

Fogg, BJ. 2009. “Creating Persuasive Technologies: An Eight-Step Design Process.” In *Persuasive’09*, 91:1–6.

Food and Agriculture Organization of the United Nations. 2018. “The State of Food Security and Nutrition in the World.” Rome. http://www.fao.org/state-of-food-security-nutrition/en/.

Forlano, Laura. 2016. “Decentering the Human in the Design of Collaborative Cities.” *Design Issues* 32 (3): 42–54.

———. 2017. “Posthumanism and Design.” *She Ji The Journal of Design, Economics, and Innovation* 3 (1): 16–29.

Forlizzi, Jodi. 2018. “Moving Beyond User-Centered Design.” *Interactions* 25 (5): 22–23.

Freeman, Guo, Jeffrey Bardzell, and Shaowen Bardzell. 2017. “Aspirational Design and Messy Democracy: Partisanship, Policy, and Hope in an Asian City.” In *Proceedings of the ACM Conference on Computer Supported Cooperative Work - CSCW ’17*, 404–16.

Freeman, Guo, Jeffrey Bardzell, Shaowen Bardzell, Szu-Yu (Cyn) Liu, Xi Lu, and Diandian Cao. 2019. “Smart and Fermented Cities: An Approach to Placemaking in Urban Informatics.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’19*, 44:1-44:13.

Freeman, Guo, Shaowen Bardzell, and Jeffrey Bardzell. 2018. “Bottom-Up Imaginaries: The Cultural-Technical Practice of Inventing Regional Advantage through IT R&D.” In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI ’18*, 325:1-325:11.

Freire, Paulo. 1970. *Pedagogy of the Oppressed*. *The Applied Theatre Reader*. The Continuum International Publishing Group Inc.

French, Fiona, Sofya Baskin, Billy Wallace, Adrian David Cheok, Anna Zamanzky, and Eleonora Nannoni. 2017. “FarmJam 2017: Designing Enrichment for Farm Animals.” In *Proceedings of the Fourth International Conference on Animal-Computer Interaction - ACI ’17*, 21:1-21:6.

French, Fiona, Clara Mancini, and Helen Sharp. 2016. “Exploring Methods for Interaction Design with Animals: A Case-Study with Valli.” In *Proceedings of the Third International Conference on Animal-Computer Interaction - ACI ’16*, 3:1-3:5.

Fry, Tony. 2010. *Design Futuring: Sustainability, Ethics and New Practice*. Bloomsbury.

Galloway, Anne. 2013. “Towards Fantastic Ethnography and Speculative Design.” Ethnography Matters. 2013. http://ethnographymatters.net/blog/2013/09/17/towards-fantastic-ethnography-and-speculative-design/.

Ganglbauer, Eva, Geraldine Fitzpatrick, and Rob Comber. 2013. “Negotiating Food Waste: Using a Practice Lens to Inform Design.” *ACM Transactions on Computer-Human Interaction - TOCHI* 20 (2): 11:1-11:25.

Gatto, Gionata, and John R. McCardle. 2019. “Multispecies Design and Ethnographic Practice: Following Other-Than-Humans as a Mode of Exploring Environmental Issues.” *Sustainability (Switzerland)* 11 (18).

Gaver, Bill; Dunne, Tony; Pacenti, Elena. 1999. “Design: Cultural Probes.” *Interactions*, 1999.

Gaver, William. 2012. “What Should We Expect From Research Through Design?” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’12*, 937–46.

Giaccardi, Elisa, Elvin Karana, Holly Robbins, and Patrizia D’Olivo. 2014. “Growing Traces on Objects of Daily Use.” In *Proceedings of the 2014 Conference on Designing Interactive Systems - DIS ’14*, 473–82.

Gibbens, Sarah. 2019. “Why California Deserts Are Experiencing a ‘Super Bloom’?” National Graphic. 2019. https://www.nationalgeographic.com/news/2017/03/california-desert-anza-borrego-super-bloom/.

Given, Lisa M, Denise Cantrell Winkler, and Kathryn Hopps-Wallis. 2017. “Social Media for Social Good: A Study of Experiences and Opportunities in Rural Australia.” In *Proceedings of the 8th International Conference on Social Media & Society - #SMSociety17*, 1:1-1:7.

Gomes, Carla, Thomas Dietterich, Christopher Barrett, Jon Conrad, Bistra Dilkina, Stefano Ermon, Andrew Farnsworth, et al. 2019. “Computational Sustainability: Computing for a Better World and a Sustainable Future.” *Communications of the ACM* 62 (9).

Gongora, Daniela Azumendi, Juan Jose Diaz Baquero, Juan Felipe Franco, and Ivan Mura. 2018. “Simulation to Predict Cyclists’ Exposure to Air Pollution Along Bikeways.” In *2018 Winter Simulation Conference (WSC)*, 2387–98.

Goodling, Erin, and Cameron Herrington. 2015. “Reversing Complete Streets Disparities: Portland’s Community Watershed Stewardship Program.” In *Incomplete Streets: Processes, Practices, and Possibilities*, edited by Stephen Zavestoski and Julian Agyeman, 176–202. Routledge.

Goodman, Elizabeth, Mike Kuniavsky, and Andrea Moed. 2012. *Observing the User Experience: A Practitioner’s Guide to User Research*. 2nd ed. Morgan Kaufmann.

Green&Blue. 2015. “Bees Block.” 2015. https://www.greenandblue.co.uk/products/bees-block.

Grusin, Richard, ed. 2017. *Anthropocene Feminism*. University of Minnesota Press.

Guin, Ursula K Le. 2009. “The Critics, the Monsters, and the Fantasists.” In *Cheek by Jowl*, 25–42. Seattle, WA: Aqueduct Press.

Gulia, Sunil, S M Shiva Nagendra, Mukesh Khare, and Isha Khanna. 2015. “Urban Air Quality Management-A Review.” *Atmospheric Pollution Research* 6 (2): 286–304.

Gunn, Wendy, Ton Otto, and Rachel Charlotte Smith, eds. 2013. *Design Anthropology: Theory and Practice*. Bloomsbury Academic.

Gutiérrez Borrero, Alfredo. 2015. “Resurgimientos: Sures Como Diseños y Diseños Otros.” *Nómadas*, no. 43: 113–29.

Habermas, Jurgen. 1984. *The Theory of Communicative Action Volume One: Reason and The Rationalization of Society*. Beacon Press.

———. 1985. *The Theory of Communicative Action, Volume Two: Lifeworld and System: A Critique of Functionalist Reason*. Beacon Press.

Håkansson, Maria, and Phoebe Sengers. 2013. “Beyond Being Green: Simple Living Families and ICT.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’13*, 2725–34.

Halpin, Zuleyma Tang. 1989. “Scientific Objectivity and the Concept of ‘the Other.’” *Women’s Studies International Forum* 12 (3): 285–94.

Halse, Joachim. 2013. “Ethnographies of the Possible.” *Design Ethnography: Theory and Practice*, 180–96.

Hamilton, Isobel Asher. 2018. “Amazon Built an AI Tool to Hire People but Had to Shut It down Because It Was Discriminating against Women.” Business Insider. 2018. https://www.businessinsider.com/amazon-built-ai-to-hire-people-discriminated-against-women-2018-10.

Hamilton, Lindsay, and Nik Taylor. 2017. *Ethnography after Humanism: Power, Politics and Method in Multi-Species Research*. London: Palgrave Macmillan.

Hankerson, David, Andrea R. Marshall, Jennifer Booker, Houda El Mimouni, Imani Walker, and Jennifer A. Rode. 2016. “Does Technology Have Race?” In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA ’16*, 473–85.

Hannah, Dehlia, and Natalie Jeremijenko. 2017. “Natalie Jeremijenko’s New Experimentalism.” In *Anthropocene Feminism*, edited by Richard Grusin, 197–220. University of Minnesota Press.

Haraway, Donna. 1991. *Simians, Cyborgs, and Women: The Reinvention of Nature*. Routledge.

———. 2003. *The Companion Species Manifesto: Dogs, People, And Signigicant Otherness*. Prickly Paradigm Press.

———. 2006. “A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late 20th Century.” In *The International Handbook of Virtual Learning Environments*, edited by Joel Weiss, Jason Nolan, Jeremy Hunsinger, and Peter Trifonas, 117–58. Springer Netherlands.

———. 2008. *When Species Meet*. London: University of Minnesota Press.

———. 2016. *Staying with the Trouble: Making Kin in the Chthulucene*. Duke University Press.

———. 2017. “Symbiogenesis, Sympoiesis, and Art Science Activisms for Staying with the Trouble.” In *Arts of Living on a Damaged Planet: Ghosts and Monsters of the Anthropocene*, edited by Anna Tsing, Heather Swanson, Elaine Gan, and Nils Bubandt, M25–50. University of Minnesota Press.

Harding, Sandra. 2008. *Sciences from Below: Feminisms, Postcolonialities, and Modernities*. Duke University Press.

Hardwick, Tim. 2020. “EU Lawmakers Vote Overwhelmingly in Favor of Common Charging Standard, Despite Apple’s Protestations.” MacRumors. 2020. https://www.macrumors.com/2020/01/31/eu-votes-in-favor-of-charging-cable-standard/.

Hardy, Jean, Susan Wyche, and Tiffany Veinot. 2019. “Rural HCI Research: Definitions, Distinctions, Methods, and Opportunities.” *Proceedings of the ACM on Human-Computer Interaction* 3 (CSCW): 196:1-196:33.

Harrison, Rodney. 2015. “Beyond ‘Natural’ and ‘Cultural’ Heritage: Toward an Ontological Politics of Heritage in the Age of Anthropocene.” *Heritage & Society* 8 (1): 24–42.

Hasselqvist, Hanna, Cristian Bogdan, and Filip Kis. 2016. “Linking Data to Action: Designing for Amateur Energy Management.” In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems - DIS ’16*, 473–83.

Hassenzahl, Marc, and Noam Tractinsky. 2006. “User Experience- A Research Agenda.” *Behaviour and Information Technology* 25 (2): 91–97.

Hayes, Gillian R. 2020. “Inclusive and Engaged HCI.” *Interactions* 27 (2): 26–31.

Hayles, Katherine. 1999. *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. *University Of Chicago Press*. University of Chicago Press.

Heagle, Allen S, Denis E Body, and Walter W Heck. 1973. “An Open-Top Field Chamber to Assess the Impact of Air Pollution on Plants 1.” *Journal of Environmental Quality* 2 (3): 365–68.

Heitlinger, Sara, Nick Bryan-Kinns, and Janis Jefferies. 2013. “Sustainable HCI for Grassroots Urban Food-Growing Communities.” In *Proceedings of the 25th Australian Computer-Human Interaction Conference - OzCHI ’13*, 255–64.

Henderson, Kathryn. 1991. “Flexible Sketches and Inflexible Data Bases: Visual Communication, Conscription Devices, and Boundary Objects in Design Engineering.” *Science, Technology, & Human Values* 16 (4): 448–73.

Hern, Alex. 2020. “Facebook and Google Announce Plans to Become Carbon Neutral.” Guardian. 2020. https://www.theguardian.com/environment/2020/sep/15/facebook-and-google-announce-plans-become-carbon-neutral.

Hesse-Biber, Sharlene Nagy. 2013. *Feminist Research Practice: A Primer*. Sage Publications.

———. 2017. *The Practice of Qualitative Research*. Third Edit. SAGE Publications.

Heywood, Ian, ed. 2017. *Sensory Arts and Design*. Bloomsbury Academic.

Hicks, Marie. 2018. *Programmed Inequality: How Britain Discarded Women Technologists and Lost Its Edge in Computing by Marie Hicks*. The MIT Press.

Hind, Michael. 2019. “Explaining Explainable AI.” *XRDS: Crossroads, The ACM Magazine for Students*, April 2019.

Hine, Christine. 2000. *Virtual Ethnography*. Sage.

Hirsch, Tad. 2014. “Beyond Gardening: A New Approach to HCI and Urban Agriculture.” In *Eat, Cook, Grow: Mixing Human-Computer Interactions with Human-Food Interactions*, edited by Jaz Hee-Jeong Choi, Marcus Foth, and Greg Hearn, 227–42. The MIT Press.

Hirsch, Tad, Phoebe Sengers, Eli Blevis, Richard Beckwith, and Tapan Parikh. 2010. “Making Food, Producing Sustainability.” In *CHI ’10 Extended Abstracts on Human Factors in Computing Systems - CHI EA ’10*, 3147–50.

Hitchings, Russell. 2006. “Expertise and Inability.” *Journal of Material Culture* 11 (3): 364–81.

Holmes, Kat. 2018. *Mismatch: How Inclusion Shapes Design*. The MIT Press.

Hong, Sun-ha. 2020. *Technologies of Speculation: The Limits of Knowledge in a Data-Driven Society*. NYU Press.

Höök, Kristina. 2018. *Designing with the Body: Somaesthetic Interaction Design*. The MIT Press.

Hooks, Bell. 2015. *Feminism Is for Everybody: Passionate Politics*. Second edi. Routledge.

Horst, Heather A., and Daniel Miller, eds. 2012. *Digital Anthropology*. Berg.

Houston, Lara, Steven J. Jackson, Daniela K. Rosner, Syed Ishtiaque Ahmed, Meg Young, and Laewoo Kang. 2016. “Values in Repair.” In *Proceedings of the 2016 CHI Conference on*

Human Factors in Computing Systems - CHI '16, 1403–14.

Howard, Dorothy, and Lilly Irani. 2019. "Ways of Knowing When Research Subjects Care." In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems - CHI '19*, 97:1-97:16.

Hsu, Yen-Chia, Jennifer Cross, Paul Dille, Michael Tasota, Beatrice Dias, Randy Sargent, Ting-Hao Kenneth Huang, and Illah Nourbakhsh. 2019. "Smell Pittsburgh: Community-Empowered Mobile Smell Reporting System." In *Proceedings of the 24th International Conference on Intelligent User Interfaces - IUI '19*, 65–79.

Hsu, Yen-Chia, Paul Dille, Jennifer Cross, Beatrice Dias, Randy Sargent, and Illah Nourbakhsh. 2017. "Community-Empowered Air Quality Monitoring System." In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 1607–19.

Hu, Ke, Yan Wang, Ashfaqur Rahman, and Vijay Sivaraman. 2014. "Personalising Pollution Exposure Estimates Using Wearable Activity Sensors." In *2014 IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP)*, 1–6.

Huang, Sunrise, and Deborah Kuo. 2010. "Premier Looks at 'green' Aspects of Pinglin Township." Focus Taiwan. 2010. http://focustaiwan.tw/news/aliv/201006270016.aspx.

Huang, Ya-Xuan (NaiNai). 2018. "2018 土拉客柑橘園用藥說明." 土拉客實驗農家園. 2018. http://landdykecsa.blogspot.com/2018/07/2018.html?view=magazine.

Hunt, Jamer. 2011. "Prototyping the Social: Temporality and Speculative Futures at the Intersection of Design and Culture." In *Design Anthropology: Object Culture in the 21st Century*, edited by Alison J. Clarke, 33–44. Springer.

Hutson, Matthew. 2018. "AI Researchers Allege That Machine Learning Is Alchemy." Science. AAAS. 2018. https://www.sciencemag.org/news/2018/05/ai-researchers-allege-machine-learning-alchemy.

Ikemiya, Miwa, and Daniela K. Rosner. 2014. "Broken Probes: Toward the Design of Worn Media." *Personal and Ubiquitous Computing* 18 (3): 671–83.

Ingold, Tim. 2015. *The Life of Lines*. Routledge.

Irani, Lilly C., and M. Six Silberman. 2013. "Turkopticon: Interrupting Worker Invisibility in Amazon Mechanical Turk." In *Proceedings of the 2013 CHI Conference on Human Factors in Computing Systems - CHI '13*, 611–20.

Irani, Lilly, Janet Vertesi, Paul Dourish, Kavita Philip, and Rebecca E. Grinter. 2010.

"Postcolonial Computing: A Lens on Design and Development." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '10*, 2:1311–20.

Iyer, Vikram, Rajalakshmi Nandakumar, Anran Wang, Sawyer B. Fuller, and Shyamnath Gollakota. 2019. "Living IoT: A Flying Wireless Platform on Live Insects." In *Proceedings of the 25th Annual International Conference on Mobile Computing and Networking - MobiCom '19*, 5:1-5:15.

Jackson, Melody M., Giancarlo Valentin, Larry Freil, Lily Burkeen, Clint Zeagler, Scott Gilliland, Barbara Currier, and Thad Starner. 2015. "FIDO—Facilitating Interactions for Dogs with Occupations: Wearable Communication Interfaces for Working Dogs." *Personal and Ubiquitous Computing* 19 (1): 155–73.

Jackson, Melody Moore, Allison Rapoport, Ceara Byrne, Shuyi Sun, Larry Freil, Devon Peet, Giancarlo Valentin, et al. 2018. "Technology for Working Dogs." In *Proceedings of the Fifth International Conference on Animal-Computer Interaction - ACI '18*, 6–10.

Jackson, Steven J., and Laewoo Kang. 2014. "Breakdown, Obsolescence and Reuse: HCI and the Art of Repair." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '14*, 449–58.

Jafferis, Noah T., E. Farrell Helbling, Michael Karpelson, and Robert J. Wood. 2019. "Untethered Flight of an Insect-Sized Flapping-Wing Microscale Aerial Vehicle." *Nature* 570 (7762): 491–95.

Jenkins, Tom, Christopher A. Le Dantec, Carl Disalvo, Thomas Lodato, and Mariam Asad. 2016. "Object-Oriented Publics." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, 827–39.

Kampa, Marilena, and Elias Castanas. 2008. "Human Health Effects of Air Pollution." *Environmental Pollution* 151 (2): 362–67.

Karen Hao. 2019. "This Is How AI Bias Really Happens—and Why It's so Hard to Fix." MIT Technology Review. 2019. https://www.technologyreview.com/2019/02/04/137602/this-is-how-ai-bias-really-happensand-why-its-so-hard-to-fix/.

Kim, Sunyoung, Eric Paulos, and Mark D Gross. 2010. "WearAir: Expressive T-Shirts for Air Quality Sensing." In *Proceedings of the Fourth International Conference on Tangible, Embedded, and Embodied Interaction - TEI '10*, 295–96.

Kim, Yongsung, Julien Eberle, Riikka Hanninen, Erol Can Un, and Karl Aberer. 2013. "Mobile Observatory: An Exploratory Study of Mobile Air Quality Monitoring Application." In *Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing*

Adjunct Publication, 733–36.

Kimmerer, Robin. 2014. “Returning the Gift.” *Minding Nature* 7 (2): 18–24.

Kirksey, S. Eben, and S. Helmreich. 2010. “The Emergence of Multispecies Ethnography.” *Cultural Anthropology* 25 (4): 545–76.

Kjeldskov, Jesper, Mikael B. Skov, Jeni Paay, Dennis Lund, Tue Madsen, and Michael Nielsen. 2015. “Eco-Forecasting for Domestic Electricity Use.” In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI ’15*, 1985–88.

Knowles, Bran, Oliver Bates, and Maria Håkansson. 2018. “This Changes Sustainable HCI.” In *Conference on Human Factors in Computing Systems - Proceedings of CHI ’18*, 471:1-471:12.

Knowles, Bran, Lynne Blair, Stuart Walker, Paul Coulton, Lisa Thomas, and Louise Mullagh. 2014. “Patterns of Persuasion for Sustainability.” In *Proceedings of the Conference on Designing Interactive Systems - DIS ’14*, 1035–44.

Knowles, Bran, and Maria Håkansson. 2016. “A Sustainable HCI Knowledge Base in Progress.” *Interactions* 23 (3): 74–76.

Ko, Donghyeon, Daye Kwon, Eunjin Kim, and Woohun Lee. 2018. “BubbleTalk: Enriching Experience with Fish by Supporting Human Behavior.” In *Proceedings of the 2018 Designing Interactive Systems Conference - DIS ’18*, 919–30.

Kobayashi, Hiroki, Kana Muramatsu, Junya Okuno, Kazuhiko Nakamura, Akio Fujiwara, and Kaoru Saito. 2015. “Playful Rocksalt System: Animal-Computer Interaction Design in Wild Environments.” In *Proceedings of the 12th International Conference on Advances in Computer Entertainment Technology - ACE ’15*, 61:1-62:4.

Kobayashi, Hiroki, Ryoko Ueoka, and Michitaka Hirose. 2009. “Human Computer Biosphere Interaction: Towards Sustainable Society.” In *CHI ’09 Extended Abstracts on Human Factors in Computing Systems - CHI EA ’09*, 2509–18.

Kohn, Eduardo. 2013. *How Forests Think: Toward an Anthropology Beyond the Human*. University of California Press.

Koskinen, Ilpo, John Zimmerman, Thomas Binder, Johan Redstrom, and Stephan Wensveen. 2011. *Design Research through Practice. From the Lab, Field, and Showroom*. San Francisco: Morgan Kaufmann Publishers Inc.

Kuklinska, Karolina, Lidia Wolska, and Jacek Namiesnik. 2015. “Air Quality Policy in the US and the EU--a Review.” *Atmospheric Pollution Research* 6 (1): 129–37.

Kumar, Neha, and Naveena Karusala. 2019. “Intersectional Computing.” *Interactions*, 2019.

Kuznetsov, Stacey, George Davis, Jian Cheung, and Eric Paulos. 2011. “Ceci n’est Pas Une Pipe Bombe: Authoring Urban Landscapes with Air Quality Sensors.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’11*, 2375–84.

Kuznetsov, Stacey, George Noel Davis, Eric Paulos, Mark D Gross, and Jian Chiu Cheung. 2011. “Red Balloon, Green Balloon, Sensors in the Sky.” In *Proceedings of the 13th International Conference on Ubiquitous Computing - UbiComp ’11*, 237–46.

Kuznetsov, Stacey, Scott E Hudson, and Eric Paulos. 2014. “A Low-Tech Sensing System for Particulate Pollution.” In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction - TEI ’14*, 259–66.

Kuznetsov, Stacey, William Odom, James Pierce, and Eric Paulos. 2011. “Nurturing Natural Sensors.” In *Proceedings of the 13th International Conference on Ubiquitous Computing - UbiComp ’11*, 227–36.

Kuznetsov, Stacey, and Eric Paulos. 2010. “Participatory Sensing in Public Spaces: Activating Urban Surfaces with Sensor Probes.” In *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS ’10*, 21–30.

Kuznetsov, Stacey, Christina J. Santana, and Elenore Long. 2016. “Everyday Food Science as a Design Space for Community Literacy and Habitual Sustainable Practice.” In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI ’16*, 1786–97.

Lamb, Max. 2014. “157- Marmoreal.” Max Lamb. 2014. http://maxlamb.org/157-marmoreal/.

Land Dyke CSA. 2018. “2018 土拉客柑橙檢驗報告結果說明.” 土拉客實驗農家園. 2018. http://landdykecsa.blogspot.com/.

Landon, Amanda J. 2008. “The ‘How’ of the Three Sisters : The Origins of Agriculture in Mesoamerica and the Human Niche.” *Nebraska Anthropologist* 23: 110–24.

Lanza, Jorge, Luis Sánchez, Luis Muñoz, José Antonio Galache, Pablo Sotres, Juan R Santana, and Verónica Gutiérrez. 2015. “Large-Scale Mobile Sensing Enabled Internet-of-Things Testbed for Smart City Services.” *International Journal of Distributed Sensor Networks* 11 (8).

Latimer, Joanna. 2013. “Being Alongside: Rethinking Relations amongst Different Kinds.” *Theory, Culture & Society* 30 (8): 77–104.

Latimer, Joanna, and Mara Miele. 2013. “Naturecultures? Science, Affect and the Non-Human.” *Theory, Culture & Society* 30 (7–8): 5–31.

Leavy, Patricia. 2015. *Method Meets Art: Arts-Based Research Practice*. Guilford Publications.

Liao, Q. Vera, Daniel Gruen, and Sarah Miller. 2020. “Questioning the AI: Informing Design Practices for Explainable AI User Experiences.” In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems - CHI ’20*.

Lichfield, Gideon. 2020. “We’re Not Going Back to Normal.” MIT Technology Review. 2020. https://www.technologyreview.com/2020/03/17/905264/coronavirus-pandemic-social-distancing-18-months/.

Light, Ann, 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 - C&T ’17*, 270–79.

Light, Ann, Irina Shklovski, and Alison Powell. 2017. “Design for Existential Crisis.” In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA ’17*, Part F1276:722–34.

Lin, Amber. 2017. “Land Dyke Feminist Family Farm: Women Create Farming Community.” *CommonWealth Magazine*, June 2017. https://english.cw.com.tw/article/article.action?id=1630.

Lin, Gang, Jingying Fu, Dong Jiang, Wensheng Hu, Donglin Dong, Yaohuan Huang, and Mingdong Zhao. 2014. “Spatio-Temporal Variation of PM2. 5 Concentrations and Their Relationship with Geographic and Socioeconomic Factors in China.” *International Journal of Environmental Research and Public Health* 11 (1): 173–86.

Lindtner, Silvia, Shaowen Bardzell, and Jeffrey Bardzell. 2016. “Reconstituting the Utopian Vision of Making: HCI After Technosolutionism.” In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI ’16*, 1390–1402.

———. 2018. “Design and Intervention in the Age of ‘No Alternative.’” *Proceedings of the ACM on Human-Computer Interaction* 2 (CSCW): Article 109.

Lindtner, Silvia M. 2020. *Prototype Nation: China and the Contested Promise of Innovation*. Princeton University Press.

Lindvall, Martin, Jesper Molin, and Jonas Löwgren. 2018. “From Machine Learning to Machine Teaching: The Importance of UX.” *Interactions*, October 2018.

Liu, Jen, 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 - CHI ’18*, 1–13.

Liu, Jun, Denise L Mauzerall, Qi Chen, Qiang Zhang, Yu Song, Wei Peng, Zbigniew Klimont, et

al. 2016. “Air Pollutant Emissions from Chinese Households: A Major and Underappreciated Ambient Pollution Source.” *Proceedings of the National Academy of Sciences* 113 (28): 7756–61.

Liu, Liang, Wu Liu, Yu Zheng, Huadong Ma, and Cheng Zhang. 2018. “Third-Eye: A Mobilephone-Enabled Crowdsensing System for Air Quality Monitoring.” *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2 (1): 20.

Liu, Szu-Yu (Cyn), Jeffrey Bardzell, and Shaowen Bardzell. 2018a. “Photography as A Design Research Tool into Natureculture.” In *Proceedings of the 2018 Designing Interactive Systems Conference - DIS ’18*, 777–89.

———. 2019a. “Decomposition as Design: Co-Creating (with) Natureculture.” In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction - TEI ’19*, 605–14.

Liu, Szu-Yu (Cyn), Shaowen Bardzell, and Jeffrey Bardzell. 2018b. “Out of Control: Reframing Sustainable HCI Using Permaculture.” In *Proceedings of the 2018 Workshop on Computing within Limits - LIMITS ’18*, 2:1-2:8.

———. 2019b. “Symbiotic Encounters: HCI and Sustainable Agriculture.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’19*, 317:1-317:13.

Liu, Szu-Yu (Cyn), Jen Liu, Kristin Dew, Patrycja Zdziarska, Maya Livio, and Shaowen Bardzell. 2019. “Exploring Noticing as Method in Design Research.” In *Proceedings of the 2019 ACM Conference on Designing Interactive Systems - DIS ’19*, 377–80.

Livio, Maya. 2019. “A Rough Sketch on Thermoregulation, Technology, and the American Pika.” In *Multispecies Storytelling in Intermedial Practices*. Växjö, Sweden.

Lockton, Dan, Luke Nicholson, Rebecca Cain, and David Harrison. 2014. “Persuasive Technology for Sustainable Workplaces.” *Interactions* 21 (1): 58–61.

Lockton, Dan, Delanie Ricketts, Shruti Aditya Chowdhury, and Chang Hee Lee. 2017. “Exploring Qualitative Displays and Interfaces.” In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA ’17*, 1844–52.

Loren, Leonard. 1998. *Wabi-Sabi: For Artists, Designers, Poets, and Philosophers*. Berkeley: Stone Bridge Press.

Lovelock, James. 2007. *The Revenge of Gaia*. Penguin Books.

———. 2009. *The Vanishing Face of Gaia: A Final Warning*. Basic Books.

Lyle, Peter, Jaz Hee-jeong Choi, and Marcus Foth. 2014. “Designing for Grassroots Food

Production: An Event-Based Urban Agriculture Community." In *Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures - OzCHI '14*, 362–65.

———. 2015. "Growing Food in the City: Design Ideations for Urban Residential Gardeners." In *Proceedings of the 7th International Conference on Communities and Technologies - C&T '15*, 89–97.

Lynch, Kevin. 1992. *The Image of The City*. MIT press.

Maag, Balz, Zimu Zhou, and Lothar Thiele. 2018. "W-Air: Enabling Personal Air Pollution Monitoring on Wearables." *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2 (1): 24:1-24:25.

Madison, D Soyini. 2020. *Critical Ethnography: Method, Ethics, and Performance*. 2nd ed. Sage Publications.

Maestri, Leah, and Ron Wakkary. 2011. "Understanding Repair as a Creative Process of Everyday Design." In *Proceedings of the 8th ACM Conference on Creativity and Cognition - C&C '11*, 81–90.

Makinde, Ayoola, Muhammad Muhaiminul Islam, and Stacey D. Scott. 2019. "Opportunities for ACI in PLF: Applying Animal- And User-Centred Design to Precision Livestock Farming." In *Proceedings of the Sixth International Conference on Animal-Computer Interaction - ACI '19*, 13:1-13:6.

Mancini, Clara. 2011. "Animal-Computer Interaction: A Manifesto." *Interactions* 18 (4): 69–73.

Mancini, Clara, and Jussi Lehtonen. 2018. "The Emerging Nature of Participation in Multispecies Interaction Design." In *Proceedings of the 2018 Designing Interactive Systems Conference - DIS '18*, 907–18.

Mankoff, Jennifer C, Eli Blevis, Alan Borning, Batya Friedman, Susan R Fussell, Jay Hasbrouck, Allison Woodruff, and Phoebe Sengers. 2007. "Environmental Sustainability and Interaction." In *CHI '07 Extended Abstracts on Human Factors in Computing Systems - CHI EA '07*, 2121–24.

Martin, Richard. 2007. "Wabi-Sabi." *Photo Life*, November 2007. http://dt.pepperdine.edu/courses/greatbooks_v/gbv_101/Wabi- Sabi.PDF.

Massey, Doreen. 1992. "Politics and Space/Time." *New Left Review*.

Matsakis, L. 2017. "Google Employee's Anti-Diversity Manifesto Goes 'Internally Viral.'" *Vice*. https://motherboard.vice.com.

Matthews, Kristine. n.d. "Pollinator Pathway." Studio Matthews. Accessed October 30, 2020.

http://www.studiomatthews.com/work/pollinator-pathway/.

Mauriello, Matthew Louis, Manaswi Saha, Erica Brown, and Jon E. Froehlich. 2017. “Exploring Novice Approaches to Smartphone-Based Thermographic Energy Auditing.” In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI ’17*, 1768–80.

Mayer, Helmut. 1999. “Air Pollution in Cities.” *Atmospheric Environment* 33 (24–25): 4029–37.

McCarthy, John, and Peter Wright. 2004. *Technology as Experience*. The MIT Press.

McLaughlin, S B. 1985. “Effects of Air Pollution on Forests: A Critical Review.” U.S. Environmental Protection Agency. 1985.

McLean, Katherine Jane. 2019. “Nose-First: Practices of Smellwalking and Smellscape Mapping.” Royal College of Art.

McShane, Katie. 2007. “Anthropocentrism vs. Nonanthropocentrism: Why Should We Care?” *Environmental Values* 16 (2): 169–85.

Meijer, Eva. 2019. *When Animals Speak: Toward an Interspecies Democracy*. Vol. 21. New York University Press.

Merleau-Ponty, Maurice. 1945. *Phenomenology of Perception*. Routledge.

Metcalfe, Daniel. n.d. “Using Dance to Learn about Animal Behaviour.” Accessed October 29, 2020. http://www.danimetcalfe.com/index.php/somatic-design-/.

Metcalfe, Daniel J. 2015. “Multispecies Design.” University of the Arts London and Falmouth University.

Meurer, Johanna, Dennis Lawo, Lukas Janßen, and Volker Wulf. 2016. “Designing Mobility Eco-Feedback for Elderly Users.” In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA ’16*, 921–26.

Milano, Michela. 2013. “Sustainable Energy Policies: Research Challenges and Opportunities.” *Proceedings of the Conference on Design, Automation and Test in Europe - DATE ’13*, 1143–48.

Milgram, Stanley. 2010. *The Individual in a Social World: Essays and Experiments*. Edited by Thomas Blass. Pinter & Martin.

Miller, Daniel, and Don Slater. 2000. *The Internet: An Ethnographic Approach*. 1st ed. Bloomsbury Academic.

Mohai, Paul, Byoung-Suk Kweon, Sangyun Lee, and Kerry Ard. 2011. “Air Pollution around Schools Is Linked to Poorer Student Health and Academic Performance.” *Health Affairs* 30 (5): 852–62.

Møllenbach, Emilie, and Jens Hoff. 2012. “HCI and Sustainability: The Role of Macrostructures.” In *CHI ’12 Extended Abstracts on Human Factors in Computing Systems - CHI EA ’12*, 2159–64.

Mollison, Bill. 1988. *Permaculture: A Designers’ Manual*. 2nd ed. Tasmania, Australia: Tagari Publications.

Mubin, Omar, Joshua Tubb, Mauricio Novoa, Mustafa Naseem, and Samia Razaq. 2015. “Understanding the Needs of Pakistani Farmers and the Prospects of an ICT Intervention.” In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA ’15*, 1109–14.

Murer, Martin, Verena Fuchsberger, and Manfred Tscheligi. 2017. “Un-Crafting: De-Constructive Engagements with Interactive Artifacts.” In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction - TEI ’17*, 67–77.

Myers West, Sarah, Meredith Whittaker, and Kate Crawford. 2019. “Discriminating Systems: Gender, Race and Power in AI.” AI Now Institute. 2019.

Nardi, Bonnie. 2010. *My Life as a Night Elf Priest: An Anthropological Account of World of Warcraft*. University of Michigan Press.

———. 2016. “Designing for the Future: But Which One?” *Interactions* 23 (1): 26–33.

National Museum Wales. 2007. “Hunting for Food in the Stone Age.” 2007. https://museum.wales/articles/2007-05-11/Hunting-for-food-in-the-Stone-Age/.

National Park Service. 2019. “Where Does Air Pollution Come From?” 2019. https://www.nps.gov/subjects/air/sources.htm.

Nelson, Jonathan K., and Patrick C. Shih. 2017. “CompanionViz: Mediated Platform for Gauging Canine Health and Enhancing Human–Pet Interactions.” *International Journal of Human Computer Studies* 98: 169–78.

Nippert-Eng, Christena. 2015. *Watching Closely: A Guide to Ethnographic Observation*. *Sereal Untuk*. Oxford University Press.

Nkwo, Makuochi, and Rita Orji. 2018. “Persuasive Technology in African Context: Deconstructing Persuasive Techniques in an African Online Marketplace.” In *Proceedings of the Second African Conference for Human Computer Interaction - AfriCHI ’18*, 9:1-9:10.

Noble, Safiya Umoja. 2018. *Algorithms of Oppression: How Search Engines Reinforce Racism*. New York: NYU Press.

Norman, Don. 2005. *Emotional Design: Why We Love (or Hate) Everyday Things*. Basic Books.

Norton, Juliet, Nico Herbig, Lynn Dombrowski, Ankita Raturi, Bonnie Nardi, Sebastian Prost, Samantha McDonald, et al. 2017. “A Grand Challenge for HCI: Food + Sustainability.” *Interactions* 24 (6): 50–55.

Noz, Frank, and Jinsoo An. 2011. “Cat Cat Revolution: An Interspecies Gaming Experience.” In *Proceedings of the 2011 SIGCHI Conference on Human Factors in Computing Systems - CHI ’11*, 2661–64.

Odom, William. 2010. “‘Mate, We Don’t Need a Chip to Tell Us the Soil’s Dry’: Opportunities for Designing Interactive Systems to Support Urban Food Production.” In *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS ’10*, 232–35.

———. 2014. “‘You Don’t Have to Be a Gardener to Do Urban Agriculture’: Understanding Opportunities for Designing Interactive Technologies to Support Urban Food Production.” In *Eat, Cook, Grow: Mixing Human-Computer Interactions with Human-Food Interactions*, 177–94. The MIT Press.

Oduor, Erick, Peninah Waweru, Jonathan Lenchner, and Carman Neustaedter. 2018. “Practices and Technology Needs of a Network of Farmers in Tharaka Nithi, Kenya.” In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI ’18*, 39:1-39:11.

Ogbonnaya-Ogburu, Ihudiya Finda, Angela D.R. Smith, Alexandra To, and Kentaro Toyama. 2020. “Critical Race Theory for HCI.” In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems - CHI ’20*, 1–16.

Ogden, Charles Kay, and Ivor Armstrong Richards. 1923. *The Meaning of Meaning: A Study of the Influence of Language upon Thought and of the Science of Symbolism*. Mariner Books.

Ogden, Laura A, Billy Hall, and Kimiko Tanita. 2013. “Animals, Plants, People, and Things: A Review of Multispecies Ethnography.” *Environment and Society: Advances in Research* 4: 5–24.

Olsen, Alex, Dmitry A. Konovalov, Bronson Philippa, Peter Ridd, Jake C. Wood, Jamie Johns, Wesley Banks, et al. 2019. “DeepWeeds: A Multiclass Weed Species Image Dataset for Deep Learning.” *Scientific Reports* 9 (1): 1–12.

Ong, Aihwa, and Stephen J Collier, eds. 2008. *Global Assemblages: Technology, Politics, and Ethics as Anthropological Problems*. Wiley-Blackwell.

Ortner, Sherry B. 1995. “Resistance and the Problem of Ethnographic Refusal.” *Comparative Studies in Society and History* 37 (1): 173–93.

Otto, Ton, and Rachel Charlotte Smith. 2013. “Design Anthropology: A Distinct Style of Knowing.” In *Design Anthropology: Theory and Practice*, edited by Wendy Gunn, Ton Otto, and Rachel Charlotte Smith, 1–29. Bloomsbury Academic.

Pan, Yue, Chit Meng Cheong, and Eli Blevis. 2010. “The Climate Change Habitability Index.” *Interactions*, 2010. https://doi.org/10.1145/1865245.1865253.

Papanek, Victor. 1972. *Design for the Real World: Human Ecology and Social Change*. London: Thames and Hudson.

Pargman, Daniel, and Barath Raghavan. 2014. “Rethinking Sustainability in Computing: From Buzzword to Non-Negotiable Limits.” In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction - NordiCHI ’14*, 638–47.

Patel, Molini M, Steven N Chillrud, Juan C Correa, Marian Feinberg, Yair Hazi, K C Deepti, Swati Prakash, James M Ross, Diane Levy, and Patrick L Kinney. 2009. “Spatial and Temporal Variations in Traffic-Related Particulate Matter at New York City High Schools.” *Atmospheric Environment* 43 (32): 4975–81.

Paulos, Eric, R J Honicky, and Ben Hooker. 2009. “Citizen Science: Enabling Participatory Urbanism.” In *Handbook of Research on Urban Informatics: The Practice and Promise of the Real-Time City*, 414–36. IGI Global.

Peeples, Lynne. 2020. “Face Masks: What the Data Say.” Nature. 2020. https://www.nature.com/articles/d41586-020-02801-8.

Petkov, Petromil, Felix Köbler, Marcus Foth, Richard Medland, and Helmut Krcmar. 2011. “Engaging Energy Saving through Motivation-Specific Social Comparison.” *CHI ’11 Extended Abstracts on Human Factors in Computing Systems - CHI EA ’11*, 1945–50.

Pierce, James, and Eric Paulos. 2012. “Beyond Energy Monitors: Interaction, Energy, and Emerging Energy Systems.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’12*, 665–74.

Pindell, Deanna. 2015. “Eco Art: The Decomposition of Art and the Art of Decomposition.” *Antennae: The Journal of Nature in Visual Culture*, no. 32: 36–43.

Pink, Sarah. 2009. *Doing Sensory Ethnography*. SAGE.

———. 2013. *Doing Visual Ethnography*. SAGE Publications.

Pons, Patricia, Marcus Carter, and Javier Jaen. 2016. “Sound to Your Objects: A Novel Design Approach to Evaluate Orangutans’ Interest in Sound-Based Stimuli.” In *Proceedings of the Third International Conference on Animal-Computer Interaction - ACI ’16*, 7:1-7:5.

Pope, C Arden, Douglas W Dockery, and Joel Schwartz. 1995. “Review of Epidemiological

Evidence of Health Effects of Particulate Air Pollution." *Inhalation Toxicology* 7 (1): 1–18.

Pope III, C Arden, and Douglas W Dockery. 2006. "Health Effects of Fine Particulate Air Pollution: Lines That Connect." *Journal of the Air & Waste Management Association* 56 (6): 709–42.

Preist, Chris, Dan Schien, and Eli Blevis. 2016. "Understanding and Mitigating the Effects of Device and Cloud Service Design Decisions on the Environmental Footprint of Digital Infrastructure." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, 1324–1337.

Prin, Ariane. 2017. "Prin London." 2017. http://www.prin.in/.

Puig de la Bellacasa, Maria. 2010. "Ethical Doings in Naturecultures." *Ethics, Place and Environment* 13 (2): 151–69.

———. 2017. *Matters of Care: Speculative Ethics in More Than Human Worlds*. University of Minnesota Press.

Purdy, Jedediah. 2015. *After Nature: A Politics for the Anthropocene*. Harvard University Press.

Quitmeyer, Andrew. 2017. "Digital Naturalist Design Guidelines: Theory, Investigation, Development, and Evaluation of a Computational Media Framework to Support Ethological Exploration." In *Proceedings of the 2017 ACM SIGCHI Conference on Creativity and Cognition - C&C '17*, 184–96.

Raghavan, Barath, Bonnie Nardi, Sarah T Lovell, Juliet Norton, Bill Tomlinson, and Donald J Patterson. 2016. "Computational Agroecology: Sustainable Food Ecosystem Design." In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '16*, 423–35.

Raghavan, Barath, and Daniel Pargman. 2017. "Means and Ends in Human-Computer Interaction: Sustainability through Disintermediation." In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 786–96.

Rapp, Amon, Maurizio Tirassa, and Lia Tirabeni. 2019. "Rethinking Technologies for Behavior Change: A View from the Inside of Human Change." *ACM Transactions on Computer-Human Interaction - TOCHI* 26 (4): 22.

Rasmussen, Majken K, Mia Kruse Rasmussen, Nervo Verdezoto, Robert Brewer, Laura L Nielsen, and Niels Olof Bouvin. 2017. "Exploring the Flexibility of Everyday Practices for Shifting Energy Consumption through ClockCast." In *Proceedings of the 29th Australian Conference on Computer-Human Interaction - OZCHI '17*, 296–306.

Rault, Jean-loup, Sarah Webber, and Marcus Carter. 2015. "Cross-Disciplinary Perspectives

on Animal Welfare Science and Animal - Computer Interaction." In *Proceedings of the 12th International Conference on Advances in Computer Entertainment Technology - ACE '15*, 56:1-15:5.

Remy, Christian, Oliver Bates, Alan Dix, Vanessa Thomas, Mike Hazas, Adrian Friday, and Elaine M Huang. 2018. "Evaluation beyond Usability: Validating Sustainable HCI Research." In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*, 216:1-216:14.

Remy, Christian, Oliver Bates, Vanessa Thomas, and Elaine M. Huang. 2017. "The Limits of Evaluating Sustainability." In *Proceedings of the 2017 Workshop on Computing Within Limits - LIMITS '17*, 103–10.

Ringenson, Tina, Elina Eriksson, Miriam Börjesson Rivera, and Josefin Wangel. 2017. "The Limits of the Smart Sustainable City." In *Proceedings of the 2017 Workshop on Computing Within Limits - LIMITS '17*, 3–9.

"Ripple." 2013. Poetic Lab. 2013. http://www.poetic-lab.com/ripple-1/.

Robbins, Holly, Elisa Giaccardi, Elvin Karana, and Patrizia D 'olivo. 2015. "Understanding and Designing with (and for) Material Traces." *Studies in Material Thinking* 13.

Robinson, Margaret. 2013. "Veganism and Mi'kmaq Legends." *Canadian Journal of Native Studies* 33: 184–96.

Rode, Jennifer A. 2011. "A Theoretical Agenda for Feminist HCI." *Interacting with Computers* 23 (5): 393–400.

Rogers, Yvonne. 2012. *HCI Theory: Classical, Modern, and Contemporary*. Morgan & Claypool.

Rognoli, Valentina, and Elvin Karana. 2014. "Toward a New Materials Aesthetic Based on Imperfection and Graceful Aging." In *Materials Experience: Fundamentals of Materials and Design*, edited by Elvin Karana, Owain Pedgley, and Valentina Rognoli, 42:145–54.

Rosner, Daniela K., and Morgan Ames. 2014. "Designing for Repair? Infrastructures and Materialities of Breakdown." In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing - CSCW '14*, 319–31.

Rosner, Daniela K., Miwa Ikemiya, Diana Kim, and Kristin Koch. 2013. "Designing with Traces." *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*, 1649.

Rusu, Cristian, Virginica Rusu, Silvana Roncagliolo, and Carina González. 2015. "Usability and User Experience: What Should We Care About?" *International Journal of Information Technologies and Systems Approach* 8 (2): 1–12.

Sakata, Kanzo. 2010. “Studies on Aroma Formation Mechanisms during Tea Manufacturing Suggest Methods Not Only to Improve the Quality of Made Teas , but Also to Produce New Types of Teas.” In *The Internatinal Conference on O-CHA(Tea) Culture and Science*. http://www.o-cha.net/english/conference2/pdf/2010/files/PROC/pr-s-08.pdf.

Satchell, Christine, and Paul Dourish. 2009. “Beyond The User: Use And Non-Use in HCI.” In *Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group - OZCHI ’09*, 411:9–16.

Schlesinger, Ari, W. Keith Edwards, and Rebecca E. Grinter. 2017. “Intersectional HCI: Engaging Identity through Gender, Race, and Class.” In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI ’17*, 5412–27.

Schön, Donald A. 1990. “The Design Process.” In *Varieties of Thinking: Essays from Harvard’s Philosophy of Education Research Center*, edited by V. A. Howard, 110–41. Routledge.

Schön, Donald A. 1983. *The Reflective Practitioner: How Professionals Think in Action*. Routledge.

Schwartz, Tobias, Sebastian Denef, Gunnar Stevens, Leonardo Ramirez, Volker Wulf, and Sankt Augustin. 2013. “Cultivating Energy Literacy— Results from a Longitudinal Living Lab Study of a Home Energy Management System.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’13*, 1193–1202.

Scott, Eric. 2016. “Oriental Beauty and Other Bug-Bitten Teas: Fact or Fiction？” World of Tea. 2016. https://worldoftea.org/oriental-beauty-bug-bitten-teas/.

Seaton, Anthony, D Godden, W MacNee, and K Donaldson. 1995. “Particulate Air Pollution and Acute Health Effects.” *The Lancet* 345 (8943): 176–78.

Sengers, Phoebe, and Bill Gaver. 2006. “Staying Open to Interpretation: Engaging Multiple Meanings in Design and Evaluation.” *Proceedings of the 6th Conference on Designing Interactive Systems - DIS ’06*, 99–108.

Sharp, Helen, Jenny Preece, and Yvonne Rogers. 2019. *Interaction Design: Beyond Human-Computer Interaction*. Fifth Edit. Indianapolis, IN: Wiley.

Shirai, Yoshinari, Yasue Kishino, Futoshi Naya, and Yutaka Yanagisawa. 2016. “Toward On-Demand Urban Air Quality Monitoring Using Public Vehicles.” In *Proceedings of the 2nd International Workshop on Smart - SmartCities ’16*, 1:1-1:6.

Shotwell, Alexis. 2016. *Against Purity: Living Ethically in Compromised Times*. University of Minnesota Press.

Silberman, M Six, Lisa Nathan, Bran Knowles, Roy Bendor, Adrian Clear, Maria Håkansson,

Tawanna Dillahunt, and Jennifer Mankoff. 2014. “Next Steps for Sustainable HCI.” *Interactions*, 2014.

Simon, Herbert A. 1996. *The Sciences of the Artificial*. 3rd Editio. The MIT Press.

Smith, Jonathan A, and Pnina Shinebourne. 2012. “Interpretative Phenomenological Analysis.” In *APA Handbook of Research Methods in Psychology*, edited by Harris Cooper, Paul M. Camic, Debra L. Long, A. T. Panter, David Rindskopf, and Kenneth J. Sher. American Psychological Association.

Smith, Linda Tuhiwai. 2012. *Decolonizing Methodologies: Research and Indigenous Peoples*. *Zed Books*. 2 edition. Zed Books.

Smith, Nancy. 2019. “Decentering Design: Bees, Biomimicry, and the Sixth Mass Extinction.” Indiana University Bloomington.

Smith, Nancy, Shaowen Bardzell, and Jeffrey Bardzell. 2017. “Designing for Cohabitation: Naturecultures, Hybrids, and Decentering the Human in Design.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’17*, 1714–25.

Smith, Rachel Charlotte, Kasper Tang Vangkilde, Mette Gislev Kjærsgaard, Ton Otto, Joachim Halse, and Thomas Binder, eds. 2016. *Design Anthropological Futures: Exploring Emergence, Intervention and Formation*. Bloomsbury Academic.

Star, Susan Leigh. 1989. “The Structure of Ill-Structured Solutions: Boundary Objects and Heterogeneous Distributed Problem Solving.” In *Distributed Artificial Intelligence*, 37–54. Morgan Kaufmann. https://doi.org/10.1016/b978-1-55860-092-8.50006-x.

Starhawk. 2004. *The Earth Path: Grounding Your Spirit in the Rhythms of Nature*. San Francisco: HarperOne.

Steiner, Helene, Paul Johns, Asta Roseway, Chris Quirk, Sidhant Gupta, and Jonathan Lester. 2017. “Project Florence: A Plant to Human Experience.” In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA ’17*, 1415–20.

Steinfield, Charles, Susan Wyche, Tian Cai, and Hastings Chiwasa. 2015. “The Mobile Divide Revisited: Mobile Phone Use by Smallholder Farmers in Malawi.” In *Proceedings of the Seventh International Conference on Information and Communication Technologies and Development - ICTD ’15*, 8:1-8:9.

Steup, Rosemary, Arvind Santhanam, Marisa Logan, Lynn Dombrowski, and Norman Makoto Su. 2018. “Growing Tiny Publics: Small Farmers’ Social Movement Strategies.” *Proceedings of the ACM on Human-Computer Interaction* 2 (CSCW): 165:1-165:24.

Stickdorn, Marc. 2012. *This Is Service Design Thinking: Basics, Tools, Cases*. Wiley.

Strachan, Jack. 2017. “Why Use Extreme Users?” Medium. 2017. https://uxplanet.org/why-use-extreme-users-345e97719e52.

Suchman, Lucy A. 1987. *Plans and Situated Actions: The Problem of Human-Machine Communication*. Cambridge University Press.

Sultana, Sharifa, and Syed Ishtiaque Ahmed. 2019. “Witchcra and HCI: Morality, Modernity, and Postcolonial Computing in Rural Bangladesh.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’19*, 356:1-356:15.

Sultana, Sharifa, François Guimbretière, Phoebe Sengers, and Nicola Dell. 2018. “Design Within a Patriarchal Society: Opportunities and Challenges in Designing for Rural Women in Bangladesh.” In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI ’18*, 536:1-536:13.

Swan, James A., and Roberta Swan. 1994. *Bound to the Earth*. Avon Books.

Szpiro, Adam A, Paul D Sampson, Lianne Sheppard, Thomas Lumley, Sara D Adar, and Joel D Kaufman. 2010. “Predicting Intra-Urban Variation in Air Pollution Concentrations with Complex Spatio-Temporal Dependencies.” *Environmetrics* 21 (6): 606–31.

“Tackle Air Quality in Neighbourhoods Together.” 2020. Umbrellium. 2020. https://umbrellium.co.uk/case-studies/tower-hamlets-pet/.

Taiwan Bluemagpie Tea. n.d. “Taiwan Bluemagpie Tea.” Accessed February 5, 2018. http://bluemagpietea.com/index.php/en/.

Taylor, Alex. 2020. “Life Less Normal.” ACM Interactions. 2020. https://interactions.acm.org/blog/view/life-less-normal.

Taylor, Alex S. 2017. “What Lines, Rats, and Sheep Can Tell Us.” *Design Issues* 33 (3): 25–36.

Taylor, Alex S. 2018. “Ethnography in Ubiquitous Computing.” In *Ubiquitous Computing Fundamentals*, 217–50. Chapman and Hall/CRC.

Taylor, Alex S, and Daniela K Rosner. 2017. “Alex S. Taylor and Daniela K. Rosner.” *Interactions*, 12–13.

“The Copenhagen Wheel.” 2019. SENSEable City Lab. 2019. http://senseable.mit.edu/copenhagenwheel/.

Thomas, Vanessa, Christian Remy, and Oliver Bates. 2017. “The Limits of HCD: Reimagining the Anthropocentricity of ISO 9241-210.” In *Proceedings of the 2017 Workshop on Computing Within Limits - LIMITS ’17*, 85–92.

Thompson, Paul B. 2015. *From Field to Fork: Food Ethics for Everyone*. New York: Oxford

University Press.

Tian, Rundong, Christine Dierk, Christopher Myers, and Eric Paulos. 2016. “MyPart:Personal, Portable, Accurate Airborne Particle Counting.” In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI ’16*, 1338–48.

Tomlinson, Bill, and Benoit A Aubert. 2017. “Information Systems in a Future of Decreased and Redistributed Global Growth.” In *Proceedings of the 2017 Workshop on Computing Within Limits - LIMITS ’17*, 21–28.

Tomlinson, Bill, Eli Blevis, Bonnie Nardi, Donald J Patterson, M Silberman, and Yue Pan. 2013. “Collapse Informatics and Practice: Theory, Method, and Design.” *ACM Transactions on Computer-Human Interaction - TOCHI* 20 (4): 24:1-24:26.

Tomlinson, Bill, M. Six Silberman, Don Patterson, Yue Pan, and Eli Blevis. 2012. “Collapse Informatics: Augmenting the Sustainability & ICT4D Discourse in HCI.” In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI ’12*, 655–64.

Torres, Natalia Garcia, and Paulina Escalante Campbell. 2019. “Aire: Visualize Air Quality.” In *ACM SIGGRAPH 2019 Appy Hour - SIGGRAPH ’19*, 1:1-1:2.

Trauth, Eileen M., Curtis C. Cain, K. D. Joshi, Lynette Kvasny, and Kayla Booth. 2012. “Embracing Intersectionality in Gender and IT Career Choice Research.” In *Proceedings of the 2012 Computers and People Research Conference -SIGMIS-CPR’12*, 199–211.

Trindade, Rui, Micaela Sousa, Cristina Hart, Nádia Vieira, Roberto Rodrigues, and João França. 2015. “Purrfect Crime: Exploring Animal Computer Interaction through a Digital Game for Humans and Cats.” In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA ’15*, 93–96.

Tse-Xin Organic Agriculture Foundation. n.d. “About Tse-Xin Organic Agriculture Foundation (TOAF).” Accessed February 5, 2018. http://toaf.org.tw/en.

Tsing, Anna. 2012. “Unruly Edges: Mushrooms as Companion Species.” *Environmental Humanities* 1 (1): 141–54.

———. 2014. “Blasted Landscapes (and the Gentle Arts of Mushroom Picking).” In *The Multispecies Salon*, edited by Eben Kirksey. Duke University Press.

———. 2015. *The Mushroom at the End of the World*. Princeton University Press.

Tsing, Anna, Heather Swanson, Elaine Gan, and Nils Bubandt, eds. 2017. *Arts of Living on Damaged Planet: Ghosts of the Anthropocene*. University of Minnesota Press.

US Environmental Protection Agency. 2014. “Air Quality Index: A Guide to Air Quality and Your Health.” 2014. https://www3.epa.gov/airnow/aqi_brochure_02_14.pdf.

Vaughan, Adam. 2016. “Pigeon Patrol Takes Flight to Tackle London’s Air Pollution Crisis.” 2016. https://www.theguardian.com/environment/2016/mar/14/pigeon-patrol-takes-flight-to-tackle-londons-air-pollution-crisis.

Vogel, Steven. 2015. *Thinking like a Mall: Environmental Philosophy after the End of Nature*. MIT Press.

Wadkar, Sagar K., Khajan Singh, Asif Mohammad, and Shivaji D. Argade. 2017. “Sustainability of the Rural ICT Project: A Case Study of AAQUA e-Agriservice, Maharashtra, India.” In *Proceedings of the 10th International Conference on Theory and Practice of Electronic Governance - ICEGOV ’17*, 384–90.

Wargocki, Pawel, and David P Wyon. 2017. “Ten Questions Concerning Thermal and Indoor Air Quality Effects on the Performance of Office Work and Schoolwork.” *Building and Environment* 112: 359–66.

Weiss, Gail. 2008. “Can an Old Dog Learn New Tricks? Habitual Horizons in James, Bourdieu, and Merleau-Ponty.” In *Intertwinings: Interdisciplinary Encounters with Merleau-Ponty*, edited by Gail Weiss, 223–40. SUNY Press.

Wilson, Catherine M, and Suresh K Lodha. 1996. “Listen: A Data Sonification Toolkit.” In *Proceedings of ICAD 06-Twelth Meeting of the International Conference on Auditory Display*, 1–7.

Wolfe, Cary. 2010. *What Is Posthumanism?* Minneapolis: University of Minnesota Press.

Woodruff, Allison, and Jennifer Mankoff. 2009. “Environmental Sustainability.” *IEEE CS*, 18–21.

World Health Organization. 2018. “Ambient (Outdoor) Air Quality and Health.” 2018. https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.

Wright, Peter, and John McCarthy. 2004. *Technology as Experience*. London: The MIT Press.

———. 2008. “Empathy and Experience in HCI.” In *Conference on Human Factors in Computing Systems - Proceedings of CHI ’08*, 637–46.

Writer, Scott. 2016. “‘Relying on Heaven’: Natural Farming and ‘Eco-Tea’ in Taiwan.” In *Green Asia: Ecocultures, Sustainable Lifestyles, and Ethical Consumption*, edited by Tania Lewis, 51–65. Taylor & Francis.

Zeagler, Clint, Ceara Byrne, Giancarlo Valentin, Larry Freil, Eric Kidder, James Crouch, Thad Starner, and Melody Moore Jackson. 2016. “Search and Rescue: Dog and Handler Collaboration Through Wearable and Mobile Interfaces.” In *Proceedings of the Third International Conference on Animal-Computer Interaction - ACI ’16*, 6:1-6:9.

Zeagler, Clint, Jay Zuerndorfer, Andrea Lau, Larry Freil, Scott Gilliland, Thad Starner, and Melody Moore Jackson. 2016. “Canine Computer Interaction: Towards Designing a Touchscreen Interface for Working Dogs.” In *Proceedings of the Third International Conference on Animal-Computer Interaction - ACI ’16*, 2:1-2:5.

Zhang, Xiaojing, Pawel Wargocki, Zhiwei Lian, and Camilla Thyregod. 2017. “Effects of Exposure to Carbon Dioxide and Bioeffluents on Perceived Air Quality, Self-Assessed Acute Health Symptoms and Cognitive Performance.” *Indoor Air* 27 (1): 47–64.

Zheng, Yu, Licia Capra, Ouri Wolfson, and Hai Yang. 2014. “Urban Computing: Concepts, Methodologies, and Applications.” *ACM Transactions on Intelligent Systems and Technology (TIST)* 5 (3): 38:1-38:55.

Zheng, Yu, Xiuwen Yi, Ming Li, Ruiyuan Li, Zhangqing Shan, Eric Chang, and Tianrui Li. 2015. “Forecasting Fine-Grained Air Quality Based on Big Data.” In *Proceedings of the 21th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, 2267–76.

Zimmerman, John, and Jodi Forlizzi. 2014. “Research Through Design in HCI.” In *Ways of Knowing in HCI*, edited by Judith S. Olson and Wendy A. Kellogg, 167–89. Springer.

Zimmerman, John, 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 - CHI ’07*, 493–502.

Zoran, Amit, Roy Shilkrot, Suranga Nanyakkara, and Joseph Paradiso. 2014. “The Hybrid Artisans: A Case Study in Smart Tools.” *ACM Transactions on Computer-Human Interaction* 21 (3): 1–29.

吳聲舜. 2016. “蜜香茶的秘密.” 農政與農情. https://www.coa.gov.tw/ws.php?id=2504568.

新北市政府農業局. 2017. “青蛙王子拚復育 有機茶園鮮體驗.” 新北市政府. 2017. https://www.ntpc.gov.tw/ch/home.jsp?id=28&parentpath=0,1944&mcustomize=news_view.jsp&dataserno=201711300005&t=null&mserno=201309100001.

黃仲杰. 2016. “推動友善環境農業.” 農政與農情, December 2016. https://www.coa.gov.tw/ws.php?id=2505838.

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RESEARCH STATEMENT

I am a Human-Computer Interaction (HCI) researcher and an award-winning product designer. My work engages with the sociotechnical dimensions of technology. My primary research focuses include non-anthropocentric HCI, sustainable and, environmental justice, community participation, data feminism, and urban informatics. Methodologically, I take a cross-disciplinary approach combining social science methods (e.g., ethnography, interview, survey), arts-and-design approaches (e.g., research through design, material probe, co-design), and methods from the humanities (e.g., design criticism, close reading). As a technology and design researcher, my goal is to develop new theories, methodologies, and applications to promote accessibility, inclusion, participation, and sustainability through design.

EDUCATION

2016 – 2020 **Ph.D., Informatics with a concentration in Human-Computer Interaction Design**
Indiana University, Bloomington IN, USA

2016 – 2018 **M.S., Informatics**, Indiana University, Bloomington IN, USA
Indiana University, Bloomington IN, USA

2010 – 2013 **M.Des., Product Design**
Taiwan Tech, Taipei, Taiwan

2011 – 2012 Full-Time Endowed Student, Product Design, Art Center College of Design, Pasadena CA, USA

2006 – 2010 **B.Des., Product Design** (honors)
Taiwan Tech, Taipei, Taiwan

2008 Exchange Student, Product Design (honors)
College for Creative Studies, Detroit MI, USA

EMPLOYMENT

Aug 2016 – Dec 2020 **Indiana University, *Graduate Researcher,*** Bloomington IN, USA
Conducted ethnography, interviews, contextual inquiries, and what-if scenarios with rural farmers to uncover design opportunities for precision and eco-friendly farming. Led a team of 5 to conduct research through design activities that support participation of nontraditional/ nonhuman stakeholders (e.g., animals, plants) in creative practices.

Jan 2020 – May 2020 **Snap Research, *Research Intern,*** Seattle, WA, USA
Led 27 remote interviews and 1000+ surveys to identify untouched product areas for co-located interactions using Snapchat app; presented findings to CTO and R&D leads. Translated user insights into design directions that guided the development of various in-app AR games and lenses deployed in Q4 2020 to increase app usage during COVID-19.

May 2019 – Aug 2019 **Microsoft Research + AI, *Research Intern,*** Redmond, WA, USA
Created a cognitive mapping toolkit that facilitated 12 in-depth interviews to understand how people experience air pollution and identify the limitation of subjective perception. Led co-design workshops with local residents and co-created a data sonification model called Project Eclipse to increases data legibility and promote community health.

Mar 2015 – May 2016 **ASUS, *User Experience Researcher,*** Taipei, Taiwan
Worked with a research and strategy team to conduct user studies, trend analyses, and cross-functional co-design sessions; laid out 3-10 years of business roadmap that is currently being adopted to align brand image and define new product pathways. Developed and embedded research templates in cross-functional teams to foster a collaborative culture with and advocated user-centered design thinking.

Mar 2014 – Mar 2015 **ASUS, *Product Designer,*** Taipei, Taiwan
Designed the award-winning Google On-Hub router and VivoMini PC; involved in the entire product development process from ideation and prototyping to mass production. Collaborated closely with project managers, researchers, designers, software/hardware engineers on 5 exploratory and tactical projects: ranging from PC and monitor to robot.

Sep 2010 – Dec 2013 **Taiwan Tech, *Graduate Research Assistant,*** Taiwan Tech, Taipei, Taiwan
Assisted in brainstorming and creating 3D prototypes to study load bearing structure using sheet material. Designed and conducted anthropological fieldwork to identify strategies of improving user experiences in product design.

May 2010 – Dec 2010 **YunTech, *Research Assistant,*** Yunlin, Taiwan
Conducted and analyzed semi-structured interviews with design practitioners to investigate the mechanisms of creativity. Project funded by National Science Council, Taiwan.

AWARDS

Research Funding

2021 – 2022 National Science Foundation, USA
CIFellow. From Data to Knowledge: Environmental Sensing and Data Narration ($253,800)

2017 – 2019 Ministry of Education, Taiwan
PI. Civic Making: Bottom-Up Innovation and IoT Proposition in Taiwan ($32,000)

Best Paper and Honorable Mention Awards

2019 ACM CHI 2019 Honorable Mention Award (2 awards)
2019 ACM TEI 2019 Honorable Mention Award

Research and Travel Awards

2019 ACM Graduate Student Travel Award. NSF. $1500
2019 GISA Spring 2019 Travel Award, Indiana University. $950
2019 SICE HCI/d Travel Award. Indiana University. $950
2019 Department Nominee of the Wells Graduate Fellowship, Indiana University. $42,000
2019 GPSG Travel Award. Graduate Professional Student Government, Indiana University. $500
2017 ACM Graduate Student Travel Award. NSF. $2,000
2016 Government Fellowship for Overseas Study. Ministry of Education, Taiwan. $51,000
2010 Graduate Student Fellowship. College of Design, Taiwan Tech, Scholar Grant. $2,400
2010 Valedictorian, School of Design, Class of 2010, Taiwan Tech

Design Awards

2015 Winner, Good Design Award, “ASUS VivoMini (UN62)”
2013 Finalist, Taiwan International Design Competition, “Turn: pencil extender”
2012 Winner, iF Concept Award, “Go Dutch: bill redesign”
2010 Honorable Mention, Nagoya Design Do! Competition, “Save Energy, Save Me: wind slot sticker”
2010 Sponsor Award, Taipei Industrial Design Award, “Under the Tree: bus stop redesign”
2009 Honorable Mention, Universal Design Award, “Wave: universal cutting board”

Service Awards

2021 Special Recognitions for Outstanding Reviews (5 awards). ACM CHI 2021
2020 Special Recognitions for Outstanding Reviews. ACM CHI 2020

PUBLICATIONS

Refereed Conference Publications

2020 **Szu-Yu (Cyn) Liu**, Justin Cranshaw, and Asta Roseway. Making Air Quality Data Meaningful: Coupling Objective Measurement with Subjective Experience through Narration. *Proceedings of the 2020 Designing Interactive Systems Conference: DIS '20*. ACM: New York. (Acceptance rate: 24%).

2019 **Szu-Yu (Cyn) Liu**, Shaowen Bardzell, and Jeffrey Bardzell. Symbiotic Encounters: HCI and Sustainable Agriculture. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems: CHI '19*. ACM: New York. (Acceptance rate: 23.8%). (**Honorable Mention, top 5%**).

2019 Guo Freeman, Jeffrey Bardzell, Shaowen Bardzell, **Szu-Yu (Cyn) Liu**, Xi Lu, and Diandian Cao. Smart and Fermented Cities: An Approach to Placemaking in Urban Informatics. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems: CHI '19.* ACM: New York. (Acceptance rate: 23.8%). (**Honorable Mention, top 5%**).

2019 **Szu-Yu (Cyn) Liu**, Jeffrey Bardzell, and Shaowen Bardzell. Decomposition as Design: Co-Creating (with) Natureculture. *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction: TEI '19.* ACM: New York. (Acceptance rate: 33%). (**Honorable Mention, top 5%**).

2018 **Szu-Yu (Cyn) Liu**, Shaowen Bardzell, and Jeffrey Bardzell. Out of Control: Reframing Sustainable HCI Using Permaculture. *Proceedings of the 2018 Workshop on Computing within Limits: LIMITS '18.* ACM: New York.

2018 **Szu-Yu (Cyn) Liu**, Jeffrey Bardzell, and Shaowen Bardzell. Photography as A Design Research Tool into Natureculture. *Proceedings of the 2018 Designing Interactive Systems Conference: DIS '18*. ACM: New York. (Acceptance rate: 25%; Pictorial).

Refereed Conference Abstracts and Extended Abstracts

2019 **Szu-Yu (Cyn) Liu.** 2019. Designing for Multispecies Collaboration and Cohabitation. *Proceedings of the 2019 ACM Conference on Computer-Supported Cooperative Work and Social Computing: CSCW '19*. ACM: New York. (Doctoral Consortium).

2019 **Szu-Yu (Cyn) Liu**, Jen Liu, Kristin Dew, Patrycja Zdziarska, Maya Livio, and Shaowen Bardzell. 2019. Exploring Noticing as Method in Design Research. *Proceedings of the 2019 Designing Interactive Systems Conference: DIS '19.* ACM: New York. (Workshop Proposal).

2019 **Szu-Yu (Cyn) Liu**. 2019. Designing with, through, and for Human-Nature Interaction. *Proceedings of the 2019 Designing Interactive Systems Conference: DIS '19*. ACM: New York. (Doctoral Consortium).

2017 **Szu-Yu (Cyn) Liu.** 2017. To Decompose Is to Create: Supporting Creativity by Incorporating Nature in Design. *Proceedings of the 2017 ACM SIGCHI Conference on Creativity and Cognition: C&C '17.* ACM: New York. (Graduate Student Symposium Paper).

2016 **Szu-Yu (Cyn) Liu**, Tung-Jen Tsai, Daniel Alenquer. 2016. Exploring Computational Composite: An Approach to Sensorial Interaction. *Proceedings of the 19th ACM Conference on Computer Supported Cooperative Work and Social Computing Companion: CSCW '16*. (Extended Abstract and Poster).

2013 **Szu-Yu (Cyn) Liu**, Jeng-Neng Fang. 2013. Surrealism Expression in Product Design. The second Global Chinese Industrial Design Conference. (Graduate Student Symposium Paper).

Book Chapters (Editor-Reviewed)

2018 Jeffrey Bardzell, Shaowen Bardzell, and **Szu-Yu (Cyn) Liu**. (2018). "Beautifying IoT: The Internet of Things as a Cultural Agenda". *Social Internet of Things*. Alessandro Soro, Margot Brereton, and Paul Roe (ed.). Springer.

TEACHING EXPERIENCE

Research Group Mentorship

2017 - 2019 Ethnographic Fieldwork and Research Through Design on Experimental Farming
Cultural Research in Technology (CRIT) group; PI: Shaowen Bardzell and Jeffrey Bardzell

Individual Student Mentorship

2019 Dominic Matthys (Undergraduate Research Opportunities in Computing)
2019 Noor Hussein (Undergraduate Research Opportunities in Computing)
2019 Pei-Ni Chiang (Master student in HCI/d)
2019 Lu Xi (Master student in HCI/d)
2018 Wei Zheng (Undergraduate Research Opportunities in Computing)

Assistant Instructor

2018 - 2020 SICE, Indiana University, Bloomington IN, USA
I453: Computer & Information Ethics (Fall, 2020)
I694: Thesis in Human-Computer Interaction (Spring 2018, Spring 2019)
I544: Experience Design (Fall 2019)

2013 College of Design, Taiwan Tech, Taipei, Taiwan
DT5017701: Anthropological Approach in Design (Spring, 2013)

2011 Department of Product Design, Art Center College of Design, Pasadena CA, USA
PRD252: Visual Communication IV (Winter 2011)

EXHIBITIONS

2015 Good Design Exhibition, Tokyo, Japan
2013 The Art & Design Elite Scholarship Program Press Conference, Taipei, Taiwan
2012 Student Gallery, Art Center College of Design, Pasadena CA, USA
2012 Dwell Design Exhibition, Los Angeles CA, USA
2011 Taiwan Designers' Week, Taipei, Taiwan
2010 Taiwan Designers' Week, Taipei, Taiwan
2010 Young Designers' Exhibition (YODEX), Taipei, Taiwan

INVITED TALKS

2019 Qualitative Methods for Social Science Studies. S110 Understanding Social Data. Indiana University Department of Sociology. Guest Lecture
2019 Mapping Air: Hyper-Local Perceptions of Pollution. Microsoft Research Redmond Lab HCI Intern Talk
2016 International Design Trends (with Dr. Jeng-Nang Fan). National Education Radio, Taiwan
2013 The Art & Design Elite Scholarship Program Press, Taipei, Taiwan
2011 School of Design Admission Seminar, Taiwan Tech, Taipei, Taiwan

PROFESSIONAL ACTIVITIES AND SERVICES

Conference Program Committee

2021 ACM CHI Design Subcommittee Associate Chair: Yokohama, Japan
2020 ACM CHI Late Breaking Works (LBWs) Track Associate Chair: Honolulu HI, USA
2019 ACM DIS Pictorial Track Associate Chair: San Diego, CA, USA

Conference Organizing Committee

2019 ACM DIS Student Volunteer Co-Chair: San Diego, CA, USA
2019 ACM TEI Social Media Chair: Tempe, Arizona, USA

Conference Student Volunteer

2020 ACM CHI (ACM Conference on Human Factors in Computing Systems, Honolulu HI, USA)
2019 ACM CHI (ACM Conference on Human Factors in Computing Systems, Glasgow, UK)
2019 ACM DIS (ACM Conference on Designing Interactive Systems, San Diego CA, USA)

Conference Peer Reviewer

2018 - 2019 CHI 2021 (Paper), CSCW 2020 (Paper), CHI2020 (Paper, LBW), DIS2020 (Paper), CHI2019 (Paper, LBW), DIS2019 (Paper, Pictorial, Provocation and WIP), C&C2019 (Pictorial), CHI2018 (Paper)

Community Services

2018 - Present Ambassador, Informatics Graduate Studies Office, Indiana University, Bloomington IN, USA
2017 - Present Student Volunteer, Prospective Student Visit, SICE, Indiana University, Bloomington IN, USA
2016 Mentor, GU2IU Prospective Student Program, SICE, Indiana University, Bloomington IN, USA
2016 Coordinator, Industry-University Collaboration, ASUS Design Center, Taipei, Taiwan
2005 - 2016 Mentor, ASUS Foundation Community Service, ASUS, Taipei, Taiwan
2009 - 2010 Co-Director, Graduation Show, Taiwan Tech, Taipei, Taiwan