Nurturing Open Design

Challenges and Opportunities for HCI to Support Crowd-driven Hardware Design

by

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ABSTRACT

Open Design is a crowd-driven global ecosystem which tries to challenge and alter contemporary modes of capitalistic hardware production. It strives to build on the collective skills, expertise and efforts of people regardless of their educational, social or political backgrounds to develop and disseminate physical products, machines and systems. In contrast to capitalistic hardware production, Open Design practitioners publicly share design files, blueprints and knowhow through various channels including internet platforms and in-person workshops. These designs are typically replicated, modified, improved and reshared by individuals and groups who are broadly referred to as 'makers'.

This dissertation aims to expand the current scope of Open Design within human-computer interaction (HCI) research through a long-term exploration of Open Design's socio-technical processes. I examine Open Design from three perspectives: the functional—materials, tools, and platforms that enable crowd-driven open hardware production, the critical—materially-oriented engagements within open design as a site for sociotechnical discourse, and the speculative—crowd-driven critical envisioning of future hardware.

More specifically, this dissertation first explores the growing global scene of Open Design through a long-term ethnographic study of the open science hardware (OScH) movement, a genre of Open Design. This long-term study of OScH provides a focal point for HCI to deeply understand Open Design's growing global landscape. Second, it examines the application of Critical Making within Open Design through an OScH workshop with designers, engineers, artists and makers from local communities. This work foregrounds the role of HCI researchers as facilitators of collaborative critical engagements within Open Design. Third, this dissertation introduces the concept of crowd-driven Design Fiction through the development of a publicly accessible online

Design Fiction platform named Dream Drones. Through a six month long development and a study with drone related practitioners, it offers several pragmatic insights into the challenges and opportunities for crowd-driven Design Fiction. Through these explorations, I highlight the broader implications and novel research pathways for HCI to shape and be shaped by the global Open Design movement.

DEDICATION

To my mom, Nirmala Lowe

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INTRODUCTION

It is possible that at this moment, you are reading this dissertation on a computer screen. If you are still a fan of physical media, you might have gotten a hard copy from a printer. In either case, the computer you are looking at, the printer you used, the chair you are probably sitting on and most of the physical artifacts in your surroundings are products of commercially-driven, capitalistic design processes. These artifacts are envisioned and developed by professionals who are usually themselves from conventional education systems. Most of these are then manufactured in mass manufacturing facilities and delivered to your doorstep through a plethora of profit-oriented logistical and supply chain operations. Their design blueprints, schematics, source codes and both the tacit and explicit knowhow needed to produce them are often highly protected through patents, copyrights laws, NDAs, and non-competing agreements.

In contrast, open design (also known as open source design and open hardware design) is a crowd-driven global ecosystem which tries to challenge and alter contemporary modes of capitalistic hardware production. Open design strives to build on the collective skills, expertise and efforts of people regardless of their educational, social or political backgrounds to develop and disseminate physical products, machines and systems. The production of artifacts is decentralized, nonindustrial and takes place mostly in low-volumes within makerspaces, shared fab lab facilities and at times, in basements and garages. Unlike in capitalistic hardware production, blueprints and knowhow are publicly shared through online platforms such as Instructables[1], code

[1]https://www.instructables.com/

repositories such as github[2], in-person and remote workshops and publications such as the make magazine[3]. These designs are shared, replicated, modified, improved and reshared by individuals and groups who are broadly referred to as 'makers'. While fundamentally building on the ethos and the philosophy of the free and open-source software (FOSS) movement, open design is particularly focused on the development of physical artifacts rather than software.

Over the last decade and half, open design has grown into a global movement and continues to make a positive impact in many areas. Arduino[4] and its other low-cost versions produced by legitimately replicating original open-source designs have made the learning and teaching of microcontroller programming open, democratic and accessible across the globe. With these developments, a range of stakeholders—from university level laboratories in resource-constrained parts of Africa to thousands of amaetuer scientists who practice science outside of conventional laboratories across the world—are empowered by open-source scientific equipment such as, for example, the OpenPCR[5]. Similarly, the project RepRap[6], initiated by the University of Bath and now being supported by hundreds of contributors worldwide, has given rise to a series of low-cost 3D printers making computer-aided design and fabrication accessible even in the remotest parts of the world.

1.0.1 Motivations and Research Goals

Inspired by the continuous positive impact of open design across the globe, my dissertation broadly examines the open design ecosystem from the perspective of Human

[2]https://github.com/

[3]https://makezine.com/

[4]An open source microcontroller platform: https://www.arduino.cc/

[5]A Do-it-yourself thermal cycler for DNA extraction: https://openpcr.org/

[6]https://reprap.org/wiki/RepRap

Computer Interaction (HCI). My work is particularly motivated by the repertoire of methods, tools, theories and practical knowhow within HCI which can potentially be applied to further broaden the positive impact of open design at a global scale. I am also equally interested in exploring the ways in which open design can challenge and (re)shape HCI research and the hitherto uncharted avenues it might open up for HCI. In recent years, interest in open design and related topics such as DIY making and the maker culture have been steadily growing within the HCI academia (e.g., Kuznetsov *et al.*, 2012; Mellis, 2013; Irannejad Bisafar *et al.*, 2018).

My work tries to extend and expand HCI's current understandings of and involvement in open design by examining open design from three perspectives—functional, critical and speculative. Below, I detail my research goals along these perspectives and their positioning within the contemporary HCI research landscape.

The Functional Perspective: In recent times, a multitude of work has examined the role of HCI in supporting functional (utilitarian) aspects of open design. In other words, contemporary HCI research has explored the materials (e.g. Posch, 2017), tools (e.g., Mellis *et al.*, 2013a) and platforms (e.g., Buechley *et al.*, 2008a) that enable the production and dissemination of hardware artifacts outside of conventional settings. However these works mostly focus hobby, personal and educational contexts (e.g., Mellis, 2013; Dalton *et al.*, 2014; Martelaro *et al.*, 2020). As open design continues to grow across continents, there is a gap in pragmatic understanding of the challenges and opportunities it presents for HCI at the global scale. To this end, my dissertation first explores the real world practices of open design with an eye towards understanding the role of HCI in supporting open design's global missions of democratizing hardware production.

The Critical Perspective: Within the context of HCI, materially-oriented hands-on engagements such as digital-physical prototyping, hardware hacking, craftworks etc., are not solely valued for the utilitarian end products they output. HCI has evidently looked at these engagements from a critically reflective point of view — the act of making as critical exploration. This line of thinking largely stems from Matt Ratto's critical making, in which collaborative construction of physical artifacts is argued as a site for joint conversation and reflection of critical sociotechnical issues around the objects that are being made (Ratto, 2011). Notably, in an acclaimed contemporary HCI research, Lindtner *et al.* (2014) showed DIY making as a *site for highly politicized discourse* and highlighted critical making as a tool for HCI to support *deep engagements and critical reflectiveness* within open design. With this backdrop, what this dissertation examines next is open design as a venue for critical sociotechnical discourse. It askes: a) how can the materially-oriented engagements within open design such as workshops, maker faires, hackathons etc., prompt critical thinking and dialogue among participants and beyond? and b) what are the ways in which HCI can intervene in supporting such critical engagements?

The Speculative Perspective: Speculative Design introduced by Anthony Dunne and Fiona Raby argues for design as a medium for provoking critique around potential futures through designed objects and reflecting on the ways in which those objects help or hinder the futures we prefer to create (Dunne and Raby, 2013). My work particularly draws from design fiction—a genre of speculative design which utilizes imaginary and often provocative scenarios presented in diegesis style narratives to critique the future (Blythe, 2014). Within HCI, design fiction has been applied and studied in multiple contexts, including participatory endeavours that actively engage the public. Such participatory forms of design fiction have mostly taken place in relatively small scales, for example in focus group studies, workshops, town hall meetings (e.g, Hoang *et al.*, 2018; Stals *et al.*, 2019; Lawson *et al.*, 2015; Akama *et al.*, 2016). However, the potential of bringing out broad and diverse design fiction inputs from the public through distributed online platforms has not yet been explored within HCI. On the other hand, as of now, the open design ecosystem is largely focused on the actual material production of hardware artifacts. There is a potential, along the lines of design fiction, to extend its scope towards crowd-driven processes that allow people to envision what hardware should or should not be produced. Thus, the third area of discussion in this dissertation explores: (a) how can crowd-based design fiction leverage distributed inputs to envision future hardware products, their (mis)uses, and potential social, ethical and environmental consequences and (b) how such crowd inputs can (re)shape today's design, engineering and decision making processes towards realizing our collective aspirations of the future.

1.0.2 Contributions to HCI

This dissertation expands HCI research within the domain of open design in two ways. First, it deeply examines open design's sociotechnical processes that haven't been previously studied within HCI. Second, it draws from a repertoire of HCI theories, methods and practices to introduce and study novel workflows that enable new modes of open, inclusive and participatory engagements while uncovering new research pathways for HCI.

More specifically, this dissertation offers several key contributions to HCI. First, it explores the growing global scene of open design through a long-term ethnographic study of the open science hardware (OScH) movement, a genre of open design. While building on and operating within the global open design ecosystem, the OScH movement itself encapsulates the key essence of open design within its materials, processes, and people. My long-term study of OScH provides a focal point for HCI to deeply understand open design and the ways in which HCI can shape and be shaped by it.

Second, my dissertation examines the application of critical making within open design through an OScH workshop with designers, engineers, artists and makers from local communities. While providing an insightful case study of critical making in a novel application domain, this work foregrounds the role of HCI researchers as facilitators of collaborative critical engagements within open design.

Third, I present the iterative development and the outcomes of a 6-months long study of a crowd-based online speculative design platform—dreamdrone.org. This platform invites people from different parts of the world to envision and reflect on the future of drones, a timely and controversial topic that relates to emerging aerial hardware products. In addition to presenting the technical details of this platform, this work offers several pragmatic insights into challenges and opportunities for crowd-driven speculative design engagements at scale. In particular, it highlights the potential of utilizing the *wisdom of the crowds* in influencing future technology design processes though collective envisioning and reflecting.

1.0.3 Organization

This dissertation draws from multiple academic disciplines that intersect with HCI including Design, Anthropology, Computer Science and Electrical Engineering. My research methods are largely informed by design ethnography, human centered design and design thinking. In building functional systems, both physical and digital, I rely on modern tools and practices of full stack development, UX design, electronic prototyping and digital fabrication.

In what follows, chapter 2 presents the body of HCI literature that shaped my research. Then I describe my exploration of open design across the next three chapters.

Chapter 3 presents my long-term ethnographically-oriented study of open science hardware(OScH) movement and its broader implication for HCI. Chapter 4 offers insights into the role of HCI in facilitating a critical socio-technical discourse within open design based on the outcomes of a two-part OScH maker workshop. Chapter 5 shifts the focus of this dissertation from OScH to open hardware design for drones. It presents the development and the study of the dreamdrone.org platform and implications towards crowd-driven design fiction at scale. In chapter 6, I conclude by summarizing my overall contributions and discussing future challenges and opportunities for Human Computer Interaction research in the realm of Open Design.

Chapter 2

RELATED LITERATURE

This section summarizes prior work from HCI scholarship that influence my research. My work on open science hardware draws from two major areas of HCI research: DIY making and inquiries into public participation in science. My exploration of Open Design as a site for critical sociotechnical discourse builds on prior HCI work that explore materially-oriented practices as modes of inquiry. In my work on crowd-driven design fiction, I build on the prior work on crowd-based co-design and design fiction.

2.1 HCI and DIY Making

Practices around DIY making have also been examined in a multitude of contexts within HCI, including digital fabrication techniques (e.g., Jacobs and Buechley, 2013; Mellis *et al.*, 2013b, 2011), DIY electronic prototyping platforms (e.g., Villar *et al.*, 2011; Buechley *et al.*, 2008b; Mellis *et al.*, 2013c), personal fabrication (e.g., Mellis and Buechley, 2014), and self-made tools (Bardzell *et al.*, 2014), and many others. In parallel, a body of work has focused on the broader impacts of such practices in the contexts of community engagement with technology (Wang and Kaye, 2011; Rogers *et al.*, 2014), social well being (Taylor *et al.*, 2016; Toombs *et al.*, 2015; Fox *et al.*, 2015; Meissner *et al.*, 2017), and emerging sites of open innovation (Bardzell *et al.*, 2017; Lindtner *et al.*, 2014). Another strand of research has focused on DIY knowledge sharing including the work by Torrey *et al.* (2007) on online how-to pages and the work by Tseng and Resnick (2014) investigation on the challenges of authoring DIY projects. Even though OScH overlaps with existing HCI research on DIY making and maker cultures, the scope of OScH goes beyond those topics as it tries to serve a significant global need by lowering the barriers for democratic access to scientific equipment around the world. To this end, my work on open science hardware explores real-world OScH dissemination, which comprises several underexplored areas in OScH making and knowledge sharing, including local sourcing of materials, economic and logistical constraints, language barriers and issues related to customization and troubleshooting. Moreover, in this work, we positioned ourselves as active OScH practitioners, and our approach is inspired by the work done by Wakkary *et al.* (2015) on DIY tutorial authorship, which suggests a practice-oriented role for interaction designers.

2.2 Inquiries into Public Participation in Science

Community-driven science practices have captured the attention of HCI and design researchers resulting in many publications at popular HCI venues, which explore the intersection of computation and participatory science practices (e.g., Kuznetsov and Paulos, 2010a,b; Eveleigh *et al.*, 2014). A body of recent HCI work explores these practices through participatory design (Qaurooni *et al.*, 2016), as new forms of knowledge production (Kuznetsov *et al.*, 2015), and by investigating their social, political and economical implications (lin kaiying *et al.*, 2019). More specifically in the domain of open science hardware, a series of work done by Kera et al. has explored the scientific, creative, social and humanitarian uses and non-uses of OSH on a global scale (Kera, 2018, 2012; Ausareny *et al.*, 2014)). Not only does prior HCI citizen science research aim to democratize citizen-driven science practice, it also highlights open source scientific equipment as a key opportunity area for HCI. Building on this, my work on open science hardware explores how HCI might be applied to support real-world dissemination and widespread adoption of OScH, a topic which has not been widely studied within HCI.

2.3 Materially-oriented Practices as Modes of Inquiry and Collaboration

Materially-oriented engagements around both the processes of creating artifacts and the artifacts created have been explored as a medium for provoking expressions, stimulating debate and fostering collaborations in a multitude of contexts within design scholarship. Critical design, a design research approach developed by Tony Dunne and Fiona Raby (Dunne and Raby, 2013), strives to push the goals of product design beyond fulfilling functional needs of consumers by embodying provocative and speculative elements into designed artifacts and encouraging alternative viewpoints from both designers and users. Disalvo et al.'s neighborhood networks project describes creative expressions and public discourse around civic issues facilitated through participatory production of digital-physical artifacts (DiSalvo *et al.*, 2008). Similarly, Sengers' work on reflective design (Sengers *et al.*, 2005) and Matt Ratto's critical making (Ratto, 2011) provide further examples of materially-oriented engagements as a site for critical reflections on complex sociotechnical issues. Explorations on the use of artifacts to foster collaborations and to enhance communication are also rooted in a series of work by Star, et al. on the concept of boundary objects (Star and Griesemer, 1989). Recent DIS research including Weisling's work on collaborations between visual artists and musicians (Weisling, 2017), Zeagler et at's study on making of a wearable musical instrument (Zeagler *et al.*, 2017) and Dalsgaard et al.'s work on emerging boundary objects and boundary zones (Dalsgaard *et al.*, 2014) provide several other instances of physical artifacts facilitating cross-disciplinary collaborations. Building on these, in chapter 3, I explore materially-oriented engagements around OScH as a site for interdisciplinary collaborations and a medium for provoking constructive cross-disciplinary dialogues around issues related to open science. Below, I detail the OScH workshop sessions and design activities, which facilitated such engagements.

2.4 Crowd-based Co-design

The idea of leveraging the wisdom of the crowd (Surowiecki, 2005) in design processes is not new to HCI. Many HCI work have explored the potential of using online crowds to help solve complex (Bernstein *et al.*, 2015) or creative problems (Kim *et al.*, 2014; Meissner *et al.*, 2017). For instance, Dow *et al.* (2013) explored how input from online crowds affect student learning and influence their motivation for project-based innovation activities in the classroom. CrowdCrit (Luther *et al.*, 2014), web-based system allows designers to receive design critiques from non-expert crowd workers. Another body of work has explored the involvement of online crowd in different stages of the design process: data collection (Salganik and Levy, 2015), user research (Kittur *et al.*, 2008), and evaluation of the final design (Yu and Nickerson, 2011a). The work by Park *et al.* (2013) Crowd vs. Crowd (CvC) used competitions between crowd teams, led by a designer, to crowdsource the entire design process. In the meantime, the possibility of using ideas generated by non-expert crowds to spawn new ideas has also been investigated under this topic. The project Crowdboard (Andolina *et al.*, 2017) introduced an augmented workspace to be used by co-located ideators (design teams). It projects novel inspirations and ideas that are generated in real-time by non-expert crowds,recruited on-the-fly. Similarly, Yu *et al.* (2016) used non experts to identify distant domains that have the potential to yield useful and non-obvious inspirations for solutions.

As mentioned earlier, many of these works have focused extensively on gathering crowd inputs to solve a particular, pre-identified design problem or on outsourcing aspects of the design process requiring a large number of people. However, in our work we try to build platforms and crowd-based workflows that enable the lay public to critically and open-endedly express their interests, aspirations and concerns related to socio-technological issues and actively engage them in addressing those issues.

2.5 Design Fiction and HCI

Tanenbaum (2014) pointed out three major roles for design fiction within the HCI research and practice: 1) a method of envisioning new futuress, 2) a tool for communicating new innovations, and 3) a means of providing inspiration and motivation for design. Many of the HCI work done in the realm of design fiction can be seen along one or many of these three roles. Lindley and Coulton (2015) propose design fiction as a way of showcasing prototypical interactions of technologies or devices that do not actually exist, but that are on plausible future trajectories. In a similar recent work, Wood *et al.* (2017) use short stories created by a set of online writers to examine the cultural ideals constructed of virtual reality (VR) porn. It reflects on participant generated fictional stories stem about a male character who was about to have his “very first virtual reality porn experience”, and envision future human interactions with VR technologies in the context of “Designing for Eroticism”, an agenda the authors suggest through their work. Similarly, in “50 shades of CHI”, Buttrick *et al.* (2014) use short stories written in the form of parodies of the erotic novel “50 shades of grey” to illustrate and question the subservient nature of humans in their interaction-driven relationships with computers.

In the meantime, instances of exploring the role of design fiction as a tool for communicating future innovations and its applications can be found both within and outside of HCI academia. Blythe *et al.* (2015) use design fictions created in the form of future advertisements to communicate their findings of a study related to ‘positive-aging’. They use these fictitious advertisements to communicate the aspects of the broader design space around positive-aging. Outside of the HCI academia, several practice based interaction design studios such as NearFutureLaboratory[1], SuperFlux[2], and DesignFriction[3], apply the methods of design fiction to prototype and communicate future technologies. Moreover Microsoft's future vision video[4] and Corning's "A Day Made of Glass"[5] employ design fiction to situate their products and services in utopian futures. My work builds on this rich and growing HCI scholarship of design fiction and its applications, to explore design fiction as a means of getting lay public to envision and critique future technologies.

[1] http://nearfuturelaboratory.com/
[2] https://superflux.in/
[3] https://design-friction.com/
[4] www.youtube.com/watch?v=w-tFdreZB94
[5] www.youtube.com/watch?v=6Cf7ILeZ38

Chapter 3

OSCH IN THE WILD: DISSEMINATION OF OPEN SCIENCE HARDWARE AND IMPLICATIONS FOR HCI

This chapter explores the growing global scene of open design through a long-term ethnographic study of the open science hardware (OScH) movement. While building on and operating within the global open design ecosystem, the OScH movement provides a focal point for HCI to broadely understand the open design in real world. Sections of this chapter were taken from Fernando and Kuznetsov (2020) and Fernando *et al.* (2016a).

Over the last decade, efforts to democratize access to science have grown into a global movement. At the forefront of this, the Open Science Hardware (OScH, formerly known as OSH) initiative aims to create open alternatives for often expensive proprietary scientific equipment and to reduce barriers for scientific experimentation

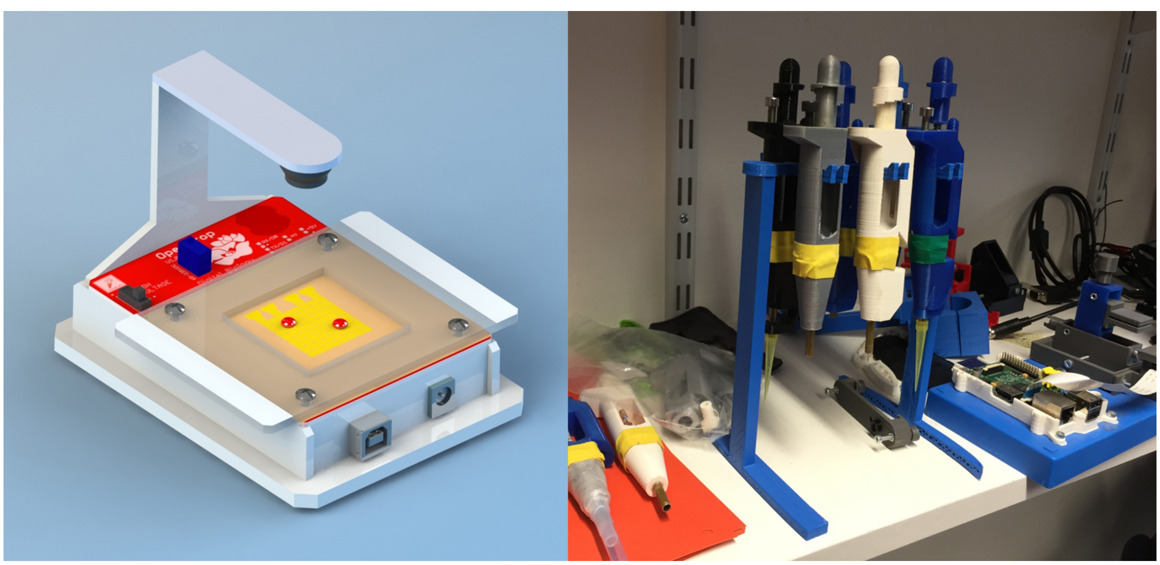

Figure 3.1: OpenDrop Digital Microfludics Platform Developed by GuadiLabs (left); 3D Printed Pipette (right)

both within and outside of professional labs (Kera, 2018). The OScH movement makes such open designs globally available through free and modifiable blueprints (e.g., Biropette - 3D printable micropipette (Figure 3.1 right)) or as pre-built open-source instruments (e.g., OpenDrop (Figure 3.1 left) or DIY assembly kits (e.g., Open PCR (PCR, 2019)), which can be obtained, built or assembled for a fraction of the cost of their commercial counterparts. The OScH movement operates within the broader maker culture and takes advantage of DIY fabrication technologies such as 3D printers, laser-cutters, and open electronic prototyping platforms such as Arduino and Raspberry Pi.

While OScH has the potential to broaden participation in science and impact community-driven knowledge production, effective dissemination of OScH in the real world proves to be challenging due to a lack of clear guidelines for documentation, protocols for quality control and widespread platforms for collaboration (GOSH, nd). With this backdrop, this chapter presents a study in which we explore real-world practices related to the dissemination of OScH, with an eye towards the opportunities and challenges for HCI. Our work builds on HCI's rich scholarship on DIY and maker movements (e.g., Bardzell *et al.*, 2017; Lindtner *et al.*, 2014), but we situate OScH as a unique domain within this landscape for two key reasons. First and foremost, OScH is not solely intended for hobby contexts and is being increasingly used for professional science experiments around the globe including resource-constrained regions (Brazil, nd). This extends the scope of OScH beyond popular HCI topics of making such as hobby work, personal use, or self-satisfaction (e.g., Mellis and Buechley, 2014; Rogers *et al.*, 2014; Jacobs and Buechley, 2013) into serving a global socio-economic need (Brazil, nd). Secondly, even though the design files and DIY instructions of OScH are openly available over the internet, in most cases, real-world end users, such as biologists, food scientists, or chemists might not possess the necessary skills or expertise in making (e.g., digital fabrication, basic electronics, etc.) needed to replicate these designs. This in turn brings novel challenges for the dissemination of OScH.

Our research goal is to better understand the challenges for dissemination and adoption of OscH, and to examine how HCI might be applied to overcome these. To this end, we conducted our study in two-parts. First, through a long-term iterative design process that started in 2015 in a collaboration with hobbyists and biologists, we developed an open science hardware platform, a DIY incubator (Figure 4.1A), and openly disseminated its design through the Instructables website (Instructables, 2015) and two maker workshops. We conducted these dissemination activities as self-reflective exercises in order to gain hands-on experience in OScH dissemination, and this work positioned us as active contributors to and members of the wider OScH community. Secondly, we interviewed eight open science hardware practitioners from different parts of the world including Africa, Asia, Europe and South America. These interviews aimed to uncover the broader experiences of developing, disseminating and using OScH in the real world.

This chapter presents findings from our research consisting of insights gained from the interviews and our own self-reflections from building and disseminating an OScH platform. Our findings reveal how different OScH dissemination modalities serve unique purposes towards the broader goal of openness and democratic access to science. Our research also reveals how current dissemination practices face challenges for widespread adoption of OScH, and highlights the importance of proactive interactions between OScH developers and end users. We conclude by discussing the opportunities for HCI to lower barriers for customization, support internationalization of OScH, and scaffold collaborations between OScH developers and end users. More broadly, our work highlights new opportunities for HCI to engage with the OScH movement and to contribute to its core mission of open and democratic participation in science.

3.1 Background

The roots of OScH go back to the late nineties. Early hardware-focused open source activities started with the emergence of the Open Design Movement in 1997, which includes the development of physical artifacts—referred to as Open Source Hardware— through the use of publicly shared design blueprints (Bonvoisin *et al.*, 2015; Geyer *et al.*, 2012). Since its inception, the Open Design Movement has been shaped and complemented by the Open Source Software (OSS) movement and maker culture (Gibb and Abadie, 2014). In the mid 2000s, the emergence of open source DIY electronic platforms such as Arduino, vendors such as Adafruit and Sparksfun, and the proliferation of affordable digital fabrication technologies like consumer-level 3D printers, gave open source hardware and the maker movement a huge boost (Bonvoisin *et al.*, 2015). This eventually sparked a new paradigm of scientific equipment production, where professional scientists as well as amateur science enthusiasts could fabricate instruments themselves.

At present, hundreds of open-source designs, build instructions, and DIY assembly kits of OScH are available online (e.g., Open-Labware.net, 2019; cathalgarvey, 2009). Additionally, there are many pre-built open-source instruments that can be bought for a fraction of the cost of their proprietary versions (e.g., PCR, 2019; Gaudi-Labs, 2019)). Over the last decade, OScH has become a global phenomenon. Today, it is being developed and used for education, research, hobby work, as well as to facilitate community driven local citizen science initiatives such as tackling environmental pollution and tracking diseases around the world. While these efforts are facilitated and coordinated by regional OScH initiatives such as TECNOx in Latin America (TECNOx, 2009) and The Tech Academy in Bangladesh (Academy, 2010), these communities are encompassed by the Global Open Science Hardware (GOSH) network[1]. To this end, since 2016 GOSH annually organizes the Gathering for Open Science Hardware (also known as GOSH), supports open science publications, and provides a forum for the global open science hardware community.

Foundational Principles of the GOSH community:

The global Open Science Hardware network operates in accordance with principles laid out in the GOSH manifesto with the mission of making open science hardware ubiquitous by 2025 (GOSH, nd). In summary, the GOSH manifesto outlines 10 foundational principles highlighting the open, accessible and decentralized production and distribution of open science hardware, and its ethical and inclusive use regardless of one's *scholarly background, country, race, sex or religion.* It calls for full disclosure of design files, blueprints, source codes, schematics etc., to ensure maintainability and the right to repair, modify and redistribute. The GOSH manifesto also advocates for *moving science toward communal, accessible, and collaborative practices, and away from territorial, proprietary, institutional, and individualistic practices,* transcending science beyond traditional lab setups. Furthermore, it also details the role of OScH in empowering people and communities *to pursue research that is of interest to them, to have technological transparency and public oversight* and to *build a movement.*

While our own work has been predominantly embedded within this global open science hardware ecosystem, we also draw inspirations from two major research trends within HCI and Design—Inquiries into Public Participation in Science and DIY making—which were discussed in the related literature section.

[1]http://openhardware.science/

3.2 Methods

To investigate the real-world practices of and challenges for OScH dissemination, we conducted a two-part study: a) an interview study with eight open science hardware practitioners and b) a series of self-reflective activities where we designed and disseminated an open science hardware platform—a low cost, yet accurate DIYbio incubator—via the Instructables website and two DIY maker workshops. Below we describe our two-part study methods in detail.

3.2.1 Interview Study with Open Science Hardware Practitioners

We promoted our interview study using an invitational flyer seeking participants with at least one year of experience in building, hacking, sharing, or making use of open science hardware as a part of their open science practice. We distributed the flyer to members of the Gathering for Open Science Hardware (GOSH) network as well our personal contacts from the broader open science hardware community in which we have been embedded for several years.

We recruited eight open science hardware practitioners (P1-P8, 4 females, age range 22 to 50) from Asia (P1,P2, P5), Africa (P6, P7), Europe (P3), South America (P4), and the USA (P8) who responded to our flyer and fulfilled the selection criteria. While all eight participants had substantial experience in replicating and using OScH, P2 and P3 also had extensive experience in developing and disseminating new designs.

While all the participants were driven by a shared passion for advocating for open science hardware, they had varied personal motivations to be involved with OScH. For many of them (P1, P5, P6 and P8) OScH is a means of obtaining the necessary equipment to conduct science experiments in places where they do not have access to conventional lab equipment. These include communal places such as makerspaces and libraries, outdoor field studies, and classroom settings without access to a laboratory. P2 was particularly interested in sharing his knowledge with open science hardware communities to teach them to build their own science equipment. P3 currently operates a community driven open science lab space and runs a startup business that develops open science equipment, which is sold online. P4 who is a social science researcher, studies the community practices related to open science hardware as part of her academic research. P8, a college professor in Physics, builds and uses OScH equipment for his own research and teaching in order to overcome the financial and geo-political barriers of obtaining conventional lab equipment.

Interview Procedure

Interviews were semi-structured, 45-90 minutes long, and were conducted by video calls with the exception of one in-person interview with P8. We started the interviews by briefly introducing our research. Then we asked open-ended questions related to the OScH participants developed, replicated or used, the challenges they faced, and their suggestions to improve OScH dissemination platforms and methods. We further asked participants about their involvement with the OScH community and their aspirations related to practicing science and open knowledge sharing. We audio recorded all the interviews, which were later selectively transcribed.

3.2.2 Self-Reflective Dissemination of Open Science Hardware

In parallel, over the last five years, we have been exploring the intersection of HCI and open science hardware through several first-hand research research activities. We established a BSL-1 open biology lab—a facility that supports work with minimally-risky procedures and materials (for Disease Control and Prevention, 2018)— within

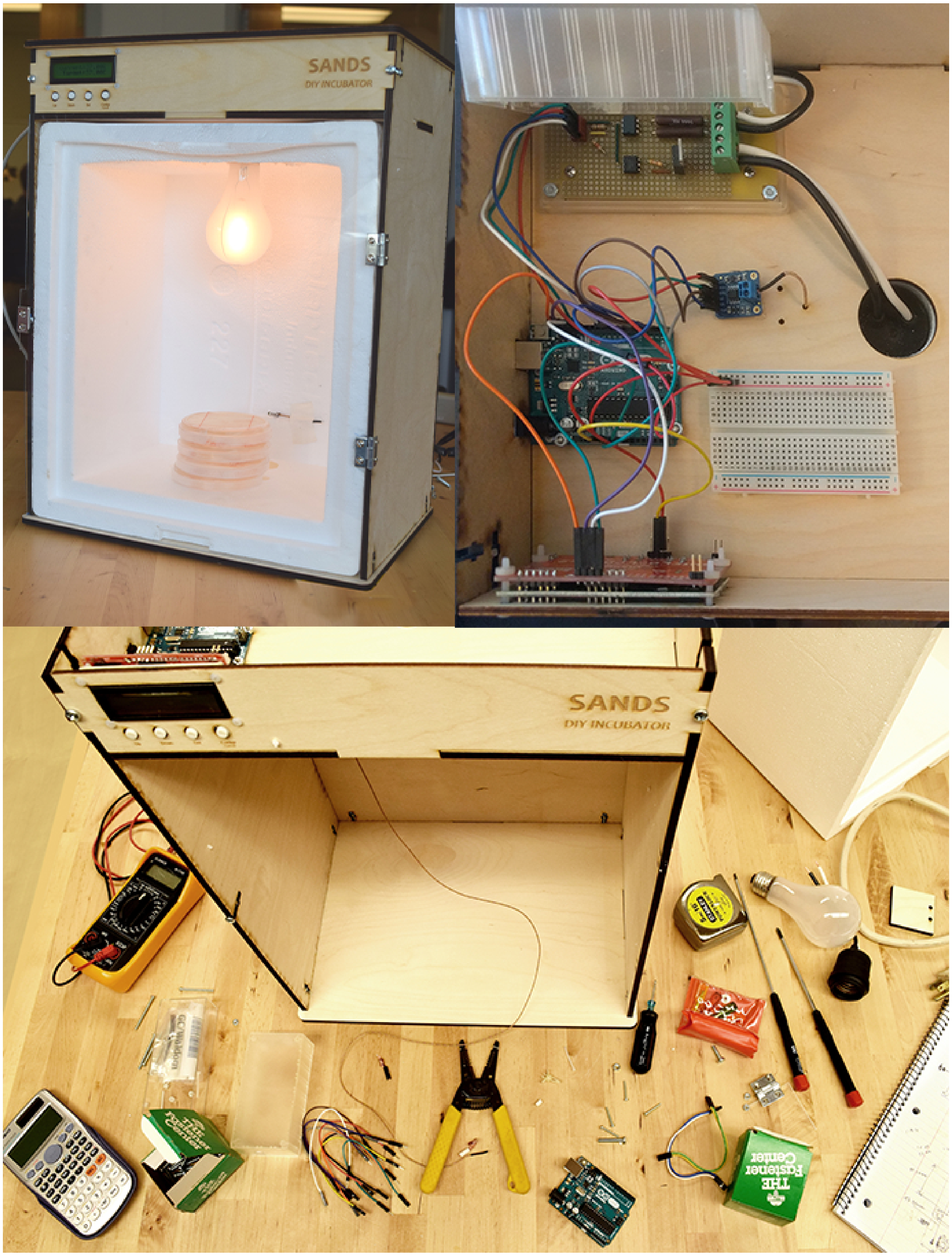

Figure 3.2: The DIYbio Incubator, Electronic Assembly and During the Maker Process

Figure 3.3: Participants Using the DIYbio Incubator During a Biochaking Workshop at ACM CHI 2017

our HCI studio (Fernando *et al.*, 2016b). Working with biologists and hobbyists, we identified a need for and designed a low-cost (USD 75) and accurate (+/- 0.25C) incubator which can be used for basic microbiology experiments such as bacteria culturing and yogurt fermentation. In our design process, we made use of low-cost, simple materials such as a styrofoam box and a tungsten light bulb, and off-the-shelf DIY electronic components such as an Arduino, an Adafruit Temperature sensor and a pre-built LCD module. In order to accurately control the temperature, we custom-designed an AC phase control module from scratch. We also designed a wooden laser cut enclosure to reliably house all the components (Figure 3.2). We successfully used this low-cost incubator in several microbiology experiments within our facility as well as at other DIYbio workspaces (Figure 3.3) including a local hackerspace and a workshop at ACM CHI 2017 (Balaam *et al.*, 2017).

Then, we disseminated our incubator using two methods: an online tutorial posted on Instructables and two maker workshops.

Disseminating via Instructables

We openly shared our design files (CAD files of the enclosure), electronic schematics, bill of materials, and step-by-step guidelines for replicating the incubator on the Instructables website (Instructables, nd). We then used the Instructables tutorial as a medium to connect with real world OScH users. To this end, we actively engaged with the users who tried out our design via online discussions, direct messages and emails. To date, our Instructable has been viewed over 15,000 times. We received around 20 messages/emails from end users on topics such as customizing or repurposing our design, seeking assistance for troubleshooting and inquiring about possibilities of using alternative materials.

Disseminating via DIY Maker Workshops

In addition, we disseminated our platform in two maker workshops. The first of the two workshops was a half-day event held at a popular makerspace in central Singapore. The second workshop was held as two 3-hour long sessions over two consecutive weekdays at Genspace—a community driven biospace in New York City (Genspace, nd).

Participating Communities: The makerspace where we hosted our first workshop is one of the most popular places among Singapore DIY communities with diverse

Figure 3.4: Workshop Participant Assembling Our OScH Kit to Build a DIYbio Incubator at HackerspaceSG, Singapore (top) and Genspace, NYC (bottom).

interests ranging from electronics and IT to art and biology. The DIYbio community with whom we co-organized the workshop is affiliated with this makerspace. Even though the makerspace does not provide bio equipment or lab facilities to conduct biology experiments, this bio community makes use of this space for regular meetups and workshops related to biotechnology. Participants were invited through a public event page created on Facebook and 6 participants (4 females, 2 males, age range 18 to 45) attended. Additionally, 3 members of the makerspace who had expertise in electronics were actively involved in the workshop by guiding the participants throughout the hands-on sessions.

Genspace, where the second workshop was held, is a well-established DIYbio community and BSL-1 lab space in New York City. This community consists of hobbyists, entrepreneurs, artists, designers, and scientists. The community space provides its members with a laboratory equipped with molecular and synthetic biology facilities. The workshop held here was promoted through an online social event page and 5 participants (3 females, 2 males, age range 20 to 55) attended. Only 2 participants had prior experience with DIY electronics.

Workshop Structure: In both workshops, participants were divided into groups of 2 or 3 people, matching participants to compliment their prior knowledge of electronics. Both workshops followed a similar structure. They started with an introduction to Arduino programming, in which participants learned how to use the Arduino IDE, connected an LED, uploaded an example code to blink an LED, and modified it. Participants were then presented with an overview of the materials required to build our incubator. After that, they relied on relevant online tutorials (e.g., product web pages and our Instructables post) and guidance from workshop organizers to experiment, build, and test the functionality of the incubators (Figure 4.2). Throughout the workshops, we encouraged questions and discussion. At the end of the maker activities, we carried out informal post-workshop discussions in order to gain feedback from the participants. All these discussions were audio-recorded with the consent of the participants and later transcribed.

3.2.3 Data Analysis

Transcripts from the eight interviews and workshops along with the records of online discussions with Instructables users and personal notes were synthesized using open coding methods to extract common themes. In this chapter, we reference data owing to participants from our interviews as P1-P8, participants from our first workshop as W1P1-W1P6, and participants from the second workshop as W2P1-W2P5.

3.3 Findings

The diversity of the interviewee pool together with our own experiences of interacting with open science hardware enthusiasts in multiple contexts allowed us to broadly understand the ways in which OScH is disseminated in the real world and the deterrents for widespread adoption. Furthermore, throughout our study, we noted the importance of proactive engagements between OScH developers and end users, and technical and social challenges for such engagements. Below we detail our findings under three themes: how different OScH dissemination modalities serve unique purposes, challenges for widespread adoption of OScH, and collaborations between developers and end users.

3.3.1 Different OScH Dissemination Modalities Serve Unique Purposes

In our research, we found that the ways in which OScH is disseminated fall into three distinct categories: online DIY instructions, pre-built open-source instruments, and OScH workshops organized by local OScH communities. While all these dissemination modalities are based on the common ethos of openness and democratic access to science, our findings revealed how each of these modalities embrace those principles in unique ways.

Online DIY Instructions Enable Reaching a Wider Audience with Less Overhead

Online DIY instructions provide step-by-step guidelines to replicate OScH designs produced by OScH developers. In most cases, such instructions also come with bills of materials (BOM), web links for sourcing materials, firmware source codes, and design blueprints such as CAD models, electronic schematics and PCB designs. End users can follow these instructions by making use of digital fabrication equipment such as 3D printers and laser cutters and basic maker skills such as microcontroller programming, wiring, soldering, woodworking etc. These instructions are shared through OScH web platforms like Hackteria (Hackteria, nd), DocuBricks (DocuBricks, nd) as well as popular DIY documentation platforms like Instructables (Instructables, nd) and, in some cases, source code repositories such as GitHub (GitHub, nd).

With the accelerated growth of online science and DIY communities in the last decade, OScH developers can now reach a wider audience by disseminating OScH instructions through DIY tutorials. This includes communities from regions which are otherwise constrained by geo-political barriers such as international trade sanctions and logistical limitations (Brazil, nd). The story of P7, an African physicist and a university lecturer who populated a physics lab from self-produced equipment provides a noteworthy example. Due to several sanctions imposed against his country, it was difficult for him to acquire instruments for his research and teaching. Because of these limitations, he went on to successfully build equipment including a signal generator and multi-gate sequence timer, by solely following DIY instructions available over the internet. Similar to open-source software, this method of dissemination is done entirely through digital mediums, which significantly reduces the overhead costs for developers. Currently, hundreds of DIY tutorials for building science instruments are available over the internet, including many derivatives of similar instruments.

Pre-built Open-source Instruments Enable Immediate Entry Into Science Experimentation

OScH is also disseminated as pre-built units that often allow complete out-of-the-box functionality (e.g., Open Drop. In some cases, these are available as kits that can be assembled without special skills or tools (e.g., Open PCR[2], a low-cost yet accurate thermocycler for controlling PCR reactions for DNA detection). These pre-built units and kits are usually sold online for a fraction of the cost of proprietary equipment by individuals or small groups of developers. They are often manufactured in relatively small quantities by low volume manufacturing facilities such as PCB houses and fab labs. Even though these pre-built instruments do not require tinkering from end users in order to function, developers make their design blueprints and source-codes openly available, which enable these instruments to be inspected, repaired, modified, and even sold by anyone.

Primarily, these pre-built units and kits provide relatively low-cost options for obtaining science instruments for practitioners who are constrained by the higher price tag of proprietary equipment and do not have the time or skills to build hardware from scratch. While online DIY instructions require time, effort, and skills in making, disseminating instruments that are already pre-built enables immediate access to affordable scientific instruments. P3 further elaborated on this: *"It is hard to think that everyone has the skills and time needed to build tools by following tutorials.*

[2]https://openpcr.org/

Sometimes you have to put in more time for troubleshooting after you build it. Some people are primarily interested in doing science they love and curious about, but not necessarily in building instruments or playing with electronics. They are just looking for tools that they can afford." Many other participants (P4, P5, P6, P7 and P8) also expressed similar sentiments, and our experience with disseminating our incubator OScH platform also resonates with them. In the DIY biology workshops we conducted, having pre-built equipment enabled the participants to not worry about wiring components, programming the Arduino or troubleshooting the circuit, and instead, they had more time to tinker with bacteria, nutrients, petri dishes, and swabs—materials they were innately interested in working with.

OScH Workshops Serve Local Needs and Scaffold Communities of Active Learners

OScH workshops are usually organized by local open science hardware activists and are highly influential in promoting local adoption of OScH around the world. These workshops are primarily intended for serving local needs related to the dissemination of OScH, such as helping communities to build their own instruments using locally sourced materials. As our interviewees mentioned, these workshops are mainly conducted in or translated into local languages when organized by non-native speakers. While these workshops often produce functional instruments, their major focus is not the final product, but rather the process of making and learning. According to P1, instead of closely following a set of instructions, these workshops try to empower people to take ownership of their scientific instruments by providing a holistic understanding of the maker process: *"Workshops teach users to understand how things work, and to know what's inside and then later improve them or customize to their needs. This is a way of empowering them to take ownership of their practice."*

Another noteworthy aspect of these workshops is the simple and opportunistic (Hartmann *et al.*, 2008) nature of the artifacts being built during these workshops. To this end, P2, who has spent substantial time in Southeast Asia conducting such workshops and open science field work, elaborated on how materiality and tools affect the participants: *"Products with nice enclosures and white laser cut wood might make them look reliable. But people may also think that they can not build these things without a laser cutter. Whereas messy prototypes with hot glued parts look easy to build and are less intimidating. I always try to keep it simple [by] only [using] everyday materials and simple tools."*

Furthermore, our participants mentioned these workshops as being highly generative encounters as they often produce constructive community discussions around open science and other local issues. To this end, P2 emphasized *"human to human interactions"(P2)* that occur during hands-on making as integral to building communities. These sentiments align with our experience as well. Our workshops also produced many impromptu discussions around broader issues related to open science hardware including safety and ethical concerns, the role of universities and research institutes in promoting open science hardware, and potential ways open science hardware can challenge and reshape traditional academic models.

3.3.2 Challenges for Widespread Adoption of OScH

In recent years, hundreds of local grassroots organizations have rallied around the global OScH movement striving to promote OScH around the world. However, our study highlighted several challenges that hinder widespread adoption of OScH. Below we describe them under three categories: challenges for customization, challenges for troubleshooting, and challenges for international adoption.

Challenges for Customization

Our studies highlight instances where users faced challenges to customize open designs to better fit their needs. Over the last three years, we have received a number of direct messages through Instructables from users seeking help to customize our incubator design. These ranged from modifying the source code to be compatible with different versions of Arduino boards, to supporting different AC input voltages or repurposing our design to build a chicken egg hatcher. However, what was most striking to us were the instances where users found it difficult to make minor adjustments to the 2D drawing of the enclosure based on the dimensions of the styrofoam box they used. The dimensions of the laser cut enclosure could be modified by editing the CorelDraw file we provided with our Instructable. Even though making smaller adjustments to a CorelDraw file may seem trivial, in most practical cases users were unable to do so due to not having access to a computer with CorelDraw (or any similar program), not knowing how to use those software packages, or (in most cases) both. Similarly, during a post-workshop discussion session, one participant (W2-P2) stated: *"This incubator is too big for my space, I want a smaller one with a smaller styrofoam box. Is there a tool that I can just enter the dimensions of my styrofoam box and it will generate a file for me? [Because] I don't know how to do it manually."*

While many of our interview participants also expressed similar concerns, according to some of them (P1, P4, P5), another major challenge for customization is the complexity of the designs. As they mentioned, sub-elements of those designs (i.e., sub-assemblies of a CAD file, individual electronic components used in a PCB, dimensions of 3rd party hardware, etc.) are tightly coupled to each other, which in turn makes doing even a simple modification challenging. P4 elaborated: *"Most of the time, if you want to change or modify a design, you should learn the required soft-*

ware tools first. Even if it is a very small change, you should have a reasonable level of competency in that software. Because of the way some of these files are originally created, a small change can lead to a lot of other changes. This is a real barrier for most of the users."

Challenges for Troubleshooting

Throughout our interviews, participants pointed out several instances in which they had to go through multiple iterations of troubleshooting in order to get their instruments to function. According to them, the biggest challenge for troubleshooting is the lack of simplified documentation on underlying working principles. P5 stated: *"If you do not understand the source code or how a circuit works you can't fix them. The problem is, most online tutorials usually don't explain how things work, even if they do, they were not written in a way that everyone can understand."* Over the last 5 years, we have received multiple emails in response to our Instructable, asking for simplified documentation on parts of our OScH design (e.g., PID logic, AC phase controller, use of Arduino hardware timers). Most of the emails mentioned that this information would help troubleshoot the OScH. We made several updates to our Instructable by integrating simplified explanations of the underlying working principles of our system.

In addition, according to P1, another facet of this challenge is the lack of information on potential issues and solutions included in online instructions. As she put it: *"Online documents provide you with sets of instructions to follow, but they do not document the ways in which you can potentially get those instructions wrong or the previous instances of people running into problems when trying to follow those instructions, [or] how did they overcome those problems."* While many of our participants mentioned instances where they ran into issues when following online instructions as well as instances where they were able to successfully troubleshoot such issues, none of them had proactively shared such experiences through online channels.

Challenges for International Adoption

Seven out of the eight participants in our interview study had substantial experience of working with non-English speaking open science hardware communities. According to them, a key challenge faced by these communties is the language barrier (e.g., P6: *"in my experience the biggest issue is the language"*). As they pointed out, the majority of online materials are in English and most open sharing platforms do not provide translations or multilingual support, which significantly hinders their use in non-English speaking regions. As P1 mentioned *"Platforms like Instructables are heavily west-centric. [Most of the] content is in English, they are not popular among non-English speaking communities."* Another challenge is that these materials are not search-engine-optimized for non-English search terms. According to P2, most of these materials do not get picked up by search engines when native language search terms are used. He further elaborated on this issue: *"Some of the tools I built are available in Hackteria for years, but people in Indonesia haven't even seen them. It is a problem in Europe as well. When people use German or French search terms, they do not see materials written in English."*

Apart from language barriers, most open designs rely on hardware components that are either only available in North America or Europe or are extremely expensive to obtain in other countries due to shipping costs and economic disparities. P2 went on to further elaborate on this: *"One popular thinking is that anything "Arduino-powered" is cheap, but the reality is Arduinos are still comparatively expensive in some countries. For the price of an Arduino you can spend a whole week in Indonesia."* Nonetheless, our interviews brought into focus many successful attempts in building functional instruments in those regions in spite of such challenges, including P7's lab equipment and P2's work in Southeast Asia using locally-sourced materials.

When reflecting on these concerns, we noted that the design of our open-source incubator is also tightly coupled to components that can only be sourced through North American distributors such as Adafruit or Amazon US. Even though we tried to make some references to local or regional vendors and tried to make it easier to build our kit using locally sourced materials, we were unable to do so due to the lack of information about regional suppliers. Because of these challenges, in many cases we responded to requests by shipping all necessary off-the-shelf components together with our custom made AC control module. However, this model is not feasible in the long run due to shipping and handling costs.

3.3.3 Collaborations between OScH Developers and Users

Unlike proprietary scientific equipment, OScH expects end-users to be more active than mere consumers, and encourages proactive participation from end users to inform the development process (GOSH, nd). As P5 eloquently stated, *"OScH [platforms] are not intended to be considered as products. They are projects. No matter if you replicate, hack or modify an existing design or just use an out of the box instrument, you can give back to the community by sharing your experience of building or using it and help improve the project."*

While iteration based on consumer feedback is not uncommon in commercial product design processes, OScH development projects significantly rely on community-driven approaches to obtain user feedback due to monetary restrictions. Most of these projects are driven by non-profit organizations or, are operated as individually-run small scale start-ups. Due to this, unlike their counterparts in capitalistic manufacturing models, OScH developers do not possess the luxury of having a dedicated budget for rigorous user testing, quality assurance, or user research. P1 elaborated on how the OScH model is designed to overcome such restrictions through participatory approaches: *"These instruments are pressure tested in the field where they are being used. They are QAed by the people who build [replicate] them or use them, not only by who developed them. At the end of the day, it is a community effort, we all should contribute."* P3, a small-scale OScH manufacturer, shared one instance of many where this model was hugely successful: *"I got really important contributions from users who bought it [OScH], used it and hacked it, then I incorporated them [their modifications] back into the design. I can say at least probably half of the success of my products are from what other people have contributed. There were instances where people suggested new things so I decided this a good way to go. I would never have been able to get to this point with these products without the help of the community."* Our own experiences with the incubator concur with our participants' feedback. The current source code used in our incubator is a much refined version of the original code written by us and refactored by makerspace volunteers. Similarly, around 90% of the in-code comments were added based on the questions raised by the workshop participants and Instructables respondents.

While these comments highlight the importance of communication and collaboration between end users and developers, several factors that hinder such communications also surfaced through our study.

Challenges for Communication and Collaboration

According to many of our study participants, there are several misconceptions among OScH practitioners that prevent developers from getting feedback from the user community. One such misconception is end users not seeing the value of documenting failures. Similar to troubleshooting, there is a lack of reporting on instances where users could not build functional instruments based on open designs or were unable to reproduce the expected outcomes by using open instruments. P5 attributed the fact that people tend to not share their failures as something derived from traditional academic practice. According to her, traditional academic publications consist of successful attempts but not of failures. She further explained how open science hardware is fundamentally different from this: *"It is kind of a pity when you try to make something and it doesn't work or doesn't perform as you expected, then it becomes garbage in your backyard. [...] Failures are an important aspect of open science hardware. [...] Feedback [on failed attempts] is what makes OScH better in different contexts."*

Our participants also pointed out that many popular online dissemination platforms lack features that proactively promote documentation of failures. Looking back, our experience of using Instructables also resonates with this. Instructables has an inbuilt feature called *"I made it "* which encourages users to share images and text content after they have finished the project. However, as we observed, there is no similar feature to nudge documentation of the attempts which failed midway.

3.4 Discussion

Thus far, we have reported insights from a two-part study where we examined real-world practices related to the dissemination of OScH. First, through a long-term iterative process, we developed an open science hardware platform, a DIY incubator, and disseminated it through the Instructables website and two maker workshops. Second, we interviewed eight open science hardware practitioners from Africa, Asia, Europe, South America and the USA. Our study revealed how different modalities of OScH dissemination serve unique purposes within the broader OScH mission to enable openness and democratic participation in science. Our findings foregrounded several challenges for customization, troubleshooting, and the global adoption of OScH. Our work further highlighted the importance of collaborations between end users and developers to understand the unique needs and improve the quality of OScH, as well as how existing dissemination platforms and end users' reluctance to share their failures sometimes hinder such collaborations.

In what follows, we discuss the broader implications of our findings for HCI by highlighting design opportunities and directions for future work under three themes: lowering barriers for customization, supporting internationalization of OScH, and scaffolding collaborations between OScH developers and end users.

3.4.1 Lowering Barriers for Customization

According to the Global OScH Roadmap, one foundational principle of the OScH movement is to allow scientists to exercise freedom in customizing their instruments. Unlike *"proprietary black-boxes"* (GOSH, nd), OScH is intended to be fully transparent and easily-modifiable, giving users the ownership of the instruments they use. From a holistic viewpoint, it can be seen that OScH has achieved this to a considerable degree by open-sourcing design blueprints, including firmware source codes, as well as CAD files, schematics and PCB designs of electronic modules. In addition, the proliferation of affordable digital fabrication tools and communal fabrication spaces significantly reduce the barriers for converting blueprints into hardware artifacts. However, our findings reveal that despite the availability of design blueprints and wider access to hardware fabrication equipment, the absence of software tools with simplified workflows to modify open design files is a key challenge for customization, especially for those who come from non-maker domains. Addressing this challenge raises new opportunities and questions for HCI: *How might HCI research support the creation of new standards for sharing open-source design files and open hardware tools to enable quick and easy modifications?*

To examine this area, future HCI research can explore new file formats and standards for sharing open-source design blueprints that store parametric relationships between different sub-elements of the design. For instance, in the case of our incubator, the overall height, width, and depth of the enclosure can be stored as a function of the respective dimensions of the styrofoam box being used. Future design tools can integrate such parametric representation to allow simple user interfaces and workflows to modify original designs. For example, a web-based tool with three text inputs for height, width, and depth of the desired dimensions of an OScH instrument can be used to generate the final design of the enclosure based on the parametric relationships stored in the design file. Such tools could be broadly applied to existing OScH platforms such as Biropette[3] (3D printable pipette available through Thingivers web platform) and Micromanipulator[4] (3D printable micropositioning system available through open-labware.net) to support widespread customization. In addition, new file formats can support meta-level information on how different parts of an OScH relate to each other. Future design tools can leverage such meta-data to visualize how making a modification could impact the relationship within the system. Moreover, future design platforms can further utilize such meta information to visualize touchpoints where users can make modifications without having to change the whole design. For instance, in the case of 3D printable pipettes, making a small change to the diameter of the pipette shaft to support a different pipette tip will not require any other modifications. However, changing the diameter of the tip eject handle will require modifications in the whole design. To this end, future design tools can intelligently mediate and guide interactions around such touchpoints based on the expertise of the user.

[3]https://www.thingiverse.com/thing:255519

[4]https://open-labware.net/projects/micromanipulator/

While prior HCI research has paved the way for simple and abstract workflows for designing custom-printed circuit boards (Lin *et al.*, 2019), future work can also support easy customization of existing electronic designs. Future PCB blueprints can carry additional meta-data such as web links for alternative components that can substitute original components and references for region-specific data such as AC voltages and frequencies. By utilizing such meta-data, future tools can enable easy modification of existing electronic blueprints. For example, a future design tool can take a country or region as a user input and automatically modify the electronic design to be compatible with the AC mains supply of that country. Furthermore, such tools can auto-generate custom BOM files by making use of relevant meta-data, based on the location and component availability.

3.4.2 Supporting Internationalization of OScH

One of the fundamental missions of OScH is to enable scientists, both amateur enthusiasts as well as trained professionals in regions that are constrained by a lack of funds to obtain scientific equipment. In recent years, volunteer-run organizations such as TReND in Africa (TReND), workshops, and fieldwork done by local and foreign open science hardware advocates in several Asian countries, as well as numerous fledgling grass-root organizations in South America have made remarkable contributions to the empowerment of scientific research in these regions. While the OScH movement continues to grow in these localities, our study pointed out several key challenges related to disseminating OScH including language barriers, not having access to popular open-source materials, and lack of support for finding local vendors for materials.

Over the years, HCI research has extensively explored avenues to facilitate multilingual communication (e.g., Bao *et al.*, 2012; Gao *et al.*, 2014, 2015). Building on this rich body of work, HCI research has a lot to contribute to support the multilingual dissemination of OScH: from automated language translation engines, to crowdsourcing platforms that mobilize globally-dispersed OScH communities to support multilingual content creation. Furthermore, future research can extend prior HCI work on the authoring and sharing of DIY tutorials (e.g., Wakkary *et al.*, 2015), by exploring the use of language-neutral and more widely understandable mediums such as pictorials for communicating DIY workflows related to OScH.

Future research can also address issues related to local sourcing of materials. To this end, future work can support community-driven, distributed material repositories that store references for *"geo-tagged materials"* enabling location-based search queries. For example, a search query for an Adafruit temperature sensor from an African country might show references to local vendors who sell alternative temperature sensor modules or used consumer products (e.g., chicken egg hatchers or thermostats) which can be recycled to obtain a functionally similar temperature sensor. In doing so, future work can build on HCI's existing knowledge on validating distributed crowd inputs, to provide meaningful and reliable information to end users. Moreover, aspects of OScH internationalization might be addressed through policy making. While exploring policy implications is beyond the scope of our work, we see great potential for future HCI research to support policy interventions for wider adoption of OScH similar to Lindtner *et al.* (2016); Freeman *et al.* (2018).

3.4.3 Scaffolding Collaborations between OScH Developers and End Users

Throughout this chapter, we have brought to light numerous interactions between OScH developers and end users, which occurred over the internet and through in-situ *"human to human"*(P2) engagements at OScH workshops. We have shown the significance of those interactions for the effective and inclusive dissemination OScH, as they allow end users to seek direct guidance from developers, help understand the local needs of diverse open science hardware communities, and improve the quality of OScH designs through participatory feedback. Our findings further highlighted how the lack of commonly-accepted international platforms and feedback mechanisms hinder collaborations between end users and developers.

Drawing on our findings, first, we see opportunities for HCI to facilitate proactive online collaborations between end users and developers of OScH. Indeed, exploring the design and use of internet-based communication platforms such as online forums has been among HCI's key interests for many years, and recent work has explored these in contexts such as social support (Introne *et al.*, 2016), career mentoring (Tomprou *et al.*, 2019) and science communication (Jones *et al.*, 2019). Future HCI research can build on this rich body of work to explore new digital mediums that allow end users to effectively communicate their experiences, challenges, and needs to hardware developers. For example, future work can explore the use of non-textual digital mediums such as timelapse images or video clips that capture key moments of end user workflows as they build or use OScH. Such mediums will reduce language barriers and allow developers to clearly understand the problems of diverse communities and efficiently support their open science hardware practices. Moreover, an exciting body of HCI work has examined several ways in which persuasive design principles can inform the user interface design processes in order to nudge people towards completing tasks (e.g., Fogg, 2002; Seering *et al.*, 2019). Drawing on those works, we see new possibilities for improving the user interfaces of online OScH platforms in a way that persuades end users to report their experiences more often during the entire workflow with OScH. Such interfaces can include new features to celebrate failures. This may in turn help change end user perceptions related to documenting failures and encourage sharing these experiences. In the long run, this would allow developers to receive constructive participatory feedback from larger user groups and communities.

Secondly, beyond online interactions, our findings also highlight opportunities for HCI in mediating real-world, in-situ interactions between developers and end users. Here, future HCI work can explore ways in which existing participatory design approaches similar to work by Lindsay *et al.* (2012a,b)) can be utilized to facilitate meaningful, reflective and generative interactions between OScH developers and users. For example, designing new OScH for and with end users would enable developers to understand the unique needs and aspirations of diverse communities. Similarly, such activities could blur the distinction between end users and developers: user feedback could be fluidly shared with developers to support the co-design of OScH that better address user needs in the future.

3.5 Conclusion

This chapter reported insights from our self-reflective dissemination of an OScH platform, a DIYbio incubator, and our interview study with eight OScH practitioners from Africa, Asia, Europe, South America and the USA. Our findings reveal how different OScH dissemination modalities serve unique purposes, as well as how the challenges for collaborations between OScH developers and end users sometimes hinder widespread adoption of OScH. Our findings suggest future research opportunities where HCI can be applied to lower barriers for OScH customization, support internationalization of OScH, and scaffold collaborations between developers and end users. Through our work, we have shown the potential of HCI to support the global open science hardware movement, and more broadly, the efforts to democratize access to science. Above all, our work foregrounds the possibilities for positioning ourselves—HCI researchers and practitioners—as active contributors to the wider global open science hardware community, and to orient our research efforts towards proactively supporting a more open, accessible, and inclusive science practice.

Chapter 4

EXPLORING OPEN DESIGN AS A SITE FOR CRITICAL SOCIOTECHNICAL DISCOURSE

In the previous chapter, I explored the growing global landscape of open design through a long term empirical study of open science hardware (OScH). There, my focus was primarily on the utilitarian functions of open design in making hardware production open, accessible and inclusive across the globe. In this chapter, I shift my focus froms utilitarian functions of open design towards its critical and reflective potential. By drawing inspiration from Matt Ratto's Critical Making, wherein the collaborative construction of physical artifacts is viewed as a method of prompting joint conversations, reflections, and critique (Ratto, 2011), I examine open design as a site for critical sociotechnical discourse. In other words, this chapter askes: a) how the materially-oriented engagements within open design such as workshops, maker fairs, hackathons etc., can prompt critical thinking, dialogue and critique among participants? and b) What are the opportunities and challenges for HCI to intervene in supporting such critical engagements within open design.

In addressing above questions, I selected to extend my exploration of OScH in the direction of critical making. Not only does it allow me to build on my previous work, the issues surrounding the global OScH movement including democratization of science, open access to knowledge, safe and ethical (mis)use of technology etc., makes it a highly relevant site for a critical sociotechnical discourse. To this end, I examine the collaborative acts of making open science hardware from a critical making point of view by conducting an exploratory two-part design workshop. During this workshop participants collaboratively assembled an open science hardware –SANDS DIY

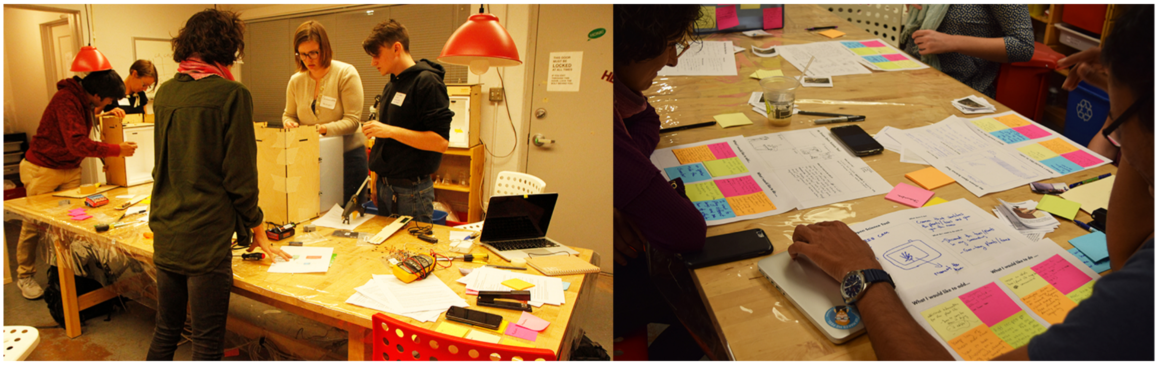

Figure 4.1: Participants Collaboratively Assembling OScH (left); During "My Dream Open Science Tool" Activity (right)

incubator—using the DIY kit developed by me. Practitioners from diverse academic disciplines including electrical engineering, biology, arts, humanities, and an active member of a local makerspace participated in this workshop. In addition to collaborative making, workshop sessions also included a series of prompts, brainstorming sessions, and co-design activities to help participants reflect on their experience of collaborative making, generate creative and speculative open science project ideas, and facilitate constructive discussions around the broader issues related to open science.

Throughout the workshop sessions, I wanted to understand how stakeholders from diverse areas of expertise engage with OScH, and how these engagements might serve as touchpoints for future HCI research.

In what follows in this chapter, first I briefly discuss the prior work within HCI which explores materially-oriented practices as modes of inquiry. Then I detail the design activities conducted during the workshop. Then, drawing on examples from my observations and data collected during the workshop sessions, I detail how the OScH kit was interpreted by practitioners from diverse disciplines, and the ways in which the design activities led to impromptu conversations around design and dissemination of OScH as well as broader issues related to open science. Building on the outcomes of this workshop, I conclude this chapter by broadly discussing how HCI can scaffold critical thinking, dialogue and critique among diverse stakeholders through materially oriented engagements within open design.

4.1 OScH Workshop: Collaborative Making and Activities for Reflection and Envisioning

To explore how OScH can serve as a platform for multidisciplinary engagements, I recruited participants by distributing an email flyer to our contacts in various disciplines including DIY making, biology, food science, engineering, arts and design, humanities, and social science. Five participants (three female, early twenties to mid thirties) took part in the workshop:

- P1: An assistant Professor specializing in the intersection of science and technology,
- P2: A PhD candidate in Synthetic Biology,
- P3: A PhD student in electrical engineering,
- P4: An active member of a local makerspace,
- P5: A recent MFA graduate in interactive arts and new media.

Participants did not know each other before the workshop.

4.1.1 Workshop Sessions

The workshops consisted of two sessions which took place in an HCI design studio (Fernando *et al.*, 2016c). Both sessions were held on weekday evenings, 4 days apart from each other. The first session lasted roughly two hours, and the second session lasted an hour.

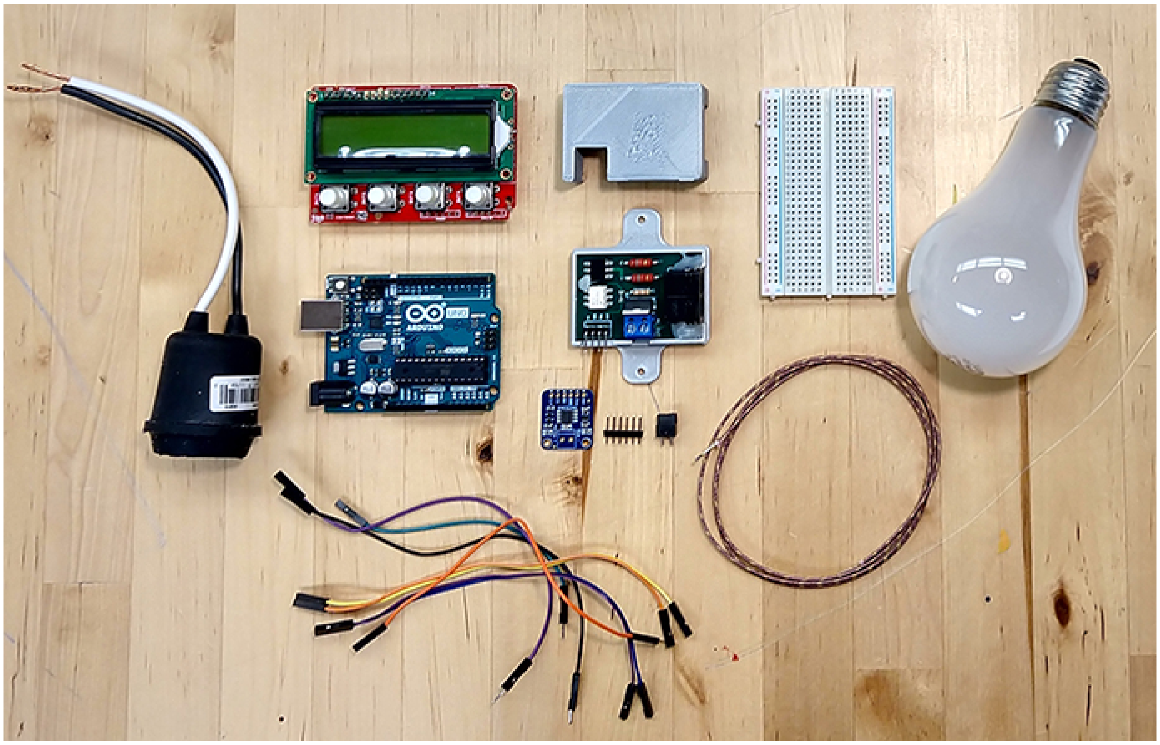
Figure 4.2: Electrical and Electronic Components of the OScH Kit

Session One: Collaborative Making of OScH and Activities for Reflection

This session started with a brief description of the goals of the workshop followed by introductions from each of the participants. To better understand each others' practices and interests, each participant was asked to describe a current or recent project in their introduction. After the introductions, I loosely divided the participants into two groups (P1 and P3 together), and each group was provided with a DIY kit for building a low-cost incubator.

A pre-assembled incubator was also shown in the studio as reference. During this activity, participants were tasked with assembling the enclosure, attaching electronic components to it, wiring electronic components according to the circuit diagram, uploading the Arduino firmware (provided by the researchers), testing, and troubleshooting. Even though the participants worked in two groups, both groups shared the same workspace and tools, and would occasionally help each other (Figure 4.1 (left). Throughout the maker activity, participants received a little guidance from the researchers, but were mainly encouraged to utilize each other's expertise to overcome the challenges they encountered. Both groups finished assembling working incubators roughly within 1 hour and 15 mins.

After the maker activity, we conducted a reflection activity based on "I-like, I-wish" framework (Faste, 2012). During a 5 minute activity, participants were asked to write things that they liked about the maker activity (starting with "I like") and things that they wish we would have done differently (starting with "I wish") on post-it notes. Then, they were asked to share the post-it notes with each other. While sharing the post-it notes, we encouraged participants to ask questions, express their viewpoints, and look for common themes by clustering post-it notes. This activity lasted around 30 mins.

Session Two: Brainstorming OScH Project Ideas and Envisioning Dream Open science Tools

The second session, which was held 4 days later, started with a 10 minute brainstorm activity wherein participants were asked to individually generate project ideas that they would like to conduct using the OScH tool—the incubator—they built. After writing their proposals down on post-it-notes, they were asked to share the ideas they generated with others. During sharing, we prompted the participants with several questions, such as "why do you want to do this project?", to facilitate discussions. Participants were also encouraged to ask questions and respond to each others' project ideas, which resulted in several impromptu discussions among participants. This activity lasted around 30 mins.

After the brainstorming activity, we conducted an envisioning co-design activity,

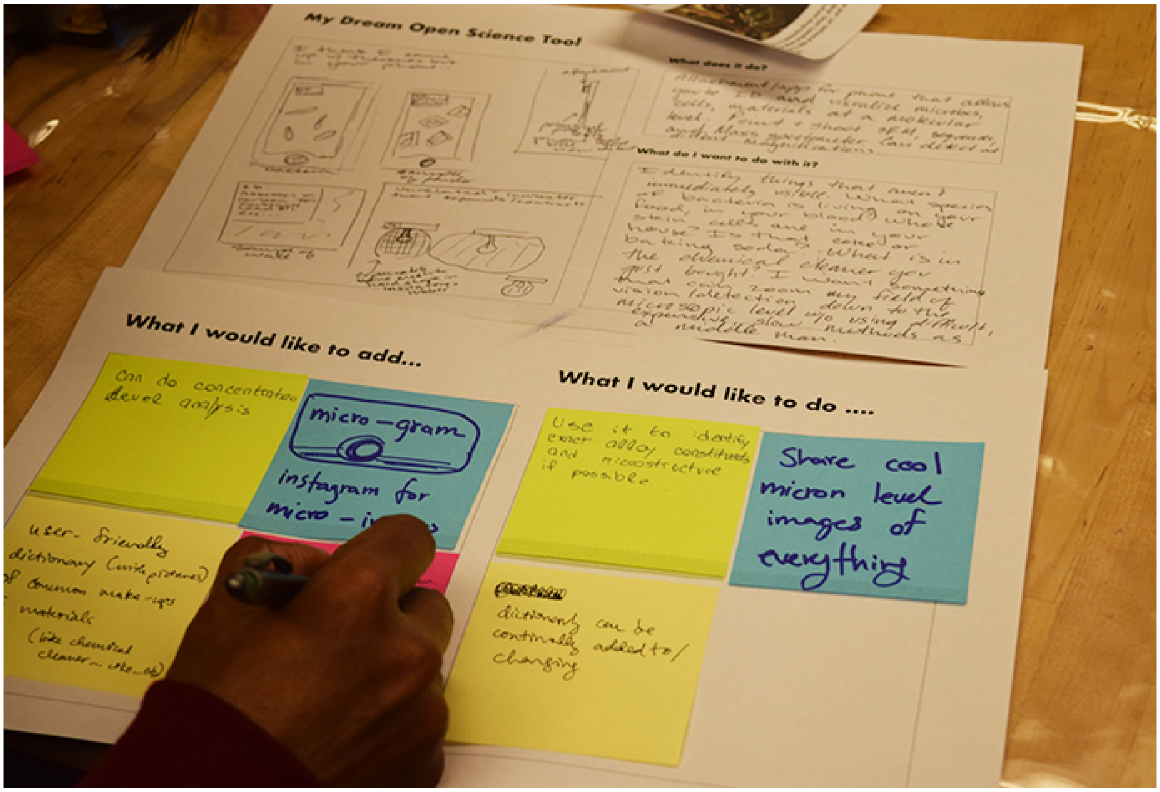

Figure 4.3: Worksheet from ”My Dream Open Science Tool” Activity

“Design your dream open science tool.” In this activity, each participant was given a worksheet and asked to draw an imaginary open science tool and write down potential applications for it. Once they had sketched their idea, each worksheet was passed clockwise to the next participant, who was asked to modify the design they received by adding a new feature to the “dream” OScH tool and to write down an application for the new feature they added. The process was repeated until each participant had contributed to everyone else’s worksheet and was passed back their own worksheet with everyone else’s edits. We then asked participants to share the new features and new project ideas added to their initial ideas. This activity also yielded impromptu discussions and lasted around 30 minutes.

4.1.2 Data Collection and Analysis

The worksheets and post-it notes were collected at the end of each session. In order to distinguish written responses, each participant used uniquely colored post-its. Throughout the workshop, all conversations were audio recorded. Audio recordings were later transcribed and analysed using the open coding method (Strauss and Corbin, 1994) together with post-it notes and worksheets to identify common themes.

4.2 Findings

As stated in the introduction of this paper, a key goal of our workshop was to explore how individuals from diverse disciplines express, critique, and collaboratively reflect on different points of view related to open science. In the findings, I reflect on these goals by highlighting insights from the making activities and participants' responses to the prompts, which were used to facilitate design activities. Below, we detail how different aspects of our OScH kit elicited different interpretations from our participants, and the ways in which our design activities triggered impromptu conversations around design and dissemination of OScH as well as broader issues related to open science.

4.2.1 Diverse Interpretations of OScH Kit

From the beginning of the first workshop session, it was particularly interesting to see the different ways in which participants saw the the OScH tool they assembled from viewpoints rooted in their respective practices. Depending on participants' unique backgrounds, it was discussed as a scientific instrument, a low-cost maker project, and a precise PID control system. For instance, while P2 interpreted it as a tool for microbiology: *"incubator is a means of controlling the temperature of the* *environment of a living thing with some degree of accuracy"* [P2], P3's focus was in the underlying working mechanism: *"it is a control system where I can program a set of parameters to control voltage and phase angle based on the temperature feedback"* [P3]. In contrast, P4, the participant from the local makerspace, was particularly interested in the use of low cost materials and the DIY electronic components used in the kit. He interpreted the incubator as a *"maker project"* which he could carry out at the makerspace.

This multifaceted nature of our OScH kit allowed participants to find some relevance between open science hardware and their respective practices. This provided them with an opportunity to explore other unfamiliar aspects of the incubator and collaborate with individuals from disciplines that they were unfamiliar with through building an artifact that has some meaning to their discipline. For example, P1 and P2 had the chance to work with an Arduino and be involved in a maker project, which they have never done before, because the final tool itself—the incubator—was familiar to their academic practices. P1 stated: "*when I hear "Arduino" I had no idea what it is, but when you put it as something that you can use to control an incubator it is not so strange. An incubator is not strange as a computer, at least I can understand what it [an incubator] actually does*" Likewise, our workshop and kit enabled P4 to collaborate with unfamiliar participants from academia by working on a "maker project" that was similar to his projects at the makerspace. Similarly, P3 and P5 used familiar tools and methods to build an interactive artifact, which happened to be a foundational tool for microbiology, a discipline they had no previous experience in.

4.2.2 Reflecting on Design and Distribution of OScH through Collaborative Making

Throughout the collaborative maker activity, participants who were not familiar with the tools and technologies used in our kit asked interesting and unexpected questions. Those questions elicited immediate responses from other participants, in turn leading them into constructive discussions around the physical design and distribution of OScH.

For instance, P2, who had no experience with laser cutting before, asked '*'Can I program the machine that cut these parts to resize and cut bigger ones? I kinda like to build a bigger incubator than this"* pointing to the laser cut enclosure of the incubator. This question led to a discussion around why and to what extent the initial designs of OScH should be customizable and the degree of control/agency exercised by end users when altering such open source designs or kits to build their own tools. Similarly, P1, who was completely new to electronics prototyping, asked, *"Should the colors of these wires be matched with the colors of the breadboard?"* This question triggered an immediate response from P5, the artist: *"no, but I think it would be really helpful if we can add colors to the pins of the Arduino to be matched with the breadboard, it would look nice and would be easy to see what to connect and what not to."* This conversation led to a discussion around the problems faced by amateurs in using electronic prototyping tools and how these tools can be potentially re-designed to support beginners in assembling or modifying open science hardware.

The reflection activity (I wish - I like) which took place after the making activity enabled participants to express their individual experiences of making the OScH kit on post-it notes. For example, P2 expressed how she found the instruction sheet with circuit diagrams low in clarity compared to *"extremely detailed protocols"* which she is used to following in her biology work. *"I feel like I wanted an IKEA manual.*

If I were to build this by myself I would have struggled without simple step by step instructions." [P2 on a post-it]. Conversations around individual experiences enabled some of our participants, especially the ones from engineering and maker backgrounds, to understand the importance of disseminating OScH designs in a way that they can be easily built or assembled by the end users who might not possess advanced engineering or maker skills. For example, P3 stated: *"As an EE, my thinking is to make things work. Once I made something work, I just stop there. I don't make enclosures or don't think about how others would use my design. Having built this thing with [P1], it made me think about how I can design things that others can also build. Even the little hole you add to the design of the enclosure to make it easy to reprogramme the Arduino or how clearly you label the pinouts of a PCB makes a huge difference [to the end-users who are replicating your design]"* [P3].

Moreover, while we did not intend to discuss the underlying technologies, such as the PID controller and the Arduino firmware code used in the incubator during the workshop, all participants wrote that they wished they had an opportunity to learn about (or teach) how the incubator actually works. These comments resulted in a dialogue around how someone's knowledge of the underlying technology behind a tool might affect the applications of that particular tool and how OScH should avoid being *"black boxes"*[P4] to the users. Interestingly, these conversations also led our participants to reflect on several contemporary movements such as *"Right to Repair"*[1].

4.2.3 Engaging with OScH to Reflect on Open Science Practice

Throughout our workshop sessions, the making of the OScH kit and related design activities led participants to collectively generate a set of creative open science project

[1] https://repair.org/stand-up/

ideas, which could be done in future workshops. Unexpectedly, the initial conversations around project ideas resulted in impromptu discussions around broader issues related to open science. These included safety and ethical concerns, the role of universities and research institutes in regulating open science, and potential ways open science can challenge and reshape traditional academic models.

Notably, some of the project ideas written by P4 involve potentially pathogenic microorganisms and procedures, which require systematic training with regards to hands-on microbiology. This triggered an interesting discussion, specifically between P2 and P4, around safety and ethical concerns related to existing open science practices of P4's local DIYbio community. This conversation resulted in participants discussing the role the university and academics can play in helping the local makerspace to raise awareness and regulate their practices, and how such involvements might hinder the freedom and openness that such communities are primarily motivated by. In P1's words: *"I'm interested in teaching the ethics to open science communities and exploring how we [as academics] can create self discipline among these communities without ruining their freedom. Something like a self-police."* In spite of being a biology graduate student with access to professional biology equipment and lab facilities, P2 suggested several applications that she personally wanted to carryout outside of her academic work. She explained her reason: *"I want to do these experiments at home, I don't want [name of her academic institute] to own my IP."* This conversation evolved to a discussion around how open science can challenge and reshape conventional academic practices and models, especially when it comes to research funding. As P2 further elaborated, *"An open science community is a pretty useful resource to learn about how you can do research with a scrappy budget. It is a cool concept even to academic labs, specially for the labs just start with a small budget. It gives you the freedom to do your own research without relying too much on* *a funding agency."*

In addition, the envisioning activity, *"Design your dream Open Science Hardware"*, promoted a rich set of imaginary and futuristic open science project ideas. Through modifying each others' initial sketches by adding new features, participants collectively brought forward different interpretations and points of view around the original designs, which further facilitated rich discussions related to the open sharing of scientific knowledge. During this activity, P5, a new media artist, sketched an imaginary incubator that listens to the organisms growing inside it and produces a human audible sonic signal. In our round-robin sketching session, her initial sketch was eventually modified into an imaginary *"Sonic Science Journal"* which shares scientific data by encoding them into sound, instead of *"texts and numbers"* [P3]. Conversations around *"Sonic Science Journal"* led to a rich discussion on new mediums for representing and sharing scientific data and how and why open science can use new publication mediums beyond academic papers and journals. P2's dream tool, *"Portable micro-camera,"* which can take micron-level images and determine the molecular composition of the materials in the image, eventually prompted the idea of a new social media platform *"Microgram: Instagram for micro-images"*(Figure 4.3). Even though some of these ideas came through playful conversations, the discussions ultimately turned into serious reflections on broader issues around open science. In the case of *"Microgram,"* it resulted a conversation on why existing social media should or shouldn't be used as platforms to share scientific data, specially prompting unexpected topics such as *"Facebook as a Science Journal."*

4.3 Discussion and Implications

As I mentioned earlier in this dissertation, open design and the maker culture surrounding it have been the site for a highly politicized discourse around the issues related to open access to knowledge, freedom of education, intellectual property rights, ethical use of technology and many more. In fact, several prior HCI work has highlighted Matt Ratto's critical making and of course, the repertoire of other tools and methods within HCI that are capable of eliciting collective dialog and reflection (Lindtner *et al.*, 2014) as avenues for HCI to contribute towards scaffolding constructive critical engagements around those issues. With this backdrop, my work examined the critical and reflective potential of materially oriented engagement within open design through a two-part open science hardware workshop. This workshop brought together practitioners from diverse disciplines to broadly reflect on the open science movement through collaborative making of a DIYbio Incubator and subsequent design activities.Throughout the workshop I kept an eye towards understanding how the act of making and design activities support discussions, questioning and sometimes debate.

The findings of the workshop illustrate the different ways this OScH kit facilitated constructive and highly generative engagements among participants from diverse backgrounds. Below I discuss the broader implications of the outcomes of my workshop for future HCI research.

As stated earlier in this chapter, the backgrounds of the workshop participants were varied from electronic engineering to life sciences to media arts. Of note is that each of these participants from varying backgrounds had different interpretations for the DIYbio incubator they assembled and all of them found some aspects of it (i.e. physical design, materiality, underlying technology or applications) relevant to their own practices. For example, while the participant from electrical engineering interpreted the incubator as a programmable control system, the biologist saw it as an optimized environment for bacteria growth. Likewise the participant from the local maker community interpreted it as a maker project.These diverse interpretations highlighted interesting parallels between open science hardware and Star and Griesemer's concept of boundary objects—objects that have different interpretations across communities, yet maintain a common identity while facilitating collaboration across different domains (Star and Griesemer, 1989). An inherent possibility within boundary objects is to bridge gaps between different and sometimes conflicting schools of thought, intellectual traditions, thinking patterns and social worlds. During the workshop, I observe the DIYbio incubator acts as a bridge between the participants' different academic backgrounds and facilitating collaborations and collective discussions among them.

Indeed, the concept of boundary objects has been widely discussed and adopted in a multitude of prior works within HCI (e.g., Zeagler *et al.*, 2017; Dalsgaard *et al.*, 2014; Weisling, 2017; Kaiying and Lindtner, 2016; Lee *et al.*, 2014; Blomkvist *et al.*, 2015; Zhou *et al.*, 2011; Aarhus and Ballegaard, 2010) in fostering collaboration. The framing of the DIYbio incubator as a boundary object opens up novel space for HCI to rethink other commodities (i.e, materials, tools, platforms etc.,) within open design beyond their utilitarian values and explore their potential of facilitating collaborations across disciplines. For example, take the Arduino. While it is largely considered as a material for electronic hobbyists and DIY makers, the underlying electronic schematic designs of Arduino boards are being reused by professional engineers in many commercial projects. Seeing the Arduino as a boundary object opens up possibilities to bring electronic hobbyists and professionals to collaborate in activities such as hardware hackathons and in turn trigger constructive discussions around how professional practices can shape and be shaped by amatuer work. Similarly, the 3D printer is a quintessential equipment not only within well-funded industrial design studios but also within local community-driven makerspaces. The 3D printer as a boundary object brings opportunities to bridge professional designers and local maker communities through CAD workshops and push them towards critically reflecting on the preconceived notions of mass production and creative (mis)uses of personal fabrication technologies.

Beyond academia, events consisting of somewhat similar collaborative hands-on activities around OScH are increasingly being organized by the open science movement globally in the forms of hackathons and maker fairs, in much larger scales compared to our workshop (e.g., GOSH, 2019). While such events often focus on either utilitarian and emancipatory goals of OScH in offering relatively inexpensive scientific equipment (Kera, 2018), what our workshop tries to call to attention is the evocative nature of such-hands on involvements with OScH. For example, in our workshop sessions we saw broader reflections around effective dissemination of OScH designs and kits, alternative mediums of open knowledge sharing, safety and ethical issues etc. While our workshop was focused on the collaborative assembly of OScH, future HCI research can further explore this trajectory by facilitating interdisciplinary hands-on engagements around open science projects as well (e.g., a yogurt fermentation workshop or a bacteria culturing activity). Such engagements might invite discourse around the disposal of bio-waste, antibiotic resistance, and various biases, limitations, and errors inherent in the scientific method. Such explorations could be grounded in the conceptual and applied understanding of design as a medium for collaboration, expression, envisioning and critique, and support a more open, accessible, inclusive and safe science practice.

4.4 Conclusion

In this chapter, I described a two-part OScH workshop, where practitioners from multiple disciplines collaboratively assembled open science hardware, and engaged in a series of design activities. I detailed how our OScH kit was interpreted in diverse ways by the participants based on their respective practices, and how workshop activities elicited impromptu discussions around issues related to open science. With the growing interest in open science, the HCI can continue to explore what roles academics can take on in these contexts. Efforts to shape such practices somewhat authoritatively through academic encounters is typically received poorly by those communities. Instead, our work foregrounds the role of design researchers as facilitators of collaborative engagements within Open Design.

Chapter 5

DREAM DRONES: EXPLORING CROWD-DRIVEN DESIGN FICTION

Fast paced idea-to-market cycles and highly profit-oriented innovation processes within commercially-driven hardware production give designers very little time to ponder the consequences of their products before they hit the market and are subsequently consumed by millions. On the other hand, such rapid technology design processes could make designers oblivious to the broader opportunities their innovations might present, resulting in sprees of incremental and narrow-minded product releases.

In addressing these issues, speculative design practices have been proposed and have become popular among design academics and practitioners in recent times. At its core, speculative design tries to shift the purpose of design from its modernist definition of utility and commercial viability towards provoking critique and dialog around possible futures that could be the result of designed objects (Dunne and Raby, 2013). In other words, speculative design tries to push designers to critically envision the consequences of the products they will put into the market and reflect on the ways in which those products help or hinder the futures they prefer to create. My work presented in this chapter draws from design fiction—a commonly used genre of speculative design which utilizes imaginary and often provocative scenarios presented in a diegesis style narrative through designed artifacts to critique the future (Blythe, 2014).

Even though design fiction may have primarily emerged as a tool for designers, technologists and academics, a plethora of recent prior work, both within and outside of HCI, can be found trying to actively engage the public in creating design fiction. Such participatory design fiction activities have often taken place as focus group studies, workshops, town hall meetings and civic activism campaigns and have shown great potential in generating broad and diverse inputs towards envisioning a multitude of technological futures (e.g., Hoang *et al.*, 2018; Akama *et al.*, 2016; Lawson *et al.*, 2015; Stals *et al.*, 2019).

So far in this dissertation, I have explored the processes within open design that are predominantly centered around the materially-driven production of hardware artefacts, from both functional and critical perspectives. In this chapter, I strive to push the envelope of open design towards crowd-driven speculative engagements through design fiction. To wit, this chapter is focused on crowd-driven processes that enable us to collectively and critically envision future hardware products. It is also concerned with the ways in which such processes in turn lead us to (re)think what hardware should or should not be produced in order to realize our collective aspirations of technology.

Building on the growing body of design fiction applications both within and outside of HCI (e.g., Tanenbaum *et al.*, 2012; Coulton *et al.*, 2017), in collaboration with my colleagues at the Social and Digital Systems Group, I have developed a web-based platform —“dreamdrone.org”— which engages the public to speculate on future drones through imaginary narratives. This platform provides a simple web user interface to envision futuristic imaginary drones and create fictitious narratives around them. I particularly selected drones as the topic of focus because on the one hand, drone related technologies are increasingly being translated into consumer products, resulting in several growing concerns among the public ranging from privacy issues to noise pollution. On the other hand, drone technologies also show significant potential for positively impacting our everyday lives through providing new modes of transportation, accurate weather forecasts, personal assistance and many more.

In what follows, I first present the background in which this chapter builds on.

Secondly, I describe the iterative development of the dreamdrone.org platform, its crowd-driven workflow and the data collected through a 6-month long public deployment. Thirdly, I present the findings from an interview study in which 8 drone experts responded to the data collected from the public. Finally, reflecting on the outcomes of the public deployment and expert interviews, I conclude the chapter by discussing the broader implications for HCI, highlighting opportunities and challenges for crowd-driven design fiction.

5.1 Background

Philip Pullman, an English writer once said: "After nourishment, shelter and companionship, stories are the thing we need most in the world." According to narrative psychologists, storytelling is a powerful medium of communicating experiences, both real and mythical (Woodside *et al.*, 2008; Delgadillo and Escalas, 2004). Stories help us to envision scenarios which we do not have first hand experiences that happened in the past, happening now or will happen in the future. Storytelling is not only powerful, it is also a familiar medium for us, humans. We all grew up listening to stories and telling them to others. As we started talking, we came up with our own stories, mumbled them to our parents and made them laugh. We spent our teen days thinking about what would happen in the next book of the Harry Potter series. As adults, we came up with our own theories and story lines explaining how the Game of Thrones series should be ending (and we signed internet petitions against the producers when they ruined it). No matter if you are a world famous writer or not, we all have some level of innate ability for storytelling.

Design Fiction uses stories as a medium to explore, envision and critique future technologies and our interactions with them through speculative, and often provocative narratives. In simpler terms, design fictions are stories of the future, a term first coined by the futurist Bruce Sterling in 2005 in his book "Shaping Things". Design Fiction depicts fictional scenarios of future technology to tell stories about the world in which that technology is situated (Sterling, 2005). Largely stemming from the diegesis style of storytelling[1], design fictions use a narrative structure to communicate, probe into and critic on the potential futures for technology. From the narratives around the Star Trek's transporter, a teleportation machine which can instantaneously transport an object from one location to another, to almost all the stories in Netflix's Black Mirror series can be considered as examples of Design Fiction.

I attempt to build on people's innate ability to tell stories and get them to envision and express imaginary future technologies through simple narratives. In other words, my work tries to get lay public to create design fictions. By bridging crowdsourcing techniques (detailed in the literature review in chapter 2) and Design Fiction, I explore crowd-generated Design Fiction as a means of understanding people's collective aspirations, delights and fears related to emerging technologies, and in turn use them as inputs towards shaping future technologies.

5.2 The Dream Drone Crowd-driven Design Fiction Platform

The genesis of this work is an in-person participatory workshop I conducted in collaboration with my colleagues at SANDS. During this workshop, members of a local drone hobbyist community collaboratively speculated on the future of drone technologies. The outcomes of this workshop inspired us to scale up the speculative design activities we used in this workshop to gather inputs from a larger online community. Below, I first present a brief overview of the in-person workshop and then

[1] a style of fiction storytelling that presents an interior view of a world in which the details about the world itself and the experiences of its characters are revealed explicitly through narrative

detail the iterative development of the Dream Drone platform.

5.2.1 Workshop with Local Drone Hobbyists

Together with my colleagues at SANDS, I held a participatory design workshop with a group of drone hobbyists at a local public library with the goal of critically exploring future community uses of drone technologies. We particularly chose this location because of a community of drone and citizen science enthusiasts affiliated with it. Eight participants (3 female, 5 male, ages mid 40's to late 50's) took part in our workshop, which consisted of an envisioning activity whereby participants, working in 3 groups, collaboratively sketched out fictional drone concepts ("dream drones") augmented with new features or "superpowers". To seed visionary ideas that were not constrained by technological feasibility, we provided participants with a set of cards that contained imaginary superpowers such as a "Lie Detecting Microphone", "Invisibility", or "Ability to Speak Human Languages", to name a few. Each group was asked to develop stories (scenarios) about where their imaginary drones would fly and what they would do in those locations. As part of this activity, participants marked the flight paths of their drones on a large printed map of the neighborhood around the library (approximately 10-mile radius). Afterwards, participants presented their drone concepts and narrated scenarios around their fictional drones. Throughout the workshop activities, we observed participants collaboratively refining their initial stories and drone designs to better reflect their community needs and aspirations. For instance, participants collectively envisioned new contexts for drone use, including community-operated drones that report toxic emissions from industrial sites, as well as drones that fly autonomously to record and broadcast extreme weather events. Participants also discussed their concerns related to privacy and security around unfamiliar/unmarked drones flying over personal property. Focusing on these concerns, several workshop discussions revealed design directions for improving the physical appearance of community drones, such as communicating the owners' identity and intent, and giving the drones a friendlier look and feel.

5.2.2 Implementation of Dream Drone Online Platform

During our workshop, we observed how the collaborative activities inspired participants to iterate on and refine their concepts together, and how the group discussions led to a deeper understanding of local issues around drone use. Through this, we saw an opportunity to expand our design fiction based participatory workflows to gather input from a larger group. To this end we implemented a web platform, Dream Drone, that invites users to envision drones with new capabilities or "superpowers" and imaginary scenarios that those would operate in.

The workflow of the Dream Drone platform consists of three steps:

Step 1: Create a Dream Drone by Adding Superpowers

The users of our platform can start creating a fictional drone by first adding up to four superpowers (or features) to their dream drone (the drone they are envisioning). Here, they can create their own superpowers or select superpowers that were submitted by previous users (Figure 5.1). We seeded our platform with a list of superpowers generated by the researchers and our library workshop participants. This step aims to support ideation by enabling users to combine and build upon the ideas of others Yu and Nickerson (2011b).

Step 2: Write a Dream Drone Story

After adding superpowers, the second step of our platform prompts users to create a meaningful name for their dream drone. Users are then asked to write a dream drone

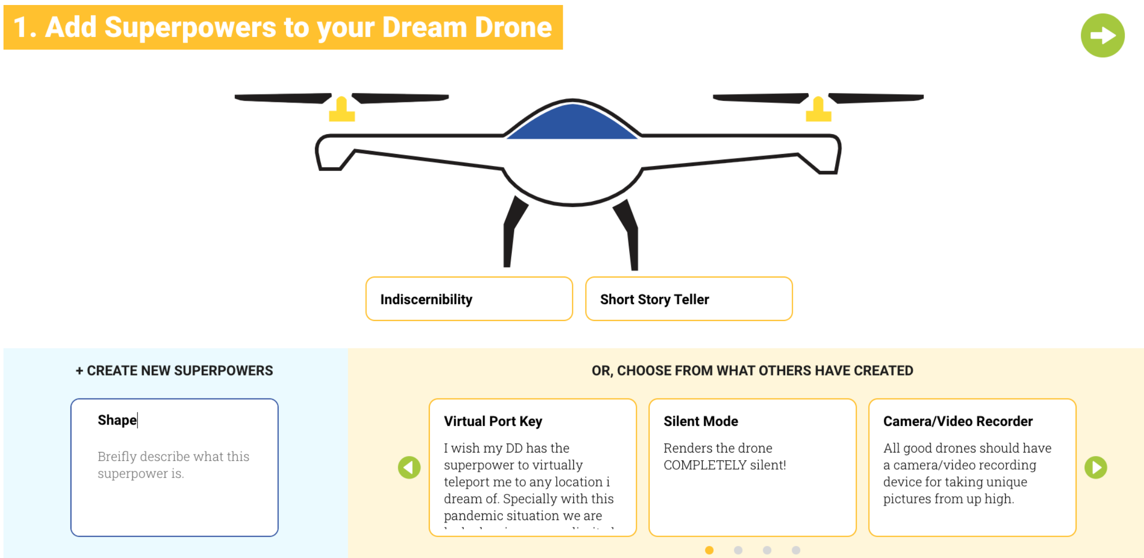

Figure 5.1: A Screenshot of the Step 1 of Dream Drone Workflow

story (a design fiction scenario about their drone) describing the world it operates in, the locations it flies, and who it interacts with (Figure 5.2).

Step 3: Respond to dream drones created by others

In the third step the users are shown a dream drone story, randomly selected by the system which was created by a previous user. Users are then asked to respond to several prompts by critically reflecting on the drone story which has been randomly picked by the system. These prompts include "Would you like to see this drone in real life?", "Tell us why you would/would not like to see this drone being implemented?", "Tell us how would you like to modify this drone?", and "Do you see any intended or unintended consequences of this drone that might cause adverse effects in the Future?" (Figure 5.3).

The above steps are introduced to users on the landing page of the Dream Drone platform through playful and creative illustrations. In designing the user interface, I intentionally used a simple and colorful aesthetic to encourage creative and wild ideas

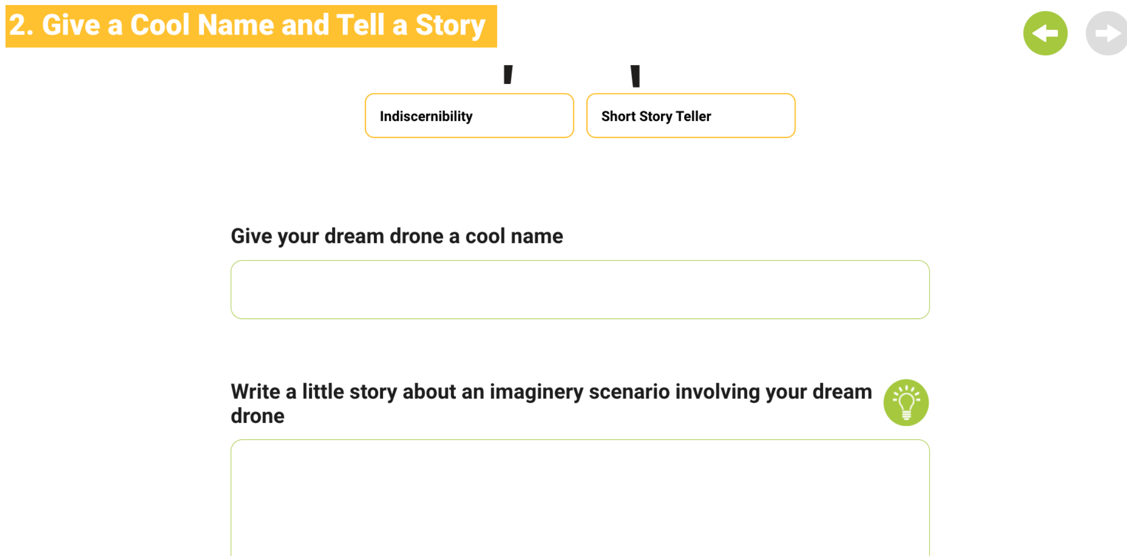

Figure 5.2: A Screenshot of the Step 2 of Dream Drone Workflow

from users (Figure 5.4).

5.2.3 Data Collection

The Dream Drone platform disseminated through several social media channels. These include Facebook pages, Linked groups and reddit threads related to drones, science fiction, writing and design. In addition, an e-flyer was also circulated via personal social media posts, emails and direct messages. A printed version of the flyer consisting of QR code of the web link was placed at multiple sites within ASU including the Hayden Library, Design School and Memorial Union. Over a period of 3 months, I collected 95 responses resulting in 155 superpowers and 95 unique dream drone stories. The length of the stories varied from 15 to 640 words with an average of 65.8 and standard deviation of 92.6. The Dream Drone platform also gave participants the option to share some of their demographic information. Out of the 95 responses, 58 remained anonymous and 37 of them shared the following data: 20 identified as female and 17 identified as male; 19 were between the ages of 18-25,

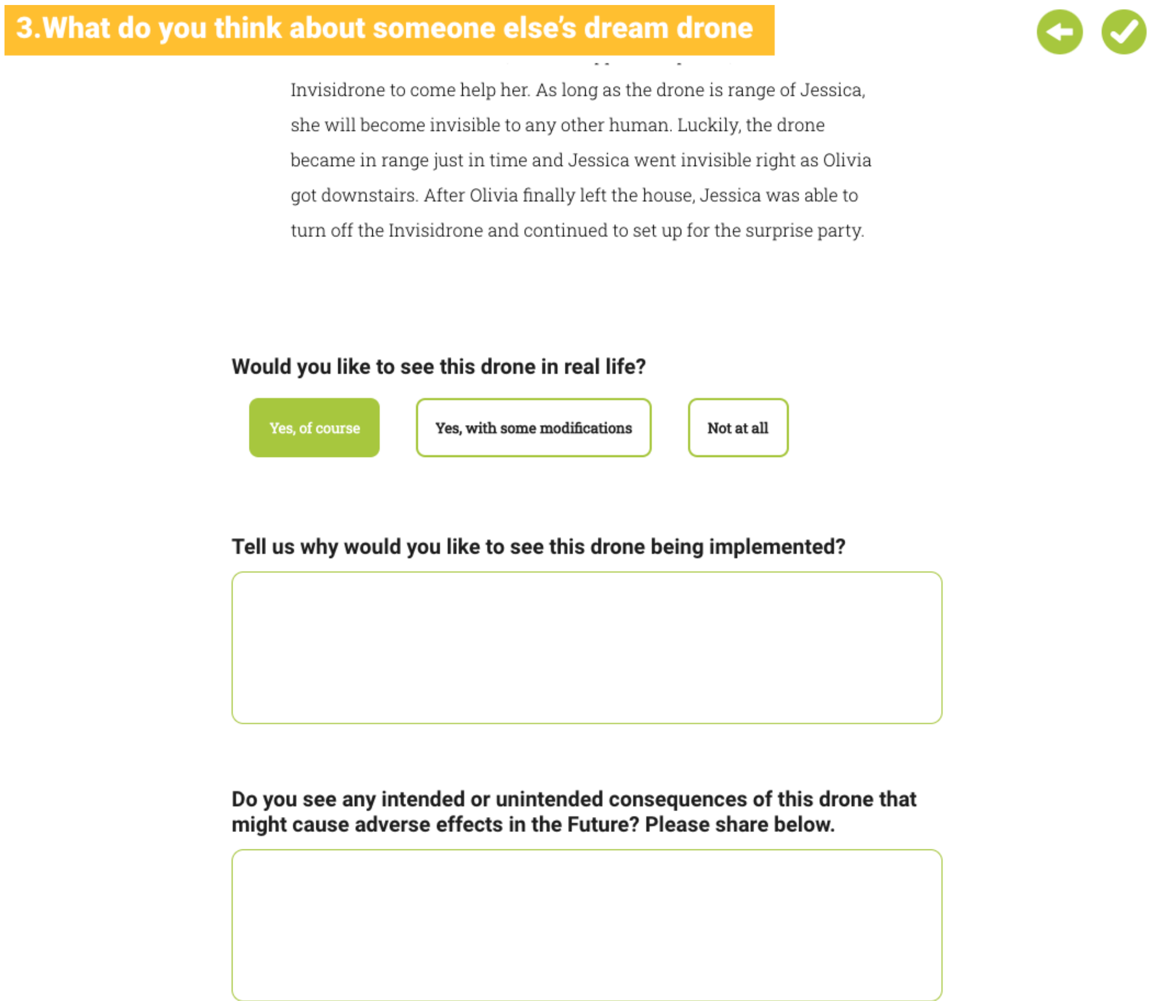

Figure 5.3: A Screenshot of the Step 3 of Dream Drone Workflow

13 between the ages of 26-35, 3 between 36-45, 1 between 46-60, and 1 participant was 60+. Participants self-identified with a range of backgrounds including drone hobbyist, engineering, design, environmental science, and policy making to name a few. Participants self-reported to be from different parts of the world, including the USA, United Kingdom, South Africa, Russia, France, India, Sri Lanka and New Zealand.

In addition to the superpowers and stories, I was able to collect a total of 134

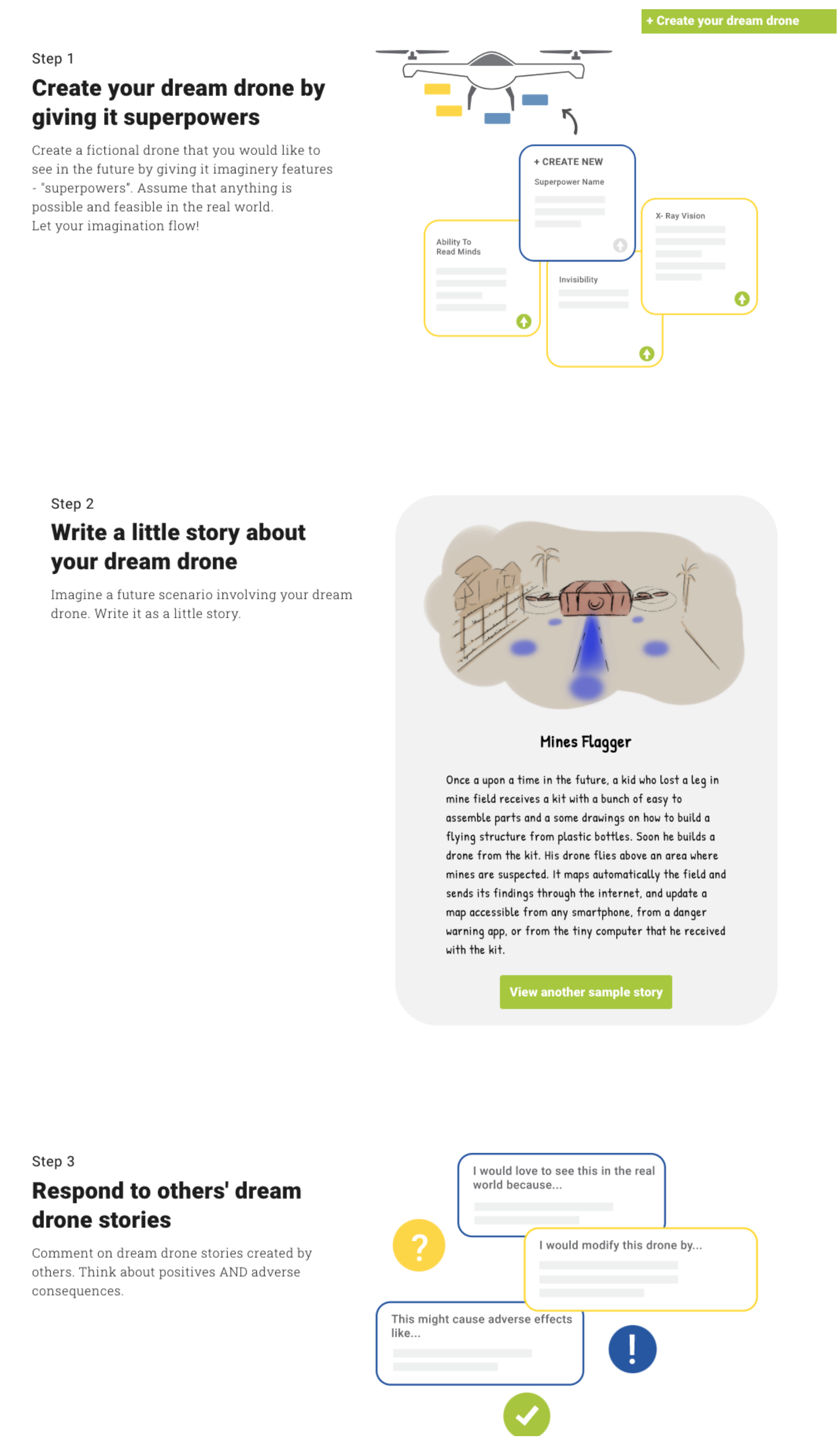

Figure 5.4: A Screenshot of the Landing Page of Dream Drone Platform

reactions from the public (step 3). However, I have noticed most of the recently added stories are lacking sufficient responses for step 3 due to the relatively smaller duration they were in the system. In order to populate the system with more reactions, I invited 10 practitioners (6 female, 4 Male) from arts, design and social science domains. I particularly selected practitioners from these domains because of their potential of offering critical inputs from diverse viewpoints which will be valuable in the next steps of this research. Through zoom video calls they were given instructions to submit reactions (step 3) for as many dream drone stories as possible within a period of an hour. The practitioners were paid 50USD for their time. At the end of these sessions, all the stories contained at least 3 reactions. In total, the system contained 238 reactions, out of which, 96 were contributed by the 10 invited practitioners.

5.2.4 Sample Data

The breadth of the crowd inputs collected through the Dream Drone platform was reflected in several ways. The superpowers range from highly imaginary futuristic features (e.g., Zoolingualism) to realistic technical enhancements (e.g., IR vision). The dream drone stories depicted a variety of contexts and scenarios from personal assistance to public services to military use. The crowd reactions covered a remarkably broader spectrum of positive (e.g.,empowering the elderly) and negative(e.g., noise pollution) aspects of drones and potential unintended consequences similar to creating ecological imbalances and losing human-human interactions that goes beyond the mainstream topics of privacy and security concerns.

Below I present several examples from the collected data set consisting of superpowers, stories and reactions.

Example 1	
Name	Hot Pursuit
Superpowers	Ninja Agility :The ability to do extreme stunts, super sharp turns and barrel-rolls and flips Net launcher/ ”Bolas” Thrower :A mechanism used to entangle and impair a target without inflicting physical harm. Engine Stopper :Can stop the engine of a targeted vehicle by emitting a special laser beam
Story	It is a cold morning in the New York city. NYPD low enforcement officers just received a call about a bank robbery and the suspects driving a blue Mustang along interstate 86. NYPD deploys 20 hot pursuit drones over the highway. One of the them detects the Mustang and starts to follow. Mustang takes an exit and drives along a narrow bendy road. Mustang takes sharp turns but the drone is keeping up with it. NYPD police officers watches the live footage from the long range feed and command the drone to emit its laser beam. Drone emits the beam at the right time, car engine stops. Before the suspects even know drone launches a net on to the car. No one is harmed, no one can move. NYPD catches the suspects.
Reactions	*“I don’t believe police need more funding or policing supplies. I don’t think this will help citizens stay more safe or create more efficiency for the tax payers of the US.”*

Example 2	
Name	Balto
Superpowers	Medical Spray :Ability to disperse medicinal spray across a large area, allowing for a larger population to get medicine they need instead of the normal vaccine-style.
Story	Another virus has struck Africa, infecting many who don't have the medical resources to have access to a cure. It is so infectious, no country will send doctors to administer vaccines. Balto, the medicinal drone, was the only one that could save the many dying of infectious disease. A cure was put in spray form and carried through Balto to the affected African countries, where it was released without endangering lives.
Reactions	*"Could lead to chemical pollution of water and soil, if used incorrectly"* *"I would place limits on who the drone could use this spray on - making sure that consent was gathered before it was used. Obviously, most would want the spray, but as a precaution, I think a consent first system would ensure that humans still get a say in their care."*

Example 3	
Name	Dronettna
Superpowers	5G Modem :5G transmitter or Antenna
Story	John Smith bought the newest smartphone that is 5G capable. The download speed exceeds 1Gbp/s and AR/VR games are smooth as butter. He wonder how that was possible before I look up in the air to see hundreds and thousands of Dronettna moving back and forth. Some Dronettnas go back to the ground for recharge while new Dronettnas replaces their position.
Reactions	*"Silent as to not be annoying and distracting. Hopefully high enough to not be seen as well."*

Example 4	
Name	Celeb Escort
Superpowers	Invisibility :Ability go out of sight of people and cameras Dress-up in a 'skin' :Using sensitive cameras the drone picks up what its environment looks like and dresses up to either blend in, stay neutral or attract attention Fashionista :Can shine and gleam creating different patterns. Have fancy tails, wings and can appear in different shapes whenever required. Very eye catching.
Story	It's Oscar evening 2070. Celebrities and their Celeb Escorts are just arriving on the scene. These eye-catching Celeb escorts will fly along with celebrities when they walk red carpets, fashion events, and even when they're in public, etc. with matching outfits with their celebs. They can check the security of the path ahead, provide air conditioning if needed, and can help with a quick makeup. They'll set up an aura while escorting their celeb.
Reactions	*"It is a very fancy drone but I feel it is a very gimmick drone at the same time."* *"Overcrowding, taking the human experience out of these in-person interactions."* *"In a world grappling with climate change and resource scarcity, I feel this is a waste of resources."*

5.2.5 Challenges Faced during the Data Collection

Relatively Low Number of Completed Responses

Over three months of data collection, the dream drone platform was largely well received by the online communities whom me and my colleagues shared the link with. Many of them responded to our online posts by mentioning that they are interested in taking part in the study by completing the dream drone activity. However, compared to this positive reception, the number of actual completed responses were somewhat underwhelming. Out of all the users who visited the platform, less than 20% completed all three steps. I also observed a pattern where many visitors only completed step 1 (adding/creating superpowers). 60% of participants who completed step 1, left the platform without completing step 2 and beyond.

If we compare the workflow of the dream drone platform to tasks in a regular online survey, writing even a brief story could be regarded as a relatively time consuming task. It also requires a significant amount of attention, concentration and some level of creative thinking. It was indeed challenging for us to get people to complete all three steps. Similarly, I observed that the dream drone workflow does not really fit into the regular internet routines of people. Many of them encountered the platform while scrolling through social media or while checking emails/direct messages. Understandably, some of them replied to me by saying that they will complete the activity later in the day or during the weekend. However, based on the total number of completed responses we can derive that only a few of them actually went back to complete the activity.

Unstory-like Responses

During the initial testing stages of the platform I observed that a majority of the responses for step 2 were not written in narrative form. Instead, they were written as detailed descriptions of the features (superpowers).For example: *Jaws is a Solar powered drone capable of picking up small amounts of plastic pollution and its main job is to find major deposits of plastic pollution in the ocean and notify near by ships and organizations to clean up the plastic. It is named jaws because it is meant to protect the marine ecosystem from plastic pollution, and like a shark hunts seals the drone hunts for plastic.*

While such detailed descriptions can still be interesting, it hinders the ability to provoke discussions around future technological scenarios involving drones which is one of the fundamental goals of this research. In addressing this issue, I included several example story starting lines (e.g., "Once upon some time in the future...", "It is the year 2050...") in the user interface to nudge people to write their stories in narrative forms. This change significantly reduces the amount of unstory-like responses. From the total of stories of stories were written in narrative style.

Concerns Related to the Authenticity of the Research

During the data collection, there were some instances where the online users critically questioned the motivation of the research. In response to one of our reddit posts, some of them commented questioning whether it was a fraudulent tool to collect people's ideas for "free" (Figure 5.5). While I believe that the dream drone platform can operate in the similar spirit as many other existing open-source platforms (e.g., Apache software foundation, Wikipedia platform, Arduino, etc.), I observed that the

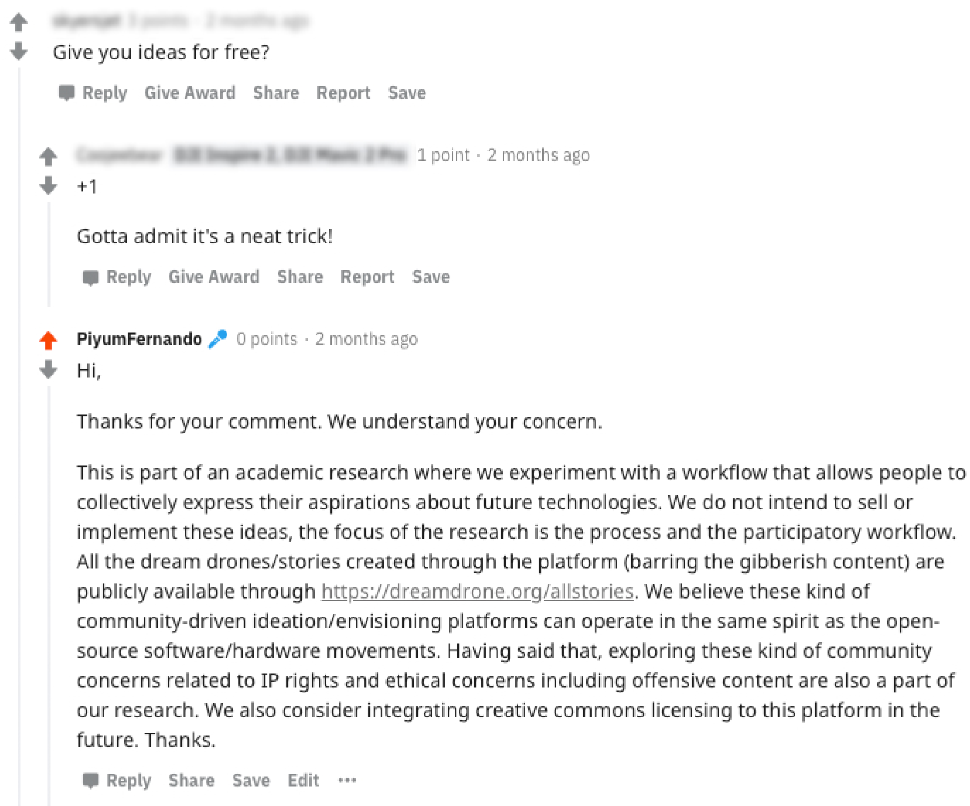

Figure 5.5: A Discussion Thread which Indicates the Concerns Related to the Authenticity of Dream Drone Platform

motivations of the platform were not communicated clearly enough to visitors. I responded to these comments by appreciating their concerns and clearly iterating the motivations of our research (Figure 5.5.

5.3 Making Sense of Crowd-generated Design Fiction

So far in this dissertation, I have detailed the iterative development of the Dream Drone platform, several examples from the data set which is collected from the public during a period of 3 months and the challenges faced during the data collection. Earlier in this chapter, I mentioned that my ultimate goal is to explore the ways in which collective inputs of the people potentially impact present day design, engineering and decision making processes. My approach towards addressing this was to implement an experimental user interface that allows drone practitioners (e.g., drone designers, engineers, policy makers) to effectively access crowd-generated inputs. I use this interface as a probe to study the broader potential and challenges of making use of crowd-generated design fiction inputs. My probe based approach is particularly inspired by one of my previously published work (Fernando *et al.*, 2019) and several other prior work within HCI (e.g., Wallace *et al.*, 2013).

I envisioned the experimental user interface as a platform that provides divergent leads to drone practitioners to expand their points of view of the projects they are involved in. My goal is to utilize the crowd-inputs to make them rethink their preconceptions, explore diverse possibilities and critically reflect on the potential consequences of their work. To this end, the experimental interface consists of two key features: a semantic similarity based search mechanism and presentations of dream drone crowd inputs.

5.3.1 Semantic Similarity-based Search Mechanism

The user input for the search function was designed in a way that the users input a brief text description of their project by completing the sentence "I'm working on a drone that [blank]". For example: "I'm working on a drone that monitors animals" or "I'm working on a drone that helps elderly".

Once the user input is added, it is then compared with all sentences of the dream drone stories stored in the database. This comparison is done using a Machine Learning based Natural Language Processing application. This application was written in Python language based on the Sentence-Bert technique (Reimers and Gurevych, 2019). In implementing the search application I reused the open-source Python library provided by the authors of the Sentence-Bert technique. Based on pre-trained models provided with the Sentence-Bert library, the search application calculates sentence embedding — n dimensional vectors— for each sentence in the stories. It also generates the sentence embedding for the text input added by the user. The semantic similarity between each sentence in stories and the user's input description is determined by calculating the cosine similarity between vectors. In other words, a higher cosine similarity value between the user's text input and a sentence in a story means that the sentence shows a greater similarity to the semantic meaning of the user's input. The similarity between the stories and the user's text input (I call it the similarity score here onwards) is determined by adding up the highest k cosine similarity values within each story. k= 3 is empirically determined through my personal observations of the results relative to the data set. The story with the highest similarity score is considered as to be describing the most similar scenario in relation to the user input.

Presentation of Crowd Inputs

Earlier, I mentioned that my goal with this interface is to fuel divergent thinking among drone practitioners. I particularly drew inspiration from several prior work on the topic of online ideation within HCI which suggest that the breadth of the ideation inputs,i.e., the diversity of meaning, is a key factor determining the outcome of divergent ideas (e.g., Siangliulue *et al.*, 2015). To this end, the first of the two presentations of the crowd inputs shows three dream drones in their raw format,i.e., as they were added to the system, based on their similarity scores: one with the highest similarity score, one with the least similarity score and a randomly picked one. By clicking on any of the drones, users are able to see the full drone story, their superpowers and the crowd reactions(Figure 5.6).

Figure 5.6: Interface Showing the Drone Story, Superpowers and Reactions

While the presentation of raw data shows that reactions are written targeting a particular story, I also wanted to provide a more generalized summary of them. My goal here is to see how such a generalized representation of reactions will be interpreted by drone practitioners during the interviews and how such representations might guide their thinking. Therefore, I first tried out creating a summary of reactions in the form of a semantic word cloud. Figure 5.7 shows an example generated based on the reactions received for the "Mines Flagger" dream drone using an online semantic word cloud tool developed by researchers from the University of Arizona [2]. However, as observed in Figure 5.7, the representation of reactions through a set of single words was not sufficient to communicate their essence. Therefore, I explored the possibilities of generating phrases instead of single words using existing Machine Learning based text summarization techniques with the intention of creating a more meaningful tag cloud in lieu of the word cloud. For example: the conversion of the reaction "Building a drone for a critical task like finding land mines without the necessary expertise can be dangerous." to a more generalized, meaningful phrase similar to "critical tasks performed by non-experts". However, I concluded that, generating phrases that meaningfully communicate the essence of the reactions requires a significant amount of work on Machine Learning and NLP which is beyond the scope of my dissertation.

In order to evaluate the effectiveness of such a tag based open-ended interpretation, I performed the conversion of reactions to meaningful tags manually. During the manual tagging, I created two sets of tags for each dream drone: positive tags summarizing the responses to the prompt "Tell us why you would like to see this drone implemented" and negative tags summarizing the responses to the prompts " "Tell us why you would like to see this drone implemented" and "Do you see any unintended

[2]http://wordcloud.cs.arizona.edu/index.html

Figure 5.7: Word Cloud Representation of the Reactions Received for the "Mines Flagger" Dream Drone

consequences?". The manual tagging was performed based on open coding and axial coding techniques Charmaz and Belgrave (2007). The final summarized visualization of the reactions was generated by separately combining positive tags (on the left) and negative tags (on the right) of the similarity score based, previous three dream drone selections. Figure 5.8 shows the completed experimental interface with all 3 features.

5.4 Qualitative Interviews with Drone Practitioners

In order to examine how crowd-generated design fiction can influence real world design, engineering and policy making processes related drones, I conducted a remote interview series with 8 drone practitioners. During these interviews, I used the experimental interface as a probe to broadly understand the ways in which the crowd-generated design fiction could be effectively communicated to the stakeholders.

Participants were recruited by posting an invitation on professional groups related

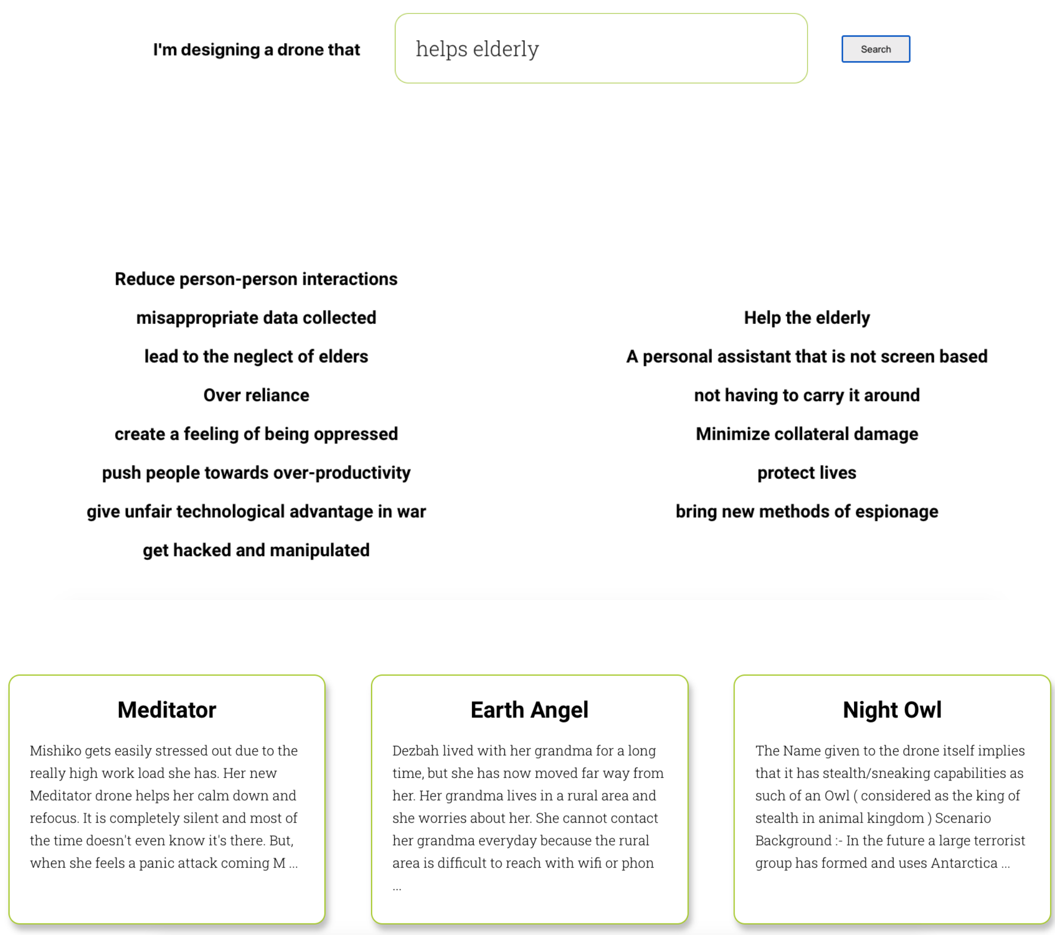

Figure 5.8: The Experimental User Interface

to drones on the networking platform LinkedIn and through personal contacts. They were screened based on the following: *having at least 1 year of experience in designing, building or conceptualising drones for commercial or personal use, drone related policy making or drone related law-enforcement.* In response, 8 drone practitioners (6 males, 2 females, from mid twenties to mid fifties) were recruited. Below is a summary of their backgrounds.

- P1: Drone builder with Mechanical Engineering degree
- P2: Environmentalist with experience in building custom drones for forest observation
- P2: Risk Analyst for emerging drone applications
- P4: Hobby drone maker and the founder of a popular online community related to DIY drone making
- P5: Policy advocate for drone related security issues
- P6: Researcher in Geography with experience in building custom drones to monitor weather events
- P7: Drone educator and drone concept developer
- P8: Attorney at law and the owner of a business related to aerial photography

Interview Procedure

All interviews were conducted remotely through the Zoom video call platform. A few days prior to the interviews, participants were provided with a link for a web page that lists all the dream drone stories collected from the public in a random order.

Participants were asked to go through the dream drone stories in preparation for the interview and pick 3 stories that they would like to discuss during the interview.

At the beginning of each interview, participants were given a brief overview of the research goals and objectives of the interview. After that they were asked to describe their backgrounds and their projects related drones. Then they were prompted to talk about the three dream drone stories and the reasons as to why they picked those. They were particularly encouraged to express their opinions about superpowers and stories and articulate how such crowd inputs might influence their work. Next, they were directed to the experimental interface and asked to input a brief description of a drone they are working on now or are hoping to work on in the near future. They were then asked to read through the three dream drone stories that were presented by the system in response to their input. They were particularly prompted to talk about how the crowd reactions to the resulting drones and the tag based visualization could influence their work. Furthermore, during the interviews the participants stated their opinions about the overall concept of the dream drone platform and the ways in which it could be improved to make a stronger impact on their work.

5.4.1 Data Analysis

All the interviews were video recorded with the consent of the participants. Conversations were transcribed using Zoom platform's in-built transcription feature. Transcriptions were then analysed by me using the open coding technique. In the next section, I detail the common themes that emerged from the data analysis.

5.5 Findings

I present the findings of the qualitative interviews with drone practitioners under three themes: responses to dream drone stories and superpowers, responses to crowd reactions and the various ways in which crowd input can influence participants' practices.

5.5.1 Responses to Dream Drone Stories and Superpowers

As mentioned earlier, participants were given the opportunity to go through the list of crowd-generated dream drones (superpowers and stories) prior to the interviews. During the interviews, participants described them as *"interesting"*(P7) , *"fun"*(P1), *"engaging"*(P3) , *"insightful"*(P2) and *"refreshing"*(P5). They mentioned that the superpowers and stories prompted them to think about novel ways that drones can be used. Notably, many of them (P2,P3,P5,P6, P8) stated that the superpowers with somewhat unrealistic characteristics such as "zoolingualism", "mind reading" and "invisibility" have prompted them to think about unusual contexts for future drone applications. For example, P2, an environmentalist stated: "When I see zoolingualism, it actually made me think about how drones can be built to communicate with animals. Like during a wildfire, we can use some kind of communication methods to guide the animals to safer areas"

They also described different ways these dream drones prompt them to reflect about their practices involving drones. For example P6 stated how "The Tornado Tracker" (a narrative around a future drone that detects an upcoming storm and warns the people in the path of the storm) helps her to think beyond her current usage of drones for climate events.

In the case of the Tornado Tracker, it has helped me shift my thinking. I have a tendency to go out and survey damage using drones [after a weather event has happened]. That is essentially kind of like a Crime Scene Investigation. I was really trying to understand the dynamics of the storm based on the damage. The tornado tracker drone made me think how I could use drones to help people before a storm *could happen.*(P6)

Some of the participants (P1,P3,P4,P7) highlighted dream drones as a medium to understand people's broader expectations of future technology. For example, P4 mentioned that the dream drone "Hot Pursuit" (a narrative around a set of drones deployed by the Police to safely carry out a pursuit mission without harming the suspects) could be an indication of people's desire for safer policing practices. He went on to further explain how the "Hot Pursuit" drone story prompted him to think about the potential use of drones to record the activities of police officials in addition to their body cameras. Interestingly, P4 stated that the "Mines Flagger" (a scenario where a child builds a DIY drone to detect landmines and publish warnings to the internet) led him to look at drone technologies from the perspective of people in war-affected regions. He expressed:

"Where we live you don't have to worry about stepping outside and landing on a landmine. We are kind of safe from that and we kind of get stuck in our little world. Just seeing the stories from other people, I understand they definitely got a different point of view on the technology."

Similarly, P3 stated that the superpowers added by people was a way of understanding what features designers should prioritize in drones to better address people's needs. He went on to elaborate, *"..the superpowers definitely help you gain more clarity on the direction we need to take and also the priorities [...] what we need to improve, focus, and put funding on. Is it improving the camera so that we can get 4K video of celebrities versus should we need to invest on drones that has stable wings to withstand a storm"*

5.5.2 Responses to Crowd Reactions and Tag based Visualization

During the second half of the interviews, participants were presented with the experimental user interface developed by me. Once they input a brief description of a drone they are working on now or are hoping to work on in the near future, the system resulted in three dream stories based on their similarity (most similar, most dissimilar and a random pick) to the participant's input. Participants were then asked to go through the resultant dream drones and the reactions (positive aspects and negative consequences) added by people in response to the drones. Participants were also asked to respond to the tag based visualization generated by the system (Figure 5.8). Participants responded to this activity in a variety of ways.

In response to P1's description of his current project, "a drone that detects pests and fungi in tea plantations", the system resulted in "The Pest Exterminator" as the most similar story. This dream drone consisted of several crowd reactions indicating multiple negative consequences such as "It might create air and soil pollution by shooting chemicals", "Using as a chemical weapon" and "People might use this to kill species that they find irritating but are not harmful." Commenting on these reactions, P1 expressed how these reactions prompted him to critically think about the future iterations of the drone he is working on.

"The adverse consequences mentioned here made me think a step ahead.. Right now, I'm only thinking about detecting pests and fungi in the tea plantations. However if the plantation owners wanted me to build pest control features also in the future, I would have also thought about the negative effects such as air and soil pollution mentioned here, and build functions to avoid those."(P1)

One noteworthy observation during this activity is that the reactions of the semantically unrelated dream drones prompted the participant to think about the aspects of their work that they are usually oblivious to. For example, in response to P8's input, "a drone that is an indoor personal assistant", the algorithm resulted in "Bloom" as the most dissimilar drone story which describes a drone that spreads flower seeds. Based on the reactions to "Bloom", the tag visualization contained the tag saying "Destroy ecological systems". Even though this tag seems inapplicable to a personal assistant drone, it prompted P8 to think about how her drone can potentially create ecological issues. She stated:

"As an indoor companion, I want this drone to be able to take my trash out. Now I see this [the tag], it makes me think that this drone should have a safer mechanism to carry trash from my kitchen to the outside dumpster without spilling it in the neighbourhood."(P8)

In a similar example, P6 was shown the tag "Harm animals" as a result for her input "a drone that monitors weather". In response to this she stated: *"When I select a drone platform for my climate studies, I only think about my research objectives. I choose the platform that best suits my work. I do not think about whether there are quieter platforms or can I find a less invasive platform for my work. Is there a way I can avoid my drone hitting a bird. I think as a consumer if I start to ask those questions, I can push the vendors to be more sensitive to the disturbance that drones causes to animals and environment"*

In addition to the negative aspects mentioned in the reactions, participants saw value in the positive reactions. As many of the participants mentioned, seeing people highlighting the positive aspects of the dream drones that are similar to what they are working on makes them "feel good"(P1) about their work.

However there were some instances where participants mentioned that they feel *"some of the adverse consequences mentioned are too far fetched"*(P1) , *"almost too dystopian"*(P7), and *"not applicable"*(P4). While most of the participants considered being aware of the consequences of their work and attempting to mitigate the negative effects as part of their responsibility towards society, P4 had a somewhat contrasting opinion in this regard. He expressed:

"There's really nothing on this earth that can't be misused. At the end of the day, like I said, this is something I do with a passion of mine. If they made it illegal then I'd be a criminal because I'm not going to stop this just because somebody's going to have a problem against it."

5.5.3 Various Ways Crowd Input Influences Participants' Practices

Participants reflected on various ways in which crowd inputs gathered through the dream drone platform can influence their individual practices. To this end, P1 considered dream drone scenarios as ideation inputs for him to explore new project ideas. He pointed out the possibilities of *"fusing"* his existing ideas with the dream drones to brainstorm new features. While P3 and P4 shared similar sentiments, P2 highlighted the significant potential of crowd inputs to assist in exploring divergent modes of risks pertaining drones, within his practice as a threat analyst. He stated:

"Drones are still an emerging technology. There are various unknown ways that drones can go wrong, fail or do harm. We have actually run out of ideas [of the risks that should be considered for the analysis]. The ideas and consequences put by people here can really help us to explore the potential risks we haven't yet thought about"

P5, a policy advocate for drone security pointed out the opportunities for proactively involving the public in regulating drone usage through platforms similar to ours. He went on to elaborate the importance of speculating the potential risks and harmful uses before they actually occur, in order to prevent impulsive reactionary policy decisions. He further expressed:

"There's a correlation between when somebody does something stupid with a drone.

And then there's an immediate knee jerk reaction, creating these rules.. ultimately inhibiting the creation of that system. And that's a big problem because, then you're going to see that the entire industry gets slammed. We're completely reactionary [when it comes to policy making] Very, very, rarely do we think proactively."

Moving on, participants also brought forward several suggestions to improve the dream drone platform to better suit their needs. Many of the participants mentioned that they would like to know about the backgrounds of the authors of the dream drones. P2 elaborated:

"if somebody is in agriculture,... and they are giving an idea of a flying taxi. I will probably not be interested in spending my time [on reading the story], But, if their background is in agriculture and he has given an idea of a drone related to agriculture, I would definitely love to see it."

In addition, participants also suggested adding a feature that enables them to filter dream drones based on the geographical location of their authors to better understand the contexts they are coming from. In a similar note related to crowd reactions , P5 mentioned:

"I need to understand the intent [of the reaction]. So when somebody says something, I really need to understand where they're coming from. A short little comment like this really won't affect my decision making. Unless this person is willing to really sit down with me and explain to me why is it that they feel this way."

In contrast, P6 preferred to have the information about the authors hidden from her as such information might create biases in her decision making. She elaborated:

"So if I see that John Smith from this big company suggested this am I going to give more weight to that vs John Smith from Podunk who doesn't have what we might consider as the correct credentials or the background. You can have a brilliant idea. I [might have] overlooked that idea just because of that background information. I kind

of like the blind process."

To summarize, The crowd-inputs gathered through Dream Drone platform prompted the participants to reflect on their work in various ways. They viewed dream drone stories and superpowers as inputs to explore new opportunities for their work, understand different contexts drones can operate and be aware of peoples needs and aspirations of future drones. Crowd reactions and tag based visualization prompted the participants to reflect on the potential consequences and divergent (mis)uses of the projects they are working on. While most participants value the crowd reactions in few instances they felt they are too dystopian or not applicable to their work. In addition participants highlighted several ways Dream Drone platform can influence their work. These applications include generating new project ideas, being aware of potential risks and advocating for proactive policy making.

5.6 Discussion

In this section, I discuss the broader implications of this work for HCI. I draw from the qualitative findings from the interviews and my observations and experiences during the dream drone data collection. First, I discuss the opportunities for supporting divergent thinking within Design Fiction through gathering inputs from people from diverse backgrounds and cultures. Second, based on the observations of using the Machine Learning based experimental user interface as a probe, I describe several directions to bridge Design Fiction and Machine Learning.

5.6.1 Supporting Divergence within Design Fiction through Diversity

In the recent Netflix documentary "The Social Dilemma", Justin Rosenstein, co-inventor of Facebook's Like button stated: *"When we were making the like button, our entire motivation was 'Can we spread positivity and love in the world?' The idea* *that, fast-forward to today, teens would be getting depressed when they don't have enough likes or it could lead to political polarization was nowhere on our radar."*

An inherent goal of Design Fiction and Speculative Design as a whole is to challenge designers to rethink such overly optimistic preconceptions towards what they are designing. Design Fiction uses diegesis-style fictional narratives to explore future scenarios that could possibly materialize as a result of what is being designed. These fictional narratives allow designers to go fast-forward in time and critically reflect on the uses, misuses and consequences of their products by asking "what if" questions (Dunne and Raby, 2013). For example: "What if Likes becomes a currency that determines social acceptance or rejection?"

From a pragmatic point of view, products or technologies that are being designed at present can have an astronomical number of potential futures. Therefore, on the one hand, becoming aware of all the consequences of a product or technology could be practically unrealistic even for the most socially and ethically responsible of designers. On the other hand, the way we project a present day product or technology into the future is subject to our prior experiences, opinions and personal interpretations. These subjective biases could still drag us towards the very preconceptions that we try to move away from. One way of addressing this issue within Design Fiction is to get the input of people from diverse backgrounds and different cultures, particularly from outside of typical design studios and academic settings.

Within the Dream Drone platform, the creation of diverse Design Fiction scenarios is explicitly supported in two major ways. First, being an open online platform, people from diverse backgrounds in many different parts of the world were able to access and contribute.Over the period of three months of data collection, the Dream Drone platform has reached contributors across a wide range of ages (18-65+) who self reported a diversity of backgrounds from engineering to environmental science to policy making. Moreover, it received inputs from many different parts of the world including USA, Russia, India, China, New Zealand, South Africa, Nederlands, UK, France, Nigeria and Sri Lanka. Second, it allowed contributors to build and reflect on each other's ideas. They were able to see a list of superpowers created by others, and the generation of new ideas by 'mixing and mashing' them (e.g., Yu and Nickerson, 2011b). In step three, they were prompted to critically think about the positive and negative aspects of other people's dream drone stories. During subsequent qualitative interviews,these diverse crowd-inputs pushed drone practitioners to critically reflect upon the divergent possibilities–both positive and negative—of the drone related projects they are involved in.

The outcomes of this research highlight several opportunities for HCI in the realm of Design Fiction to utilize the remarkable generative potential of diverse crowd inputs. Even though design fiction is largely considered a tool for designers, through the Dream Drone platform, I have shown the possibility of making Design Fiction more accessible to the public across the world. Building on this, future HCI research can further explore simplified yet effective online workflows and novel user interfaces to engage large audiences from diverse backgrounds and cultures. While the Dream Dream platform only supported text-based input, future platforms can explore other mediums including photo stories, audio recordings and short movie clips which can better represent cultural contexts. Such non-textual mediums can also mitigate the language barriers for engaging people from different cultures— an inherent limitation of the Dream Drone platform.

5.6.2 Bridging Design Fiction and Machine Learning

During the interviews, the Machine Learning based experimental user interface helped participants in two ways. First, it provided a platform to browse crowd inputs from our data set in relation to the projects they are working on. Second, the tag based visualization provided them with a list of open-ended leads to think about their project critically and divergently. By using this interface as a probe, this work uncovered several directions that Machine Learning based Natural Language Processing techniques can be applied to crowd-driven Design Fiction.

Even though the number of crowd inputs that we were able to collect was relatively lower than what we initially expected (not to mention that the data collection took place during an unprecedented time period due to the COVID-19 pandemic), I believe that through rigorous dissemination methods and long term data collection, platforms similar to Dream Drone can gather a considerably larger amount of data (in the range of thousands) in the future. Such a large amount of crowd inputs create opportunities to use Machine Learning based information extraction, sense making and visualization mechanisms to develop intelligent platforms that effectively push designers to critically reflect on divergent contexts that their products can be (mis)used. The algorithm implemented to calculate the semantic relevance of the dream drone stories was built on a pre-trained NLP model. Since this model is trained using a more general body of natural language expressions, it is particularly less sensitive to the figurative and metaphorical expressions present in dream drone stories. With a large corps of crowd-generated data, future HCI work in the domain of Natural Language Processing (e.g., Huffaker *et al.*, 2020), can explore ways of training custom NLP models that are sensitive to such story-specific language constructs presented within design fictions.

Notably, during the interviews I observed that crowd reactions received for the meaningfully dissimilar dream drones prompted participants to explore their projects in unusual contexts beyond mainstream uses. In the meantime, tag-based open ended representation led participants to interpret crowd-inputs in diverse ways. While pushing designers to think beyond the popular notions of their work is a fundamental goal of Design Fiction, my work has shown the potential of using multiple meaningfully-different Design Fiction scenarios to further scaffold such thinking. To this end, future work can also explore how Machine Learning based approaches can be used to create more generative forms of information visualizations to represent crowd-driven Design Fiction. Even though the Dream Drone platform lacks a mechanism to feed the outcome of the practitioner interviews back to the system, future work can also explore ways to dynamically improve the underlying ML models based on the practitioners' responses to the system.

Chapter 6

CONCLUSION

In this chapter, I summarize the academic contributions of my work and their broader social impact. I conclude this dissertation by highlighting broader implications of my work that can shape future HCI research in the realm of Open Design.

6.1 Summary of Contributions

This dissertation aims to expand the current scope of Open Design within HCI research through a long-term exploration of Open Design's socio-technical processes. I examined Open Design from three perspectives: the functional—materials, tools, and platforms that enable crowd-driven open hardware production, the critical—materially-oriented engagements within open design as a site for sociotechnical discourse, and the speculative—crowd-driven critical envisioning of future hardware. Along these directions, my work uncovered broader opportunities and challenges for HCI to support the global Open Design movement.

More specifically, this dissertation offered several key contributions to HCI. First, my long-term study of OScH provided a focal point for HCI to deeply understand the growing global scene of Open Design. This work uncovered the different contexts in which Open Design operates across the globe and the challenges for its widespread adoption. These challenges include the lack of support to customize open source hardware designs, the disconnect between designers and end users, and barriers for internalization. It also highlighted opportunities for HCI to overcome those challenges through simplified interfaces for customizing open source designs, language-agnostic mediums for documenting Open Design projects and platforms for bridging open designers and end users.

Second, my exploration of the collaborative making of open science hardware offered insight into the application of Critical Making within Open Design. Through this work, I have shown the possibilities of utilizing HCI's conceptual and practical understanding of Critical Making together with Co-design methodologies to trigger a constructive interdisciplinary dialogue around social and technical issues related to Open Design. In addition, this work foregrounded the potential role of HCI researchers as facilitators of critical thinking and of joint conversations within materially-oriented engagements in Open Design such as workshops, maker faires, hackathons etc.

Third, through the development and the study of the Dream Drone platform, I have introduced the concept of crowd-driven Design Fiction. This platform brought together people from different parts of the world to envision and reflect on the future of drones; a timely and controversial topic that relates to emerging technologies. Through this work, I have shown the potential of using inputs from people from diverse backgrounds and cultures to generate divergent Design Fiction scenarios. I have also shown the ways in which such crowd inputs can ultimately push practitioners to think beyond often overoptimistic preconceptions of their work. Through an experimental interface which uses a pre-trained Natural Language Processing model to filter and represent crowd inputs, this work also highlighted the potential future uses of Machine Learning within Design Fiction. Moving on, this work pointed out the pragmatic challenges for crowd-driven Design Fiction which include the increasingly shorter attention span within online interaction and the indifferent attitudes of practitioners towards crowd inputs.

6.1.1 Social Impact

Beyond the academic contributions, my work supports the global Open Design movement by identifying the broader social and technological challenges for its widespread adoption. In addition to the academic publications, I have documented my findings in the form of a digital booklet written in lay language, to be freely and openly shared with the global Open Design community. The open-source DIYBio incubator design has been reportedly used by more than 25 open-science practitioners from Asia, Africa, Europe, South America and the USA. The online Instructables post has been viewed by more than 16,000 users. My design files have been reused in a multitude of new open-source projects.

Through maker workshops, I have taught more than 50 participants/students the basics of electronics, computer programming and digital-physical making. These workshops provided a platform for local communities to broadly engage with academics and practitioners from diverse backgrounds resulting in highly constructive conversations. Through dreamdrone.org, I provided an accessible platform for the public to express their aspirations and concerns towards future technology. Moving forward, I believe that similar platforms will empower people to proactively contribute towards technology design, instead of being merely considered as passive consumers.

6.2 Broader Implications

Based on the overall research outcomes of this dissertation and my personal reflections of exploring the people, systems, tools and methods, both within HCI academic circles and outside communities, below I highlight the broader implications of my work under three topics: a ‘practice-based approach for academic research’, ’beyond design thinking’ and ‘internet-based platforms for crowd-driven critical thinking’.

6.2.1 Practice-based Approach for Academic Research

My exploration of the Open Design movement was primarily based on academic motivations. I was largely driven by mainstream academic performance indicators such as publications, grants, awards, conference attendances, etc. However, a part of me always wanted to contribute to the larger Open Design ecosystems as an active practitioner. Driven by this intrinsic passion, I proactively made the outcomes of my work accessible to the larger Open Design communities through mediums that they are mostly familiar with. During the past five years, I have had the opportunity to deeply engage with local and foriegn maker communities, both in-person and remotely. I volunteered in setting up and conducting several Open Design community events ranging from makethons to biohacking workshops. These activities gave me the chance to embed myself within the broader global Open Design community. My practice based approach not only allowed me to explore my academic research questions from an inside view, but looking back, I drew greater satisfaction from the social impact of my work.

As I iterated in the chapters three and four, highly academia-centric explorations (i.e, studies that predominantly aim at only producing academic publications) on Open Design practices are typically received poorly by Open Design communities. Through my work, I hope to have highlighted the value of more practice based approaches that simultaneously produce academic outcomes as well as valuable contributions to the broader Open Design community. As the borders between conventional academic practices and open modes of innovation and knowledge production continue to blur, I believe that my work foregrounds the importance of such practice-based hybrid approaches towards creating productive and meaningful engagements across those borders.

6.2.2 *Beyond Design Thinking*

The past five years have seen my personal views of design expanding. Coming from an engineering background, I used to see design as a process that ultimately produces things that work, things that solve problems and things that are useful to people and make them happy. Through continued explorations of non-utility-centric design philosophies including critical design, speculative design and design fiction which present design as a medium for critical reflection, I was able to expand my comprehension of design beyond utilitarianism and problem solving.

Outside of design academia, industry-based design practice is still largely driven by trends such as design thinking and human centered design. These practices are fundamentally built upon the notions of design as problem solving. For instance, at the core of design thinking are what's desirable from a human point of view, what is technically feasible within the foreseeable future and what is economically viable as sustainable business models. In contrast, non-utility centric design trends such as critical design, speculative design and design fiction, in which my work is partly built on, are principally aimed at challenging the very presumptions on which design thinking operates. Instead of finding out what user needs should be addressed to build a sustainable business, these design philosophies challenge us to rethink the value systems that our needs and wants derive from. Instead of building on what current technologies are capable of achieving, they prompt us to critique on what capabilities future technologies should or should not have. Simply put, while design thinking is concerned with deeply understanding and building on the current status quo, such critical design practices are aimed at critiquing the status quo.

Amidst the current issues we face, from climate change to global pandemics to fake news that threaten our very existence, there is a growing need to rethink the value systems that our design practices are built on. There is a need to see design beyond utilitarianism and mere human-centricity. In other words, there is a need to bring critical design, speculative design and design fiction beyond academic circles to mainstream industry-based design practice. In addressing this need, design academia can learn a few lessons from how design thinking and human centered design are preached and popularized in the first place. What global design firms like IDEO[1] did is effectively present the underlying concepts of design thinking and human centered design in simplified terms, attractive visuals and hands-on practicable steps—arguably the exact opposite of how we do it in academia. Currently, the concepts of critical design, speculative design and design fiction are still largely being disseminated through academic-style publications which are, as my personal encounters with industry-based design practitioners suggest, not very attractive to a majority of design practitioners. Hence, there is a need and opportunity to distill down these non-utility-centric design philosophies into workflows that are attractive to and practicable by mainstream design practitioners. In the Dream Drone project, my attempt to transform the concepts of Design Fiction and Speculative Design to a simpler workflow was largely effective in making such concepts attractive to the public. In fact, some of the features of my Dream Drone platform such as building on other people's ideas were directly drawn from the core concepts of human centered design and design thinking. Therefore, while trying to push the boundaries of design beyond utilitarianism, design academia should also examine the intersections and overlaps of critical design practices with existing mainstream industry-based design practices. Drawing inspiration from mediums that are used to effectively disseminate design thinking and human centered design, design academia should proactively explore ways to reframe still largely academically oriented design philosophies specifically aiming outside practitioners.

[1]https://www.ideou.com/blogs/inspiration/what-is-design-thinking

6.2.3 Internet-based Platforms for Crowd-driven Critical Thinking

Through my work on crowd-driven design fiction, I have shown the potential of engaging people from diverse domains, cultures and countries to critically envision the complex social and environmental consequences of technologies before they come into mainstream use. Over the years, the internet has been the most feasible and effective medium to engage people from such diverse backgrounds at scale. However, our current interactions with internet based platforms are increasingly being designed for shorter attention spans. User interfaces with bottomless scroll views, endless notifications, recommendations and social media trends that appear and fade out in procession have all made our collective attention spans shorter than it was two decades ago (Galloway, 2017). (If you are still reading, that means you're exceptional!) In contrast, concepts such as Design Fiction and Speculative Design are predominantly built on our ability to critically think and reflect. They require a considerable amount of time and attention compared to many mainstream activities people do online. As the internet increasingly becomes a place of mindless swiping, it will be extremely challenging to get people to put sufficient attention to critically think over the internet.

This concern is a part of many technical, social and ethical issues related to internet usage that HCI has been grappling with since the early days of the internet (e.g., Palen, 1999). My work on crowd-driven design fiction brings up a new context that HCI can explore these issues more broadly. On the one hand, it presents opportunities for HCI to explore new interaction and interface design techniques which intrinsically nudge people to slow down, think and reflect for longer time spans. Future work on this domain can indeed draw from HCI's emerging trends of *"slow technology"* (Odom *et al.*, 2012; Hallnäs and Redström, 2001) to explore the ways in which online interactions can be designed for critical reflections and deeper engagements. On the other hand, from the information overload to the addiction and compulsion we associate with the internet today, are mostly the results of conscious design decisions that interaction designers are also a part of. Hence, in order to bring critical thinking back to the mainstream internet, it is equally important that the HCI academia proactively works towards establishing a socially responsible interaction design practice.

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