Making Spaces: Mapping Opportunities for Improved Equity in Makerspaces and Virtual Reality

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored as the first and corresponding author: see Statement of Contributions included in the thesis.

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Statement of Contributions

This thesis to some extent consists of work done in collaboration with other authors. The following list describes the parts in the dissertation of which Cayley MacArthur has been a sole author and the parts that are the result of collaborations mainly towards published or working papers, in which Cayley MacArthur has been the first and corresponding author.

The collaborative work presented in the thesis is included in published papers or will be included in working papers for future submissions, which are as follows:

- **MacArthur, C.**, Wong, C., & Hancock, M. (2019). Makers and Quilters: Investigating Opportunities for Improving Gender-Imbalanced Maker Groups. Proceedings of the ACM on Human-Computer Interaction, 3(CSCW), 1–24. https://doi.org/10.1145/3359131 *(published paper)*
- **MacArthur, C.**, Grinberg, A., Harley, D., & Hancock, M. (2021). You're Making Me Sick: A Systematic Review of How Virtual Reality Research Considers Gender & Cybersickness. Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, 1–15. https://doi.org/10.1145/3411764.3445701 *(published paper)*
- **MacArthur, C.** (2021). A Critical Review of the Simulator Sickness Questionnaire: Its History and Suitability for Diverse Bodies. *(working paper)*
- **MacArthur, C.** (2021). Makerspaces Without Makers: Constructing Maker Communities Remotely. *(working paper)*

Note that descriptions of working papers, including their titles, are subject to change in the future.

Abstract

The promise of "making"—that is, learning, experimenting, DIY, creation, re-appropriation, or otherwise—has become a popular topic in human-computer interaction (HCI) research, and a subject of interest for public institutions like libraries and schools for their potential to engage the public in science, technology, engineering and math (STEM)-related learning, to build their confidence, and potentially inspire new career paths. However, embedded in the individualist ethos of these spaces are problems of inclusion: who counts as a maker, and what types of projects count as making. As a result, makerspaces can be uninviting to marginalized groups, and in this thesis I focus on women, specifically. Opportunities to improve equity in these environments by using technology exist, but run their own risks of amplifying inequities by porting in systemic biases as artifacts of the cultures in which they were produced.

In my thesis I address three main research questions: (1) What can we learn from gender-imbalanced maker groups in order to support the diverse needs of makers in STEM-focused environments? (2) What systemic barriers exist that prevent successful adoption of novel technologies to support the needs of diverse makers, and specifically women? (3) What ethical and methodological considerations do we have to take into account as human-computer interaction researchers when working to design, develop, or appropriate digital technologies with, in, or for maker communities? To address these questions, I conducted an ethnographic field study with diverse makers (Chapter 3), a systematic review (Chapter 4), and continuing research with makers in a post-COVID environment (Chapter 5).

The study presented in Chapter 3 was undertaken in a pre-pandemic world, when the default for maker groups was assumed to be large in-person gatherings. In that context, makers' needs coalesced around diversity in their goals contrasting to a narrow archetype of what makerspaces can or should offer. I also contribute a new understanding of what a makerspace even is, whereby such a space is not defined by a sign above the door, but by the presence of makers themselves.

Opportunities were identified to leverage virtual reality (VR) technology to address some of the unmet needs among makers, aiming to increase feelings of autonomy, competence, and relatedness. With an eye towards increasing satisfaction and self-efficacy, I hoped this work would help to keep makers coming back to the space to keep developing their skills, confidence, and curiosity.

But: what happens when the makers are removed from the space? In response to public health restrictions, makerspaces worldwide suddenly became inaccessible. After having witnessed deep levels of personal investment and emotional connection within maker groups, I

noted that belonging constituted part of makers' personal identities, moreso than whether they were actively *making* or not.

This called for a re-evaluation of the ends to which we might design new systems in VR. However, jumping from "building systems to engage in making activities" to "building systems to support social connectedness in the context of making" faces the same barrier that cannot be ignored, that is, that VR technology remains inaccessible for, inter alia, women, people of colour, and people with disabilities. Imposing the use of a system that in itself minoritizes people by rendering itself unusable would run against the grain of the feminist methodology underpinning this work. Thus, I conducted a systematic review to address a gap in HCI research around how VR research is designed, conducted, and reported in ways that systematically are biased against women.

Evaluating systems of production (through maker environments) and the objects produced within those value systems (VR technology itself) offers two ways to call into question the norms that, when invisible, can stand in the way of making progress towards improved equity.

As a reflection of the embedded and interdependent nature of this work, I lean on maker culture and re-appropriate one of the concepts I discovered through this work: the unfinished object, or UFO. I offer this methodological approach to researchers continuing community-based work with makers in order to overcome challenges faced in eliciting visions for more equitable futures, and for mapping opportunities for improved equity in makerspaces and virtual reality.

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List of Abbreviations

AR augmented reality 92

CAVE Cave Automatic Virtual Environment 66

CSCW computer-supported cooperative work 8, 91

FOV field of view 56

HCD human-centred design 3, 84, 86, 92

HCI human-computer interaction 1, 8, 59, 91

HMD head-mounted display 51, 66, 97

ILE informal learning environment 1, 8, 14, 15, 20, 22, 50

PD participatory design 96

SSQ Simulator Sickness Questionnaire 60, 69, 74

STEM science, technology, engineering and math v, 1, 6, 47

UFO unfinished object 11, 95, 96, 98, 99, 102

VE virtual environment 51, 54, 59

VR virtual reality 1, 7, 8, 50, 51, 92, 97, 98, 100

Chapter 1

Introduction

This thesis serves to present my contributions to human-computer interaction (HCI) research through the course of my doctoral studies. With a focus on improving gender equity, I have taken what I describe as an ecological[1] approach to understanding barriers to women's increased access and participation in STEM environments.

The first prong of addressing this challenge takes the form of an investigation into gender-imbalanced maker groups, in particular, those focused on masculinized "tech" making activities (game jams) and those focused on feminized "craft" handiwork (quilting). In this work (Chapter 3), I call into question the tendency in HCI literature to apply the label of *making* to these male-dominated environments and not to others, further perpetuating stereotypes about what we think it looks like to participate in the kinds of experimentation and creation that can build confidence and encourage the pursuit of further knowledge and skills. I also offer a new understanding of how we define "makerspace," as something metaphorical and defined by people as opposed to institutionally designated. Finally, I identify ways in which the diverse needs of makers are not currently being met due to a narrow understanding of why people participate in such events, and offer potential solutions for designers of similar informal learning environments.

One way to address unmet needs related to autonomy, competence, and relatedness in STEM informal learning environments (ILEs) is through leveraging novel technologies, like virtual reality (VR). A virtual environment could allow makers of all types to, for example, visualize materials that are difficult to acquire, plan designs, or collaborate remotely. However, a critical reading of this technology reveals a historical bias towards men—white men—in its design and evaluation. Upon learning this, one could decide to turn towards

[1] See footnote 4.

another technology instead, which serves the interests of the researcher. A decision to turn away as opposed to questioning how we got here and how we might make things better is, implicitly, a decision to be complicit in allowing an inequitably designed system to remain unchallenged, and one that would run counter to a research agenda with feminist aims. As such, in Chapter 4, I provide a systematic review of gendered issues in virtual reality. Then, I articulate the ways in which VR research is failing women and other gender non-conforming people through erasure of their experiences and framing cybersickness as an issue with people rather than with technology. Through this work, I demonstrate how the embedded bias in VR technology is a reflection of the environments in which it is developed, including a failure to question norms that have lead to perpetuating systemic bias. Addressing the disproportionate and gendered inaccessibility of this technology is essential in order to move forward so that people do not continue to be excluded or marginalized by tools that are not made with them in mind.

Designing technological solutions towards improving equity requires being attentive to context in two ways: what baggage comes along with the context in which that technology was produced (Chapter 4), and being mindful of the context in which communities are operating (Chapter 5). The COVID-19 pandemic of 2020-present[2] means that maker groups can not function, and are not functioning, as they were when this research began. Revisiting these and similar informal learning environments (a hackspace, a sewing group, and two game jams) as they adapted to the euphemistic "new normal" reveals both new challenges and familiar themes. Most notable of these themes is that of social connectedness, which is consistent with my prior findings around relatedness (Chapter 3), but elevated to a new context wherein there is no physical space to gather. Given what is already known about the benefits of making and its relation to well-being, it becomes especially important to reorient how we choose to employ technologies to support makers. In Chapter 5, I discuss what being part of a maker group has come to mean to community members during the age of physical distancing, and the implications this has on design decisions for these groups. Specifically, I stress the need for a feminist care ethics perspective in these relationships, community involvement through co-design, and a decidedly feminist speculative design practice when determining *with* makers how their worlds could be.

Throughout this dissertation I refer to "makers" as game developers, quilters, hackers, garment makers, woodworkers, and more. The Silicon Valley branding of "making" as a STEM activity taking place in shiny well-funded workspaces has served to deepen the divide between the tech orientation as masculine and arts or crafts as feminine, notwithstanding a level of social and cultural awareness in these communities that gender itself does not operate in this binary. During my research I have observed what many of us know

[2]At the time of submission.

anecdotally to be the case, that is, that this distinction is *not the case*. By queering[3] the boundary between who we consider as a maker and what they make, I hope this dissertation will provide new ground to further explore how to open up its benefits to more people, and to bridge the chasm between what we appreciate as "making."

1.1 Situating the Research

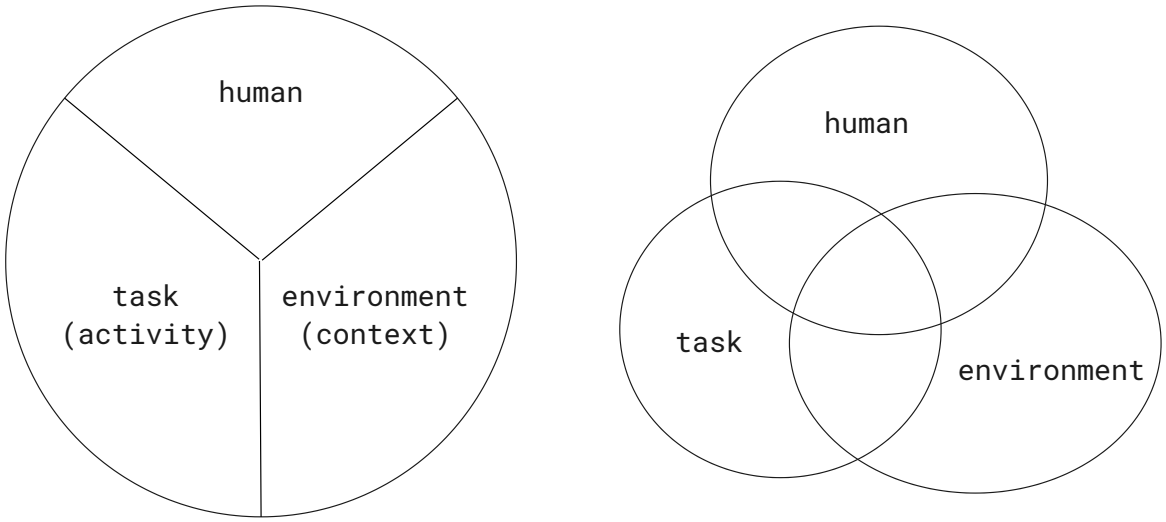
In the ten years since an agenda for Feminist HCI was first proposed (Bardzell, 2010), the research community has moved from studying marginalized identities to calls for action for, and from, the margins. An increase in participatory- and community-based research has created environments to renegotiate the relationship and power dynamics between those in the academy and equity-seeking groups. Such an attention to care has brought about new perspectives and understandings on the positionality of the researcher, and the directionality of the relationship with the groups we both study and seek to empower.

In human-computer interaction (HCI) research, we consider ourselves as taking a HCD approach, an example visualization of which is Bailey's (1996) Human Performance Model in Figure 1.1a. This way of thinking positions a human as performing a task within a broader environment, which has served researchers well for a long period of time.

While some authors have expanded on this simple diagram in various ways, I suggest a reconfiguration of this model for the purpose of my thesis as shown in Figure 1.1b. In reality, these moving parts influence one another and this is a reflection of our messy existence. By envisioning the HCD model as intersecting, it reflects some things that we take for granted. Specifically, human-computer interaction has real human impacts. Technologies impact how we relate to one another, and they impact how we relate to the world. If bias is encoded in the technologies structuring our relationships, technology can not be a tool for equity. Embedded biases limit agency and self-determination: it limits what we think we can do, and who we think we can be.

I situate my work in the centre of this Venn diagram in the space of critical computing. The work presented in this dissertation is a demonstration of how taking an ecological approach to reading the design of sociotechnical systems can allow us to consider the intersections between people, their tasks, and their environments, to uncover new opportunities

[3]Queer theory branches from feminist schools of thought. Using queer theory allows one to blur boundaries and question norms, and in celebrating transgressions we can *expose* norms. Judith Butler (1997) describes the sites of focus under queer theory sites of "collective contestation," where we can challenge how cultures perpetuate (heteronormative) binaries, with the aim of undoing hierarchies and combating social inequalities.



(a) Bailey's Human Performance Model (1996) (b) Human-centred design, reconfigured

Figure 1.1: Reorganization of the traditional relationship between human, task, and environment in human-computer interaction.

to improve equity in these spaces and places. I refer to this intersecting model of human, task, and environment as an ecology; the metaphor of an ecology allows for an understanding of these relationships as open systems that are heterogeneous and dynamic.[4] The role of the researcher is not one that is objective or omniscient, but rather a part of that system, and thus must be responsive to it. Thus, doing justice to the needs of these communities is relative to the circumstances in which we find them. Sometimes, those circumstances will change. As opposed to being a setback for the researcher, this is an opportunity to understand how we can support these groups *moving forward* as opposed to continuing to impose technological solutions which may be redundant, outdated, or just not what they

[4] "Ecology" is often used as a metaphor in different areas of HCI research, to describe relationships between technologies or practices mediating work. An artifact ecology, for instance, posits that "the use of an interactive artifact cannot be understood in isolation, but artifacts must be understood as part of an artifact ecology, where artifacts influence the use of others" (Bødker & Klokmose, 2012). Similarly, genre ecologies raise the point that technical documentation and computers do not exist in a closed system: rather, an open-system way of thinking allows researchers to take into account the way multiple artifacts mediate work practices (Spinuzzi, 2002; Spinuzzi & Zachry, 2000). Niedergeses (2012), in a study of collaborative ecologies, demonstrates how specific mechanisms contribute to the construction of these sociocultural systems. I return to the vocabulary of "ecology" as a means of describing the dynamic relationship, subject to external pressures as an open system, between people, what they hope to achieve, technologies, and spaces—physical and virtual.

need right now. Imposing the ideals of what the researcher *thinks* a community will want (or should want) erodes trust, demonstrates a lack of care, and negates the principles of a feminist research methodology.

Concretely, this manifests in the scope and direction of the research constituting this thesis. Figure 1.2 points to some of the themes covered throughout this work and demonstrates some of the research questions that are uncovered once we interrogate how the themes in each of these spaces intersect. In the section to follow, I delve into the specific problem space and research questions framing my work.

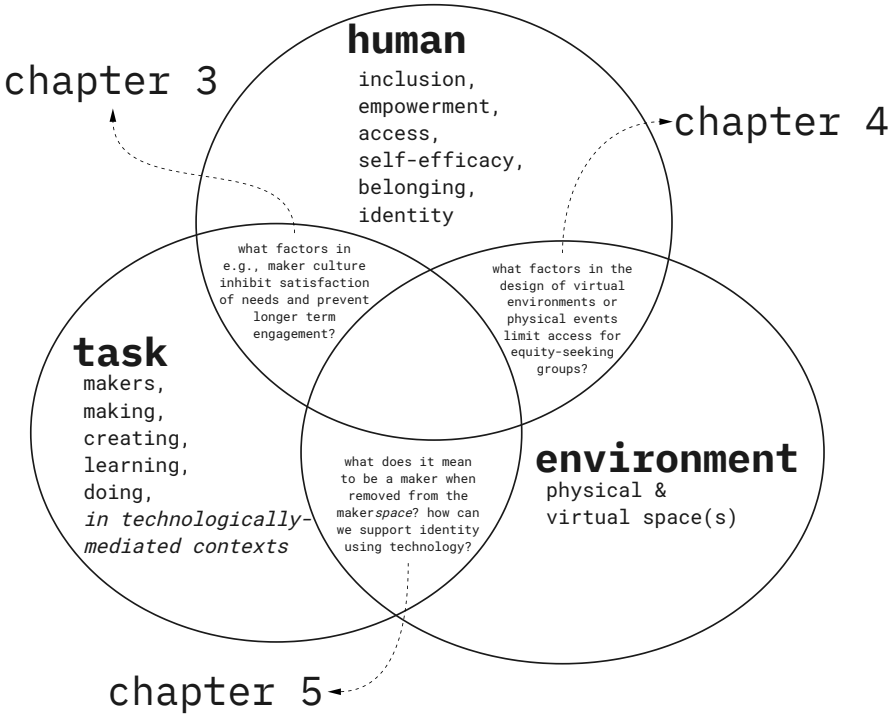


Figure 1.2: Sample research questions developed from examining the intersections of these spaces, and corresponding chapters in the dissertation

1.2 Problems and General Research Questions

While my dissertation focuses on gendered issues in making and in the context of HCI research, the root problem that inspired my research is the lack of participation by people that identify as women throughout STEM and the pipeline of education leading up to meaningful engagements or employment in STEM fields.

In Canada, women account for the majority of recent postsecondary graduates in all provinces and territories: in fact, the proportion of women with university degrees more than doubled in the 24-year period from 1991 to 2015 (Ferguson, 2016). Even more encouraging is that women account for a larger proportion of STEM graduates than in previous generations. However, they are still in the minority. This data, published in a 2016 report detailing a large-scale survey by Statistics Canada (Ferguson, 2016), is discussed in the context of the *pipeline theory*, which describes the path women take from education to a career path, and the "leaks" along the way. Once these women enter STEM careers, the leak continues: the representation of women technologists declines by 50% from entry to mid to senior and executive levels (Davis-Ali, 2017). This high level of attrition is mirrored by countless efforts to get large numbers of young girls and women interested in STEM, in anticipation that many will eventually leave. This loss of exposure to STEM activities limits opportunities for learning and experience for those interested in exploring their options, as well as limiting their ability to imagine what impact they could make in a STEM-based role in the future.

As women drop out of the workforce at a faster pace than their male counterparts, those left designing cutting-edge technologies such as virtual reality are a predominantly male group (Simard, 2008). Previous work in human-computer interaction (HCI) research has shown how implicit bias associated with this lack of diversity can manifest in a variety of ways, and it can be difficult to tease out just how much it has affected the shape of technologies we use every day (e.g., Beckwith, Burnett, Grigoreanu, et al., 2006; Bradley et al., 2015; Williams, 2014).

It is asserted in policy, technology, and business contexts that increasing the diversity of contributors in technical fields would be beneficial to a country's competitiveness and economic prosperity (Ferguson, 2016), would fuel problem-solving and innovation in companies (Simard, 2008), and would additionally enhance productivity and creativity (Davis-Ali, 2017). Much work has been done to explore methods for attracting and retaining women in STEM fields (e.g., Holtzblatt et al., 2016; McGill, Decker, et al., 2015; Patitsas et al., 2015). However, this work often turns the magnifying glass on the STEM discipline in question, rather than looking outwards for successful examples of female retention in other fields and learning from them. In a field that is looking to the future,

this has left a gap in our knowledge that can be expanded upon by looking back to our neighbours, communities, and traditions, where strong female collaboration in technical crafting and making has occurred all along.

1.2.1 Research Questions

This work addresses the themes of gendered exclusion, attrition, and bias in HCI by reflecting and refracting how concepts of gender shape spaces of ideation and our accepted approaches to evaluating the suitability of solutions that are publicly positioned as *democratizing*. This work is motivated by a pursuit of improved gender equity and an underlying belief that democratization cannot occur while these spaces remain inaccessible. I explore the below research questions (RQs) to contribute new insights, proposed solutions, and approaches to addressing challenges facing maker communities in physical and virtual spaces.

RQ1. What can we learn from gender-imbalanced maker groups in order to support the diverse needs of makers in STEM-focused environments? To answer this first question, I present a study in Chapter 3 that eschews socialized or gendered connotations of what is and is not a makerspace, instead focusing on the common goals and structures of two genres of maker events that inhabit the spaces of game development and craft, specifically quilting.

RQ2. What systemic barriers exist that prevent successful adoption of novel technologies to support the needs of diverse makers, and specifically women? In tandem with determining how and what technologies could support unmet needs of marginalized makers (as per RQ1), it is necessary to identify how appropriate these solutions are: are they useable? Are they accessible? Or do they bring with them their own set of embedded biases? VR technology presents this very issue, and is explored in Chapter 4.

RQ3. What ethical and methodological considerations do we have to take into account as human-computer interaction researchers when working to design, develop, or appropriate digital technologies with, in, or for maker communities? In Chapter 5, I reflect on the changing nature of maker communities in response to the global environment, and the changing relationships between makers, making, and their communities. The relationship of the researcher is implicated in this dynamic, and I offer a methodological approach to help these communities move forward, together.

1.3 Scope of the Research

My research is situated in areas of interest bridging the HCI and computer-supported cooperative work (CSCW) communities. I contribute to the literature on Gender HCI, Feminist HCI, maker culture, and VR, as well as opening opportunities for conversation between these areas. I offer a new perspective on the motivations of makers when they choose to participate in ILEs and show that more people than "just" women are being affected by a narrow definition of what it means to perform making. The female-dominated maker groups that I studied offered more diverse avenues for self-determination, leading to a heightened sense of community. Using this lens will benefit organizers of these groups as well as those studying them, by offering a new perspective to understand the motivations and behaviours of participants. In this work, I identify ways that technology can be used to better support the divergent needs of makers. In the technical aspect, I address a gap in the HCI literature that needs to be accounted for before VR technology can be applied to support the aforementioned needs of makers: the gender inequity that is baked into the technology itself. Rather than asking VR researchers in our community to reorient their priorities to solve the issue of gendered cybersickness, I shine a light on the ways that unquestioned norms can seep into and destabilize our understanding of how gender functions in relation to technologies. While VR is the specific technology under the microscope here, this should serve as a caution when evaluating any novel technologies to bring into communities experiencing issues of exclusion: what can we learn about these technologies in order to be confident that they will not marginalize the very people we are trying to include through the incorporation of those same tools? The suitability of this technology became clearer after makers worldwide were dispersed due to pandemic-related public health restrictions. In addition to learning about how maker groups have adapted their making practices in the face of losing access to physical spaces, I also offer a reflection on the importance of using technology to support the foundation of these groups—the communities. My ongoing research with maker groups has contributed to mapping the research space for how better to incorporate technologies to support diverse makers. I also offer methodological reflections that share my approach to an equity-oriented research agenda.

1.4 Positionality Statement

The research presented in this thesis is shaped by my perceptions of the world, a lens which in turn has been shaped by my own experiences which are particular to my own standpoint. The way that others perceive me also affects how they respond to me, thus

my identity is inextricable from what is presented to me *and* how I understand it. The purpose of this section is to describe how my identity is situated, in order for the reader to better understand who has conducted this research, and who is reporting on it. I am a white-identifying, cisgendered woman from a middle-class working family in Southwestern Ontario. I was born and raised in Canada, to parents who also have spent most of their lives in this region. Although I have one immigrant parent, her having travelled from England at a very young age means that I have not been witness to the immigrant experience in Canada. Further to this, where I grew up there was minimal everyday exposure to other races and cultures. One way that I practice reflection is to be conscious of whiteness as a norm not only in how I think about predominant narratives, but also how it plays a role in my experiences as a researcher: acknowledging that to some, my presence is welcoming, and to others, it may be something to avoid. This then perpetuates the whiteness of what accounts get recorded in theses like this, and which are left out.

I am a first-generation post-secondary student. My approach to research is informed by an interdisciplinary background: in my undergraduate degree I took research methods courses in, inter alia, archaeology, life sciences, and hands-on design projects. My master's degree trained me in methods from communication studies, media studies, rhetoric, semiotics, psychology, human factors, and human-computer interaction. When I approach a research problem or question, I always bring a combination of these understandings to designing my projects, and to the process of interpreting the data collected.

For this reason, my approach to research may feel rigid when reading with the lens of the humanities or interpretive in the sciences. I emphasize here, for the benefit of the reader, that the way I communicate results *is* interpretive: interpreting results, rather than stating facts. I share what I have observed during my projects, I am not prescriptive about what this means for the participants (e.g., that they fit into some category X or Y which acts as a predictor for future behaviour), nor do I suggest that these observations extend beyond the microcosms into which I have been welcomed as a researcher.

As a woman studying makerspaces, hackspaces, and game jams, I found myself intimidated in ways that resonated with some of the women I interviewed who were also afraid to enter those spaces. In this case, my gender was an identity factor that limited my access, even if I was only limited mentally. On the other hand, the combination of my race and gender assisted with blending in at the quilting events that I attended. I will specify "the quilting events *that I attended*" here: the practice of quilting has deep, longstanding roots in Black and First Nations communities, whose relationships to the craft are not explored here. It is not my desire nor my intention to sustain the settler narrative that quilting is the purview of affluent, white women. However, due to my positionality and my interactions with the world around me—even due to how sections like Chapter 3 are written—this may

be how it is construed. Part of my growth throughout this process has been realizing the ways that I, too, contribute to these narratives in the way that I write. This learning and unlearning exemplifies how positionality is dynamic and responsive to the experiences we continue to have. In my future as an academic, I am committed to this journey.

1.5 Method

The methodology I use throughout my dissertation interweaves feminist theory including feminist HCI and queery theory, care ethics, and aspects of participatory design. In Chapter 2, I discuss how these inform my work in more detail.

My research has involved a number of methods as it has evolved, and highlighted the need to invoke certain qualities, primarily flexibility. Foregrounding my intent to make spaces—physical or virtual—more accessible to women has meant being open to adapt my methods in response to the insights gained in the research process. In other words, on this research journey I have performed contextual observations, conducted semi-structured interviews, administered validated scales, adapted Cognitive Task Analysis, designed experimental lab studies, and carried out a systematic review. Each of these informed subsequent stages of the research, and offered a different window into the processes I was working to understand. This fluidity and responsiveness reflected my commitment to feminist approaches, and played a major component in my personal skill development as a researcher. Each chapter in this manuscript contains detail on the methods used at each stage of the research.

1.6 Contributions

This work contributes both to research and development of novel technologies, as well as directly servicing the needs of maker communities by offering accounts and advice for the organization of events and longer-lasting engagements with existing and potential members. The threads running throughout this thesis surface a pattern of five main contributions, numbered C1-C5.

C1. Providing a new definition of the makerspace: By queering the idea of the makerspace, I introduce a new way of speaking about these as more than a location, but rather a metaphorical space defined by the presence of makers themselves (Chapter 3).

C2. Identifying new ways to support makers' diverse needs using technology: By using a self-determination lens, I offer stakeholders of maker groups (e.g., HCI researchers, designers, and makerspace organizers) advice on how to connect their programming with individuals' unique motivations, as opposed to advice that is specific to the type of making activity (Chapter 3).

C3. Unearthing tensions between maker/making and an elevated importance of social connectedness: I highlight the necessity of supporting social connectedness and relatedness in maker groups by using technology, by conducting research with maker groups following a turn to remote work due to the COVID-19 pandemic. This directly reflects the dynamic nature of the relationship between human, task, and environment: a change in one can provoke a shift in others, in unexpected ways, challenging what we previously thought we understood about maker groups. In turn, I add depth to the research space with further opportunities to support maker groups based on this enhanced understanding of their needs (Chapter 5).

C4. Demonstrating systemic bias in virtual reality research that inhibits the HCI community's ability to develop equitable experiences: Although virtual reality technology offers an excellent means to provide the types of experiences needed to support makers working on their projects, and more pertinently, to support social connectedness when they cannot meet, the technology remains biased in ways that disadvantage those who are already marginalized in maker communities. Through conducting a systematic review of the literature, I offer guidance to HCI researchers using VR in their studies to prevent perpetuation of patterns of exclusion and erasure that are related to women having experiences that are at times physically intolerable (Chapter 4).

C5. Taking C1-C4 into account, using a design futures approach to inform a methodology for working with maker groups: To reflect the researcher's position as a custodian of care, a stakeholder, and a part of the makerspace ecology, I re-appropriate unfinished objects (UFOs) as a method to speculate and co-create possible futures for more equitable making engagements (Chapter 5).

Chapter 2

Background & Related Work

This dissertation comprises work spanning a variety of fields including maker culture, makerspaces, virtual reality, and feminist methodology. In this chapter, I first provide an overview of the literature on making and makerspaces. I refer the reader to Chapter 4 for an in-depth look at the literature related to virtual reality and gender issues, and do not reproduce that work here. In the latter half of this chapter, I describe the philosophical underpinnings of my methodological approach.

2.1 On Making

In this section, I contextualize recent discourse surrounding maker groups and their perceived benefits. I follow by describing relevant research into the nature of game jams, followed by a discussion of known gender issues in maker groups. I then situate the quilting environment as a maker group, and discuss how the study of craft and game development groups can advance our understanding of what benefits maker groups can potentially offer to a wider set of participants.

In much of the work surveyed, I found that the terms "makerspace", "maker group", and "maker community" were often used without clarification regarding whether the vocabulary was a deliberate choice on the part of the researchers, risking the unintentional conflation of concepts that might otherwise be delineated. Maxigas (2012) offers a discussion of the "historical and ideological geneaology" of hacklabs and hackerspaces in an attempt not to lose their distinctive underpinnings to time. The author distinguishes between hacklabs and hackerspaces on notes of, for example, sociocultural attributes such as their attitudes

toward accessibility. The focus of my work in Chapter 3 is on *groups* of makers practicing their craft in various spaces. No formally-designated "makerspaces" were observed during that study. Rather, groups of makers assembling in different locations who identified as makers per Toombs et al. (2014) and their work on forging maker identities. To this end, I believe that a space is what one makes of it, that is, a space is but a space if not for the presence of makers. I therefore strive to use "maker groups" throughout my work in an attempt to transcend some of the physical constraints imposed by "makerspace", although at times, particularly in reviewing the Related Work, "makerspaces" may be used as a reflection of the previous research on which I build.

"Making" in its various forms has been the subject of research spanning HCI, computer science, recreation & leisure studies, and education. The Kwartzlab makerspace located in Kitchener, Ontario, cites the driving forces behind its creation as "invention; innovation; cooperation." It uses the terms "makerspace" and "hackerspace" interchangeably, and defines them as "a physical location where like-minded people get together in a cooperative environment to pool their knowledge, experience, and physical resources with a goal to bringing into reality the projects about which they've been dreaming" ("About Kwartzlab", n.d.). Chu et al. (2017) show that incorporating making into educational contexts supports the growth and long-term attitudes of students towards science and STEM in general. Therefore, spaces affording maker activities can be valuable tools to foster interest in a STEM education/career path, and a vehicle for motivating entry into the STEM talent pipeline.

Throughout this section, references have been made to hackerspaces, makerspaces, game jams, and hackathons: the current research on these environments, including the research regarding gender participation in them, is limited to these STEM-centric events: those that are male-dominated, and the deliberately female-dominated response. By conducting ethnographic research in women-oriented and feminist hackerspaces in North America, Sarah Fox has made valuable contributions to understanding the qualities of such workspaces that support the creative and professional pursuits of women (e.g., Fox, 2015; Fox et al., 2015; Rosner & Fox, 2016). In particular, this work focuses on how activities within these spaces contest and reframe what constitutes hacking and technology development, for example a merging of hackerspace activities with craftwork as an "intentional entanglement of hacking and practices traditionally associated with women" (Fox et al., 2015, p. 62). This allusion opens the door to explore the relationship between crafting communities and maker communities more closely. In my work, I look outside STEM to research female-dominated crafting communities, specifically quilting groups, which bear close resemblance to the male-dominated maker communities in structure.

2.1.1 Makerspaces

Makerspaces have been popping up around the globe, touted in utopian terms for their ability to democratize technology production, while enabling marginalized groups to participate in innovation (Lindtner et al., 2016). These spaces can be defined as the environments in which "makers" come together to collaborate and learn as they create, invent, and share experiences (Hudson et al., 2016). Hackerspaces, makerspaces, game jams, and hackathons are all examples of informal learning environments, or *ILEs* (Fowler, 2016), which provide contextualized, motivating spaces that facilitate personal meaning. Incorporating making into educational contexts supports the growth and long-term attitudes of students towards science and STEM in general (Chu et al., 2017; McGill, Decker, et al., 2015; Pau et al., 2007; Rosson et al., 2011; Shaer et al., 2017). Therefore, there is increasing support in the public domain for the appropriation of these formats in places like schools, libraries, cities, and museums as "new" approaches to engaging communities (Eberhardt, 2016; Fowler, 2016; Hughes, 2017; Porter et al., 2017). Prior work (e.g., Fox, 2015) shows instances of closed maker groups facilitating an environment to explore safely and build makers' confidence, as in the case of women-only hackerspaces. However, a common constraint of the aforementioned sites such as schools, universities, art galleries, and community centres is that, as recipients of public funding, they can *not* be exclusive in the same way as private entities. How, then, might such institutions extend the benefits of making in a manner that is accessible to many? This distinction informed my approach to selecting the contexts explored in this work.

2.1.1.1 Game Jams

Game jams are energized, fast-paced get-togethers of developers and artists to make digital games. These events have emerged as a way to generate and inspire novel game ideas and new ways of thinking (Chatham et al., 2013). Recent efforts show that while gaming is no longer necessarily a boys' "club house" (Shaer et al., 2017), the continuation of overt discriminatory actions or frequent microaggressions (Pierce, 1970) demonstrate a pervasive gendered tint to what community members perceive as being "a maker" or "a gamer" (Duggan, 2015). Game jams can provide benefits that have "intrinsic value" such as making new friends, business partnerships, portfolio pieces, development practice, skill acquisition, and improved confidence in personal abilities (Smith & Bowers, 2016). Early positive experiences in gaming environments have been shown by Shaer et al. (2017) to relate to higher intention or ideas of continuing in that field in the future among women. Game jams, as makerspaces and sites of informal learning, can therefore assist with estab-

lishing positive self-identity in a field currently suffering from severe lack of diversity in the workforce (Nordicity, 2015).

2.1.1.2 Gender Issues in Maker Groups

These ILEs are currently disproportionately attended by men (Steinke et al., 2016). In their work on gender and hackerspaces, Fox et al. (2015) discuss how in practice, hacking practices afford opportunities to reaffirm masculine imagery and identities. Game jams, along with hackathons and makerspaces are becoming "gendered spaces", wherein "the social identities that people create for themselves [...] are cultures made by and for men" (Nafus, 2012, p.671). Furthermore, research on ambient belonging cues demonstrates the negative gendered impact of stereotypical elements being built into an environment on women's participation in computer science (Cheryan et al., 2009). In general, ILEs provide an entrypoint into STEM, but can also be the place where these ambient belonging cues are internalized and a person decides that there is no place for them in this domain in the future (Cheryan et al., 2009).

2.1.1.3 Quilting as Maker Groups

Quilting, because of its association with family and needlework, has in the past been associated secondary status in the production/reproduction hierarchy (Hall-Patton, 2008). Manual labour and feminized craft expertise has traditionally been depicted as menial and less valuable than the masculine, presumably more "sophisticated" cognitive labour of engineering (Rosner et al., 2018). However, contemporary sociological and cultural studies tend towards an understanding of quilting as an art form, acknowledging how past characterizations of women's art as domestic or quotidian have worked to dismiss its importance in larger conversations about what is and is not considered to be "serious art" (Hall-Patton, 2008). Studies of quilters relate their making activities to feelings of wellbeing, through experiencing flow, satisfaction, mastery, confidence, community, and relationships (Burt & Atkinson, 2012), similar to the overall benefits reported above with respect to making.

Rosner et al. (2018) highlight that the worlds of handwork and computing, "or weaving and space travel" (in reference to assembling *core memory*, an information storage method which was woven by hand and used in early NASA projects), are not as separate as once thought. Specifically, the authors focus on the "gendered forms of handwork underlying digital production and their valuation as technical work." Other explorations into quilting in HCI literature involve research through creation (Strohmayer & Meissner,

2017), and education (Smith et al., 2015). Fox (2015) focusses on how activities within feminist hackerspaces contest and reframe what constitutes hacking and technology development. Despite the relationship between the crafting space and maker groups being surfaced, quilting itself has not been examined in this context.

2.2 Methodology

Over the course of my PhD studies, I have coupled my enthusiasm for equity-focused HCI research with equity-related service work in our academic community. In doing so, I have benefited from ways of knowing that lie outside of the academy but, paradoxically, form and *in*form the grounds for the arguments made in this dissertation. In this thesis, I position *justice* as an actionable noun, as a step ladder that can be used to achieve equity. In this frame, "justice" is implicated in a researcher's value system, informing the lenses we use and the steps we take when working with historically marginalized communities, whereas "equity" is the bar we are trying to at least reach if not surpass in service of those same groups in the process of human-centred design.[1] In this section, I describe the influences on my methodology, amounting to a critical, feminist reading of the spaces in which technology is produced vis-à-vis the technology produced from the cultures of such spaces.

2.2.1 Refracting Values and Politics through the Study of Objects and Systems: A Feminist Approach

In his article *Do Artifacts Have Politics?* Langdon Winner shows how ignoring artifacts in and of themselves in order to analyze the social or economic systems in which they are embedded is, in a sense, missing the forest for the trees. Meanwhile, in speaking about how technologies fit into our society, Fred Turner (2017) characterizes them as *infrastructures*: by thinking about technology as ordinary infrastructures ingrained in our everyday lives, we notice a lack of a language for infrastructure as *politics*. To explain this idea, Turner says:

> "Design is the process by which the politics of one world become the constraints on another. How are those constraints built? What are its effects on political life? To study the politics

[1] A component of this thought system is thinking of oneself as acting "in service of" a group in order to actively counterbalance the extractive and often exploitative nature of academic research. This is not to redirect the goals of the research or the role of the researcher, but rather to reorient how we think about the actions we take. It is also a reminder that research is not only "take," but should strive to "give" as well. For more on this topic, please see e.g., Berenstain (2016) and Ymous et al. (2020).

> of infrastructure is to study the political ideas that get built into the design process, and the infrastructure's impact on the political possibilities of the communities that engage it."

When we work to understand the power relations behind technological developments, what we will find out are the social origins, or the social determination of technology; in paying attention to objects, technologies can be identified as political phenomena themselves (Winner, 1980, p. 122). To focus on an artifact or to focus on social or economic systems is not an either/or decision as positioned by these two accounts. In this thesis, I investigate both the social determinants and the produced objects that reflect beliefs and values about who is included and excluded from "progress" by way of access to participation. To this end, I draw a connection between the normative politics of exclusion identified in maker environments and how, if left unaddressed, novel technologies—in particular, virtual reality (VR) systems—produced under these conditions can continue to exclude the perspectives and experiences of the people who are not at the table.

The need to foreground justice as a means of correcting for the tendency to fail to take into account the experiences of people at the margins is especially pertinent in times of crisis. The COVID-19 pandemic of 2020-present has fundamentally altered the relationships between people, their communities, and the spaces in which those communities gather. The infrastructures connecting us have been laid bare as our increased reliance on technology exacerbates existing inequities along intersecting axes of identities. Access to technology thus becomes political, as access to essential infrastructures are a matter of policy. As digital fabrication labs and app developers rush to the rescue to offer solutions to challenges of the pandemic, communities are treated as passive bystanders in the face of technosolutionism.[2] A central critique of technosolutionism is its underlying pursuit of a certain utopian ideal: one that is imbued with the biases, values, and priorities of its creators—not those of the people ultimately living in those worlds (Cranshaw, 2013). The technological utopianist vision is totalizing, and in my work with various communities it has only served to confirm that reality itself is, in Turner's words, piecemeal. That is not to say that all utopianism is bad, however: identifying it *as* a lens enables us to then *use* it as a lens, to turn it towards existing systems, to help us to explore other ways that things *could be*. For example, contemporary feminist utopianism engages "constructively and concretely about the tasks of envisioning utopian alternatives and the labour of bringing them about" (Bardzell, 2018). Feminist utopian thought retains strengths of traditional utopianism, like its "commitment to a radically better future, shaped by a strong role for moral values," while retaining political and postmodern critiques when it is applied: in doing so, it acts as a democratized

[2]Technosolutionism is the idea that technology can and will provide solutions to complex social problems (Lindtner et al., 2016).

process for imagining futures, with an eye towards both action and activism (Bardzell, 2018).

These two items, action and activism, are necessary to counter the imposition of ideological constraints through design. Equity-seeking groups are often most severely negatively impacted by the reflex to quickly enact technosolutionism to counter society's pressing issues. Criado-Perez (2019) paints one such picture in her book *Invisible Women*. To address mounting concerns over vehicle safety issues, crash test dummies were introduced in the 1950s. These dummies were based on the fiftieth percentile male, with according muscle mass proportions and spinal column. Only in 2011 did the United States begin using a "female" proportioned crash-test dummy. The residual effect of this decision is that although men are more likely to be involved in car accidents overall, women are 47% more likely to be seriously injured, 71% more likely to be moderately injured, and 17% more likely to die. Another example relates to the global context in which this dissertation was written. A report from the Data for Black Lives advocacy group[3] dated May 2020 warns against the potential for COVID-19 data to be weaponized against Black communities in media narratives, policies reinforcing redlining, and in the creation of automated decision making systems (Milner, 2020). By June of 2020, we already see this happening. An article in the Boston Globe newspaper reports that increased phonecalls to the police to report social distancing violations had lead to more than 90% of the people arrested and 82% of those receiving summonses being Black or Latinx. These groups are hardest hit by the pandemic, while also living in high-density neighbourhoods and working in essential jobs (Triplett, 2020). The use of technology as a means of enforcement, rather than for access and empowerment, criminalizes the existence of those already most vulnerable.

2.2.2 Applying a lens of feminist care ethics

Action and activism can become a part of a justice-oriented agenda just through the choice to engage with these complex issues through research. They have therefore become a part of this work, because a failure to attend to the potential risks of technosolutionism perpetuates and exacerbates injustices and harms like those described above. My positionality is informed by a feminist care ethics lens (Toombs et al., 2016) after observing the ways in which participatory approaches to research and design are interdependent exchanges between researcher and participant(s). This lens implicates the researcher as a "custodian of care" as their presence and involvement as designers means they impact the ways people enact sociality as well as the responsibilities of care that they adopt implicitly as agents

[3]https://d4bl.org

of change (Light & Akama, 2014). Engaging with maker communities has resulted in both enacting care, such as when participants were moved to tears when reflecting on their attachments and experiences with their maker groups. It has also resulted in receiving care, as these groups have welcomed me in to join them. It is as an act of care, then, that I argue for an approach to design that works *for* and *with* communities, that respects and is responsive to their needs, and recognizes the expertise of lived experience.

Chapter 3

Makers & Quilters: Investigating Gender-Imbalanced Maker Groups

The potential for learning and engagement through making is high, but inclusivity is a major concern moving forward. Hackerspaces, makerspaces, game jams, and hackathons are all examples of ILEs as described by Fowler (2016). In this context, "informal learning" is described as any activity involving "the pursuit of understanding, knowledge or skill which occurs outside the curricula of educational institutions, or the courses or workshops offered by educational or social agencies" (Fowler, 2016, p. 1). Fowler argues that these environments provide contextualized, motivating spaces that facilitate personal meaning. Discussion regarding hackerspaces in HCI and CSCW (Computer-Supported Cooperative Work) tend to view them through a lens of hacking as grassroots entrepreneurial and technological innovation (Fox et al., 2015). In the literature, "making" is described in utopian terms and touted for its ability to democratize technology production, while also being seen as enabling marginalized groups (such as women and children in the Global South) to participate in innovation (Lindtner et al., 2016, p. 1390). However, in their work on gender and hackerspaces, Fox et al. (2015) discuss how in practice, hacking practices afford opportunities to reaffirm masculine imagery and identities. Game jams, along with hackathons and makerspaces are becoming "gendered spaces", wherein "the social identities that people create for themselves [...] are cultures made by and for men" (Nafus, 2012, p. 671). These spaces have become predominantly occupied by men, and the HCI research community has turned its focus to feminist making communities as a means of addressing making on the margins.

Supporting any creative culture, including making, "entails a serious commitment to understanding its culture, including its cultural contents and their means of production"

(Bardzell et al., 2017). For this reason, I took an ethnographic and participatory approach (Muller, 2011) where possible when gathering the data. I additionally set out to practice tenets of HCI feminist methodology, emphasizing empathetic relationships with research participants; co-construction of the research activities and goals; and self-disclosure of researchers' perspectives (Shaer et al., 2017).

In their work, Fox et al. (e.g., Fox, 2015; Fox et al., 2015; Rosner & Fox, 2016) contribute understanding of the qualities of workspaces that support the creative and professional pursuits of women. However, a main feature of the feminist hackerspaces studied was their gender-exclusivity. In the interest of extending the same benefits of participation that these women experienced to *public* venues which can not operate in the same manner due to policy limitations, in this chapter I study two maker groups that display predominantly male and female participation, respectively, which advertise open participation policies: game jams, and quilting groups.

3.1 Background

In his essay *Hackers and Painters* (Graham, 2010), Y-Combinator co-founder Paul Graham positioned an alternative take on making when he asked: "Because hackers are makers rather than scientists, the right place to look for metaphors is not in the sciences, but among other kinds of makers. What else can painting teach us about hacking?" In our work, we retain this spirit of investigating the metaphor, moving on from *Hackers and Painters* to *Makers and Quilters* in order to contribute to the growing research on making in human-computer interaction (HCI). While it is widely accepted that human-computer interaction is a discipline that incorporates research from an abundance of fields, including design, psychology, and computer science, at the heart of the field is the concern for the design of technology and the creation of novel interfaces and interaction techniques. As a result, many HCI labs incorporate a mentality of "making" and frequently house the latest equipment (e.g., "fab labs") and encourage the creation of novel interactive technology, games, interfaces, *et cetera*. Thus, not surprisingly, there has been a recent surge in interest in HCI in game jams (Chatham et al., 2013; Eberhardt, 2016; Ho, 2016), makerspaces (Hudson et al., 2016; Rosner & Fox, 2016) and crafting (Fox et al., 2017; Meissner et al., 2018), for their potential for informal learning about issues concerning design, coding and material assembly.

While the focus of "making" is often on the creation of technology for the individual (e.g., games, applications, physical devices, etc.), the communities surrounding the practice are inherently collaborative. As a result, there is a great opportunity to leverage the vast

CSCW literature and knowledge to design tools to be used in this practice. However, these emerging spaces where makers gather tend to be predominantly attractive to male participants (Steinke et al., 2016) and afford opportunities to reaffirm masculine stereotypes (Fox, 2015). Thus, in designing these systems, we must consider the need to encourage female and gender-expansive participation in these events and "making" more broadly. Rosner et al. (2018) report that 40% of women come to technology innovation spaces from a background in arts and crafts, rather than engineering. We should, therefore, be inclined to investigate whether familiar community practices from maker groups considered to be in the "arts and crafts" space contribute to a more familiar, and thus more comfortable atmosphere for women who want to explore their identities and build their confidence as makers in a technological context.

More equitable participation not only functions to support growth and long-term attitudes towards involvement in making (Chu et al., 2017), but can also mitigate the risk of designing technology that excludes the perspectives and experiences of women (Williams, 2014). The "pipeline theory" describes the trajectory women take from education to a career path, and highlights the 'leaks' along the way—attrition occurs from entry- to mid- and senior- or executive-levels of careers in technology (Davis-Ali, 2017; Ferguson, 2016). Maker groups offer an early opportunity to foster an interest and intent to pursue careers in designing technology (Fowler, 2016), and because they are still emerging, we can benefit from an understanding of what interventions can support self-determination to foster longer-term engagement, and to potentially engender more inclusive design from such groups.

In this chapter, in an effort to understand how to potentially diversify such events and to discover opportunities to improve the design of technology used in these spaces, I compare the microcosms of game jams with quilting bees, which are predominantly coded female[1] (Hall-Patton, 2008). I conducted an exploratory mixed-methods study investigating the motivations game jammers and quilters had, respectively, to engage in their events. Over observations of 334 makers across 7 events, I was specifically interested in the personal values participants assigned to their respective events, how they conceptualized community, and their overall experiences around inclusion and exclusion. In addressing these questions, I provide further insights into how ILEs can better cater to more diverse audiences through creating a space where the needs for learning and shared community are equally met.

The contributions of this work are twofold. First, we provide an understanding of both male-dominated and female-dominated groups of makers—their complex relation-

[1]While this chapter largely refers to gender as a binary as per self-report of the participants, I acknowledge that the spectrum is much broader than might be apparent in our writing.

ships, their aspirations, and how they navigate the space afforded to pursue them. Specifically, we identify that, while both jammers and quilters are highly motivated, the nature of support for feelings of autonomy, competence, and relatedness vary drastically between the groups. Second, we discuss opportunities for the design of these events, the design of tools used at such events, and the design of spaces for maker groups more generally. These opportunities build on our findings and provide suggestions for how to foster feelings of self-determination for the purpose of increasing women's participation in the "making" thought to be inherent in the practice of HCI, as well as the digital and CSCW tools used both at the events and in the making community more broadly.

3.2 Study: Gender-Imbalanced Maker Groups

Past work has identified that practices around hacking and maker groups are often masculine and tend to be male-dominated, and other work has explored providing female-exclusive spaces to counteract these stereotypes (see Chapter 2). Our work builds upon this research through an ethnographic approach that examines and contrasts existing female-dominated maker groups (quilters) with male-dominated maker groups (game-makers). Our goal was to develop a deeper understanding of the behaviour, experiences, and attitudes of participants in both groups to help inform the persistent problem of attracting and retaining women in STEM maker environments. We conducted this research through the lens of investigating opportunities for design: design of the events themselves, design of digital tools used at the events (e.g., tools for rapid game development, tools for quilting), and design of spaces for making groups more generally.

3.2.1 The Jam and the Bee

At first glance and for those unfamiliar with the format(s), quilting groups and game jams may seem unrelated. There is however significant overlap in the two practices, with a noticeable difference being whether they have predominantly female or male participation. A "Quilting Bee" was described by our participants as an ongoing tradition where quilters gather to cooperate on the completion of a quilt during a constrained period of time. Participants reported that "old-fashioned" bees had a goal-oriented focus, such as a community coming together to pitch in to finish a quilt as a gift for a new bride. The Mennonite quilters in our study adopted the term "bee" to apply to any activity that would be difficult to do by oneself, but would benefit the community as a whole: sheep-shearing bee, barn-raising bee, etc. However, in the quilting community at large, more modern twists on

Figure 3.1: Quilt Guild meeting overhead view (a) and photograph (b), Home-based quilting group configuration (c) and the members (d), Sew Social room layout (e) and participating quilters (f).

the bee format include features such as design challenges that introduce a requirement to include certain thematic or technical elements in the projects, such as the use of certain geometric forms, patterns, or colour palettes. The participants list elements of challenge, friendly competition, social cooperation, and creativity. Since quilting has historically been a feminized activity, quilting bees have offered a space for women to create together and to connect. Today, quilting communities remain strong, and offer numerous ways to engage in the craft along a spectrum between highly collaborative and solitary making conditions: mystery quilts, "block of the month" challenges, workshops, courses, tutorials, online quilt-a-longs, sew socials, quilting retreats, conferences, guild meetings, outreach activities, and, of course, bees.

The concept of the quilting bee and the community behind it struck a parallel with the game jam format and the groups that organize them, with the caveat invoked by the trope "every space is different" (Toombs, 2017): the comparisons drawn in this study are situated observations that may not reflect how other maker groups are structured. Game Jams and Quilting Bees share the same ideals as they both provide many with the opportunity to learn, challenge themselves, and explore their creativity. Although they are similar in that sense, they have striking gender imbalances (jams being male-dominated and bees being female-dominated). In the game jams studied here, participants were designated a theme to incorporate in to their designs, and completed their games over 48 hours. Some participants worked in teams, others alone. In speaking to organizers of the game jams and stakeholders of the local game development community, major concerns were raised around a number of areas: attrition of female attendees (at the first jam that we observed, 70% of female attendees left by the end of the event), a consistent inability to attract more female participants, and uncertainty around why they had been unable to create a sense of community buy-in or how to create a sustainable community of novices and experts, including both hobbyists and professionals going forward. Given the benefits associated with quilting (Burt & Atkinson, 2012) and those associated with making more generally (e.g., Meissner et al., 2017; Taylor et al., 2016), we felt that a deeper understanding of both spaces could lead to opportunities for improving the design of the events themselves, the tools used for making, and the spaces used by maker groups more generally.

3.2.2 Methods

To investigate our research agenda, we took a qualitative, ethnographic approach, in total observing 334 makers across 7 different events; the breakdown of these events can be seen in Table 3.1. In September of 2017, we began observation and interviews at a local Game Jam event. These Game Jams are hosted three times per year on the local university campus,

Table 3.1: Summary of Events and Participants in the Study

Group	*Event Attended*	*Attendees Observed*	*Gender*		*Group Labels*
			F	*M*	
Quilting	Home Quilting Group	7	7	0	QH
	Quilt Guild Meeting	144	144	0	QG
	Guild Sew Social	16	16	0	QS
	Mennonite Quilting Bee	12	12	0	QM
Total	*4 events*	*179*	*179*	*0*	
Games	Local Game Jam	91	25	66	GL
	Game Development Club Meeting	16	3	13	GC
	Global Game Jam	48	1	47	GG
Total	*3 events*	*155*	*29*	*126*	

and are open to high school and post-secondary students, professionals, hobbyists, and anyone from the public with an interest in participating. We observed members' practices in their own environment over the 48-hour duration of the jam, and documented them through drawings, field notes, photographs, and video recording (Figure 3.2, Figure 3.3). Unless specified otherwise, it is this combination of documentation methods implied when referring to "observation" for the duration of this paper. We followed up on this fieldwork with interviews in the week following the jam with three participants. Following from this experience, we refined our approach. In November of 2017, we took the same steps of an initial investigation with a seven-member home-based quilting group (Figure 3.1d). These participants represented one of many ways that quilters self-organize, and through a group interview they provided an introduction to the domain of quilting as they see and experience it, as well as the complexity of the relationships formed around their shared passion for the activity.

3.2.2.1 Field Sites

Following the first game jam and quilting group, we visited other sites in order to ensure exposure to different approaches of quilting. Between January and May of 2018 we also observed a 2.5-hour Quilt Guild meeting (Figure 3.1b), a 9-hour Sew Social event hosted by the Guild (Figure 3.1f), and an all-day Quilting Bee among Mennonite participants. We interviewed 12 quilters across the two Guild events including the guild president. We modified our procedure taking into consideration the values of the Mennonite community (e.g., privacy and independence from the use of non labour-related technologies) and took

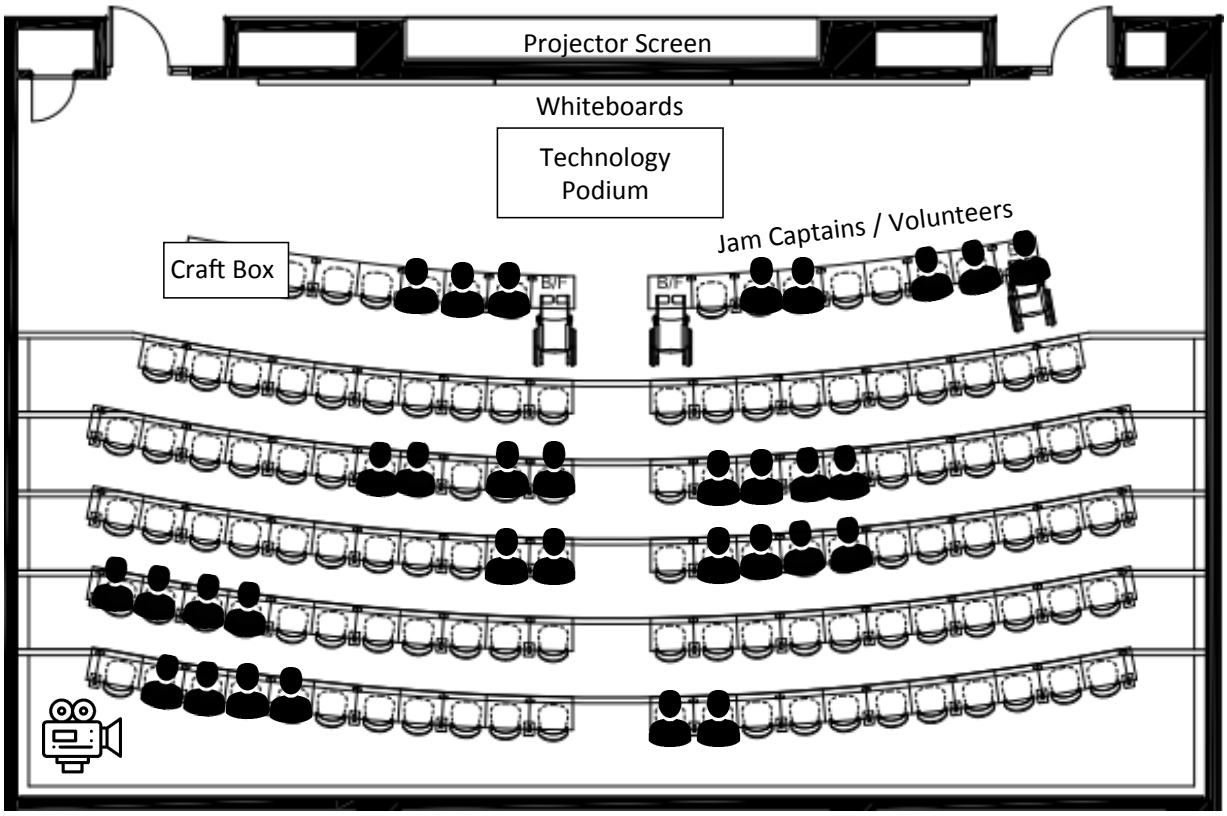


Figure 3.2: Overhead impression of Game Jam location

a more informal approach to interviewing one organizer of the Bee and the Bee participants while they worked, focusing on note-taking and observation, with limited use of recording technology. We observed and recorded a Game Development Club meeting at the local university which took place directly before the Global Game Jam in January 2018, where participants met to find potential teammates, brainstorm ideas, and ask questions of more experienced *jammers* (the name given to game jam participants). Finally, we conducted our research at the 2018 Global Game Jam host site at a local university, where we continued our pattern of observations and conducted interviews with 10 attendees. Participants at all events had the opportunity to complete an Intrinsic Motivation Inventory questionnaire to complement the qualitative data collected. Table 3.1 shows the events visited and number of makers observed. In contrast to the definition of "makerspace" defined by Sleigh et al. (2015) which rests on the availability of a workshop with tools or equipment provided by some source, we studied these groups of makers making use of what they had available:

Figure 3.3: Participants in action during a Game Jam

schools, community centres, and a small museum. Despite a lack of ownership, these constituted "both a community space and a space for communities" (Wang et al., 2015), a concept which will emerge concomitantly through our analysis.

3.2.2.2 Recruitment & Procedure

We recruited participants by contacting quilting guilds in the region through their publicly available websites. For the first game jam event, I was an event captain, which contributed insights to this work through personal experience and deeper involvement in the community. I therefore recused myself from research commitments to prevent a conflict of interest at this particular event, and other lab members conducted the research. For the second game jam, I contacted the organizers of the event for their consent to study the jam. In all cases, gatekeepers/organizers would decide whether we would be welcomed into the space.

Gatekeepers would make participants aware of the researchers' presence and agenda before arriving and upon arrival, and they were notified of how they could be exempt from photo or video recording, as well as how they could opt-in to interviews and surveys. Once on-site, we were able to introduce ourselves and explain our purposes, and be clear about the voluntary nature of the study. We embedded ourselves in the environment, having casual and non-intrusive discussions with participants throughout their activities. At a time that they felt comfortable, the participants retrieved an Intrinsic Motivation Inventory (IMI) survey, and after completing it, participated in a 15-30 minute semi-structured interview in a private space away from the main group.

This research received clearance from the institutional ethics board, and participants that completed the interview and survey were compensated $10 for their time.

3.2.2.3 Participants

We conducted one group (7 people) and 25 individual interviews, for a total of 32 participants. Of these, 10 self-identified as male (all jammers) and 22 self-identified as female (3 jammers, 19 quilters). The participants ranged in age from 13 to 89 years old. Our sample, while not representative of the general population, is consistent with published representations of game jam participants (Steinke et al., 2016) and quilters (Loeffelholz, 2014). We made observations of all attendees at the quilting and game development events, summarized in Table 3.1.

3.2.2.4 Interview Structure

Interviews followed a semi-structured format. Following the pilot study, we found improved uptake and more vivid reflections on participants' experiences were provided when interviews were conducted at their convenience during the quilting or gaming event. Participants were asked about a range of topics: demographics (e.g., their educational and career background or trajectory, their history with the craft including when they started and why they joined this particular group or event, the typical context in which they engage in making); group relations (e.g., experiences and feelings toward collaboration, group dynamics, community or social structures such as tacit knowledge of social codes or expressions of social capital); reflections (e.g., perceptions of barriers, advice for newcomers); techniques (e.g., use of tools, problem solving); and more. We thank Shaer et al. (2017) for providing their instrument used in *Understanding Gaming Perceptions and Experiences in a Women's College Community*, which helped to inform the development of our interview questions.

3.2.2.5 Survey Instrument

The Intrinsic Motivation Inventory (IMI) (Ryan, 1982) questionnaire was used in both the quilting and game development groups to assess attendees' subjective experiences and their motivations for participating in the activity. While completing the survey, participants use a seven-point Likert scale ranging from 1 (meaning "Not at all true") to 7 ("Very true") when evaluating whether each statement feels true to them.

The IMI instrument assesses participants on subscales of interest/enjoyment (IE), perceived competence (PCo), effort/importance (EI), value/usefulness (VU), felt pressure and tension (FPT), relatedness (R), and perceived choice (PCh) while performing an activity (Deci & Ryan, 2018). The interest/enjoyment subscale (IE) is most related to intrinsic motivation in itself (Deci & Ryan, 2018); however, the other subscales are included as positive predictors for motivation (PCo, PCh), negative predictors (FPT), and related concepts (EI), to understand whether participants are internalizing and becoming self-regulating with activities they find valuable for themselves (VU), and to understand situations involving interpersonal interactions and friendship formation (R).

Participants completed the survey ahead of their interviews, which prompted reflection on their personal experiences and motivations. We contextualize the use of this measure throughout our presentation of both our analysis and results.

3.2.2.6 Goals

The goals of our analysis, after identifying these male- and female-dominated maker communities, were to generate new insights through contrast and comparison of the group members' relationships with the activity, the space, and each other. With the game jam and the quilting bee serving as conceptual groundwork for both groups to come together, we aimed to capture behaviours, experiences, and attitudes of both sets of participants that could shed light from a different angle on the persistent problems faced in the STEM maker environment: in particular, the difficulty of attracting and retaining female participants, and whether this relates to any wider issues in organizational philosophy.

3.2.3 Data Analysis

In conducting our analysis, we analyzed the IMI questionnaire's reliability and responses using the IBM SPSS statistical analysis tool. For this data, we had a sample size of ten jammers and sixteen quilters. To analyze our interview data, we followed the Braun and

Clarke (2006) approach to Thematic Analysis when analyzing the semi-structured interviews. This method involved engaging with our data in six prescribed stages, briefly: (1) familiarization through immersion, (2) generation of initial codes, (3) developing candidate themes, (4) reviewing the patterns created by further refined themes, (5) defining and naming themes while beginning to develop sub-themes, and finally, (6) adding the context and evidence for the themes to cohere in a narrative illustration of the issues investigated.

3.3 Results

In this section we present the results of our statistical questionnaire and thematic interview analyses. Limited availability of existing research on intrinsic motivation in maker groups (Han et al., 2017) and game jams (Ho, 2016) show a focus on the motivations of the "typical" (male) participant in those spaces. We were not able to find any similar work describing needs-satisfaction in predominantly female maker groups, and thus we contribute an improved understanding of what both jammers and quilters seek to gain from their engagement. A meta-analysis of previous work in self-determination theory (SDT) in exercise behaviour (Guérin et al., 2012) reports consistency across (binary) gender in how men and women value the SDT constructs of autonomy, competence, and relatedness. However, through the qualitative aspect of our investigation into male- and female-dominated maker groups, our findings suggest differences both in the *ways* participants' diverse needs are being *expressed*, and how they are or are not being *met* in their respective contexts. As will be discussed, when these factors remain unchecked, they lead to gendered inequalities in who benefits from engagement in making and who is compelled to stay engaged.

3.3.1 Statistical Analyses

Tests for reliability using Cronbach's α confirm that the Intrinsic Motivation Inventory (IMI) questionnaire was reliable for game jammers across all subscales, and for quilters across all subscales except for Pressure/Tension and Perceived Choice. Levene's test confirmed homogeneity of variance for both groups across all subscales. Finally, an independent samples t-test compared the means on IMI subscales between the quilting and jamming groups. The Quilt and Game Jam groups were found to differ in their responses on the subscales for Perceived Competence ($t_{PC} = 2.2, p < .05$) and Pressure/Tension ($t_{PT} = -2.6, p < .05$). In these cases, the Jammers rated their Perceived Competence on average to be lower than the Quilters ($M_J = 5.0, M_Q = 5.7$), and rated higher Pressure/Tension ($M_J = 2.6, M_Q = 1.7$).

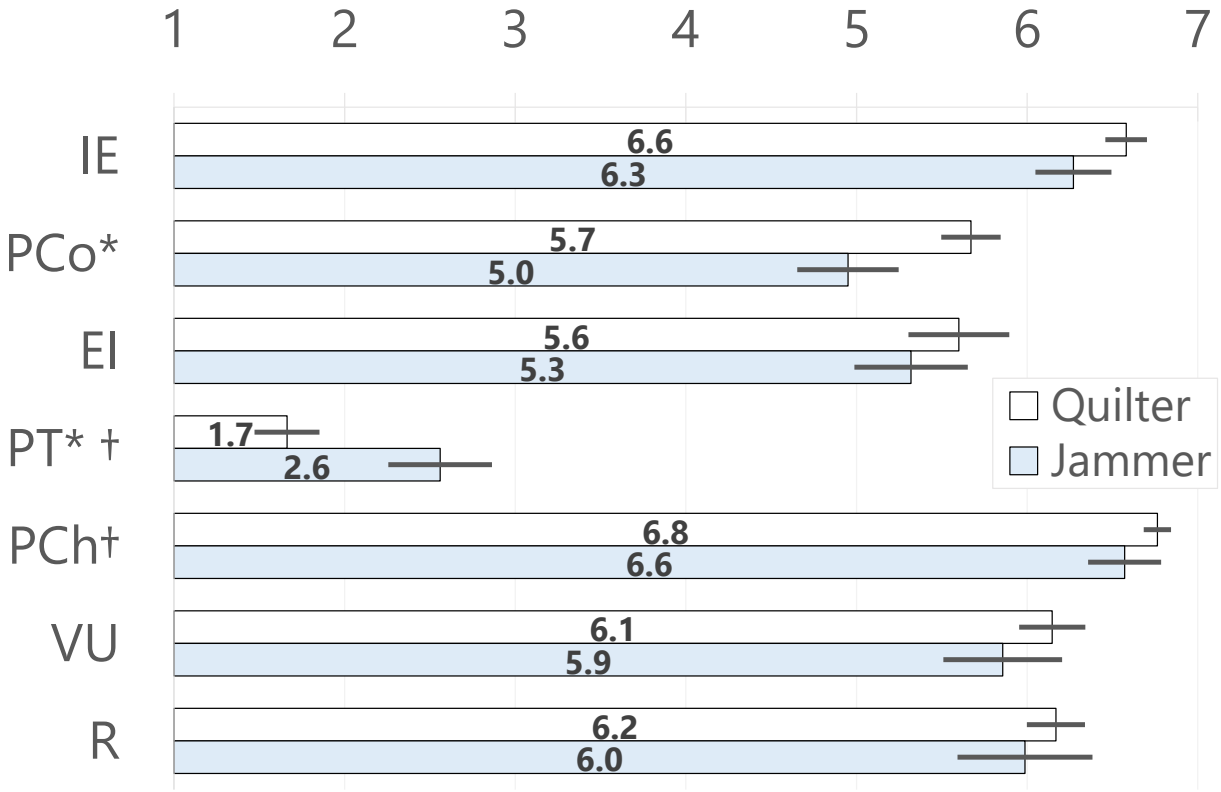


Figure 3.4: Mean Responses per Jam and Quilt Groups across Intrinsic Motivation Inventory Subscales. $*$ = significant at $p < .05$, † = subscale unreliable for quilters ($\alpha < .70$), error bars represent standard error (SE).

While we computed adequate reliability, our analysis revealed noise around specific questions and we do not consider the IMI results to be a major contributor to this study. Rather, it is supplementary information in the company of our much richer qualitative data. We share some insights and challenges faced while using the IMI in 3.3.1.1 and 3.4.2.

3.3.1.1 Context and Value of Excluded IMI Responses

Since the home-based quilting group was considered part of the pilot study, they completed the IMI surveys after the research team had left. When receiving the IMI surveys back from the group, we were made aware that they had completed and discussed it as a group, as they said they needed to explain the questions aloud to one partially blind participant

with signs of dementia who found the wording "tricky" (and who was ultimately unable to complete the survey). We therefore excluded their responses from the overall analysis as all future participants were administered the IMI in a consistent manner, completing it individually. However, qualitatively, the group's responses tell a story reflective of what we came to realize throughout our time with them.

This group, shown in Figure 3.1d, was tightly bonded and, unlike the other groups visited, stated that they had decided membership was *closed* because they were too intimately connected, and it would be too strange to bring in someone new. The first members in the group had been there for 40 years, the newest member having joined 18 years ago. More than once, the women were brought to tears over how much their bond meant to them. They somewhat jokingly referred to their group as "Therapy Wednesdays", and described supporting each other through welcoming new babies, losing children, losing husbands, surviving cancer, and more. They "share a lot more than just quilting", and also noted that they firmly do not gossip outside of what is shared in the group, creating a safe space for everyone to know they will be supported: members said that they prioritize the group over doctor's appointments and all other commitments. Following the interview, they sent a note thanking us for the opportunity to pause and look back on their history together, since each week that they met they were usually occupied with catching up.

The IMI results show that with this group of older participants (aged $72-89$, $M = 79$), questions that required a reversal during analysis that had corresponding positively-worded questions elsewhere in the questionnaire created confusion. The IMI produced reliable results for Perceived Competence and Value/Usefulness for this group. Most notably, but perhaps not surprisingly, we were not able to compute any data regarding the Relatedness subscale for the IMI, because every participant gave the maximum score on each of these questions related to trust, closeness, and wishes to stay together in the future.

This environment, complete with tea and bundt cake, may seem a planet away from the harried atmosphere of a game jam, but these women were collaborating and making design choices to achieve one final product, describing steps and challenges along the way that we also heard from game jammers. However, their values, priorities, and relationship to the space made a world of difference on their way to achieving that shared goal. In the following sections, we will delve into these items in more detail.

3.3.2 Thematic Analysis

We analyzed our interview data using the Braun and Clarke (2006) method. We collected Intrinsic Motivation Inventory responses as a means of determining whether the maker

groups had comparable feelings while engaging in their activities, and with the intention to investigate whether survey data would corroborate what we heard from participants. We did not impose any groupings or labels while developing the themes. However, once themes had developed from the analysis and we moved into the final stage of contextualizing these results, a narrative emerged surrounding the personal and collective benefits associated with participating in the game jams and quilting groups. This narrative repeatedly returned to commentary on participants' satisfaction with respect to their autonomy, competence, and relatedness. We therefore use these components of self-determination theory (Przybylski et al., 2010) as a lens and as groupings for the presentation of the thematic analysis.

3.3.3 Relatedness

3.3.3.1 Contextualizing Relationships

Fox et al. (2015) refer to a use of language among members of a feminist hackerspace describing a particularly prominent aspect of membership: being "companionable". In their research, the discourse of companionship came to both define and support feelings of *confidence* for members of that space. When quilters were asked what qualities or characteristics describe their group, their answers revolved around the same concept.

> We're friendly, we learn from each other, it's very social, you get good ideas, and it just creates a great environment for you to enjoy quilting. (QS3)

Despite the larger size of the quilting guild (200 members) compared to the at-home quilting group (7), participants still described a tight-knit connection to the group that extended beyond mere acquaintance.

> I would tell [a prospective member] it's great companionship and it's also a support group because whatever goes on in your life someone will be there and try to make it better. It's great support. (QS10)

The word "family" was used more than once to describe both the immediate group, and a feeling of belonging to a larger network: "There's a whole quilting family that's across the country" (QS7).

In contrast, one game jammer described the tentative nature of others in the room:

> Don't be afraid to be social, everyone's sitting in the room wanting someone to talk to and start a conversation. (GG1)

Other jammers described their uncertainty and hesitation around how to interact with other participants, navigating a tension between delivering feedback to achieve effective collaboration, but not wanting to risk damaging the relationship going forward:

> I wouldn't go full-on criticism because I don't really know [my teammates]. [My friend], I feel a little less bad critiquing just because, I don't know, we're a bit closer than the other guys. (GG1)

This does not mean however that the social environment of quilting was utopian compared to jamming. In fact, they also reported constraints imposed by how they felt they needed to act: holding in their opinions about design choices (one participant made everything purple, another said it reminded her of "the inside of a coffin"), and saying that they steer clear of political topics. They, too, share an awkward relationship with feedback or critique:

> Positive feedback is what most of us strive for. So we might... I can't say that we critique each other's work but we give each other positive feedback and what works and maybe possibly subtly what's not working if that's what the person wants but mostly we just encourage each other...I don't think anybody gives negative feedback. (QS3)

While the quilters were consistent to report unspoken social codes around the delivery of critique or feedback, the lack of a mutual understanding in the game development space inhibited both the ability to grow closer to one's teammates as well as satisfaction with the final product.

3.3.3.2 Balancing Social and Creative Needs

The ability to feel closer to one's companions in a maker group is moderated by how participants perceive of their own reasons for being there, and whether the events facilitate reaching their goals. Participants expressed what they felt were the implied goals of participating in the jam or bee: the quilting groups emphasized participation and effort to contribute over one's actual skill level, whereas the game jam was seen to have a focus on producing a final product, even though many members' personal goals ran counter to that—in both groups, members were highly interested in learning and developing their skills. As such, the jam environment did not provide the appropriate context to support relatedness, even though both game jammers and quilters valued this similarly in their surveys.

The following quote illustrates just how important the game jam is as a creative outlet to this individual:

> It's really the only kind of art or creative thing I'm good at, so if I want to express myself artistically then game making is really the only thing that feels accessible to me. (GG7)

Later, in subsubsection 3.3.4.1 and subsubsection 3.3.4.3 we will hear more from this same participant about how they were not fully able to reach their goals due to the constraints that they placed on themselves after deciding that they did not feel adequately confident to join a team, instead sacrificing the opportunity for social relatedness by choosing to work alone.

The feminist hackerspaces studied by Fox et al. (2015) had a closed membership process and thorough vetting for new members, in stark contrast to the openness of the quilting guild, which welcomed everyone with an interest in quilting within the limits of fire codes for their building (200 members). Both place high value on companionship over production or skill. When new members arrived, they accepted a Code of Conduct or set of bylaws that assured them of a shared set of community values. Game jammers recounted not being sure if they would be welcomed or accepted on account of their individual differences or their skill level, and the mere act of showing up was taking a leap of faith. One participant even promoted the idea of keeping communication within their own team in fear of appearing as though they would be "vulturing" ideas off of the other participants (GG2). Additionally, an obstacle to communication between participants concerning the use of space emerged. When asked how the Global Game Jam was different or similar to other events, one participant expressed a lack of mobility (see Figure 3.2):

> There's more space in the other game jams so we have more room to walk around... it's easier if you want to stand up and go, 'Hey, how's it going?' So it's not possible in this room so this is a big problem. (GG9)

A public maker group such as a game jam can improve upon the feelings of relatedness that form the foundations for community, by considering how they frame participation and success, and whether these framings are concomitant with the community's longer-term goal or vision.

3.3.4 Competence

3.3.4.1 Opportunities to Learn

The game jams and game development club that we observed marketed the jam as a time to "learn, make, and play." A majority of the jammers interviewed stated that they wanted

to make use of the time to learn or improve their skills and techniques (for example, with Unity, Blender, or Node.JS). During game jams, though, existing skills need to be applied efficiently, so there is limited time for personal learning to occur. What can be observed instead is a gendered division of labour (Richterich, 2017).

Even in the case of a female participant working alone, and therefore freed from the pressures of contributing to a team, she felt that ending the jam without a finished game would be a failure, and therefore did not pursue the new skills she was interested in learning:

> I've only ever made 2D games before, so I was thinking it would be interesting to make a 3D game in Unity and Blender. ... I got nervous and checked out of forming a team. So yeah, I just sort of made another 2D game that's in the style of what I usually make. I wouldn't say I picked up any new skills or anything. (GG7)

This jammer expressed an underlying goal of learning a new skill that was superseded by the fear of failure. This fear was still present even though the atmospheric nature of the jam was to learn over having a final product. This goal displacement may have been due to the perception of an absence of support that we found was afforded to the quilters, where the nature and variety of their events fostered a variety of opportunities to learn and try new things.

The quilting guild not only offered the groundwork for companionship similar to that found in the feminist hackerspaces, but also offered different formats for learning so that participants could have room for experimentation and failure: experiences which can dramatically affect women's feelings of self-efficacy when working with software (Beckwith & Burnett, 2004; Burnett et al., 2011). The guild provided venues including courses, workshops, retreats, sew socials, trips to quilt shows, a dedicated library, and invited speakers—in addition to the collaborative activities they engaged in that *do* have similar pressures to a jam, which prompted our initial desire to understand the contrasts between the maker groups.

At this stage in our analysis, the importance of an overarching organization involved in the administration of the maker groups began to emerge. The game jam format thwarts participants' feelings of competence, and does not offer alternative ways to engage with game development, which stands in the way of the organizers' desire to grow and sustain the local game development community by nurturing the seeds of potential in jammers. One possible explanation of the difference in organization and the ability to cater to the group's longer-term development is the relative maturity of the contexts studied. The game jam group is more experimental and fluid in how it self-organizes, and its high proportion of students leads to a rotation of membership, although it does have a mixture

of life stages involved. The jam and Game Development Club are both sponsored by a research institute that has longer-term engagement, with graduate students, staff, faculty, and industry partners. The quilters are not working on any sort of terms, thus enjoying relative stability. We therefore recommend more diversity in the stakeholders to avoid the "student government problem," that is, a revolving door of membership causing instability and an inability to work consistently towards larger goals of inclusion.

3.3.4.2 Competitive Orientation of Makers

Despite an emphasis from organizers and volunteers to have fun and set personal milestones over aiming to have "the best" game, our data confirms that jammers still viewed the event as competitive, even if they themselves said they attended for other reasons, such as networking or learning:

> [I would tell a new jammer] don't aim for some award like first place. ... It's not really about getting the prize or something. (GG4)

Notably, prizes based on performance were never explicitly advertised as part of the event. Rather, during the kick-off, the tradition of giving out literal jars of jam as honourable mentions or recognitions on a spectrum of seriousness was announced to the whole group. This game jam was the above jammer's first time participating and it is interesting how he still came to the assumption it was a competitive environment despite all messaging to the contrary. On the other hand, veterans of the jam event were more aware that organizers would provide these randomly drawn prizes and 'joke' prizes that were determined during the event based on participants' efforts. For example, during the 2018 Global Game Jam with the theme *transmission*, the organizers bestowed a prize called "The Longest Transmission" to recognize a participant (GG9) who made a game through communicating via Skype with his teammates in Sweden and Germany. This had nothing to do with the game, but rather the team's tenacity, and to highlight this unusual collaboration.

While quilters were focused on their own projects, with one participant even asking about an IMI question since she did not compare herself to others, they still did report instances of feeling inadequate when seeing others' accomplishments (QG1). However, this participant acknowledged that since they had access to so many opportunities to "find out what I'm good at" through the guild, they did not dwell on it or consider themselves inferior.

3.3.4.3 Performance Anxiety

Male and female jammers alike were frank about the role confidence in one's own abilities played in to their approach to the activity. On the one hand, we heard from a male jammer that "you have to be confident in what [you're] good at and be, idea-wise and design-wise, just flexible but you should generally know what you're good at" (GG1). On the other hand, a female jammer reported that "... the main thing is feeling like you don't have enough experience to participate, even though there [are] a lot of people who [don't] have experience with game development" (GG7).

All female jammers interviewed expressed that they only felt comfortable attending with someone they already knew:

> I always feel like since I don't code that well they might be like 'well you're a dead weight' or something. But I don't feel that way when I'm with [my partner]. (GL1)

One female jammer with advanced game development skills said:

> I sort of feel out of place a lot of the time ... [and] I worry about having that sort of feeling when I join a team with a bunch of people that I don't know. (GG7)

This anxiety contributed to thwarting the jammers' desires for improving their competence and feeling connected to the game development community. In contrast, a male jammer with no game development experience described a much different view of his prospects at his first-ever game jam:

> We're all very good ... we've all played enough and know enough and are going through engineering programs that are all about usability and user design, so we are all confident enough in that ability. (GG1)

Overall, our results showed that the perceived competence of jammers was significantly lower than that of the quilters when surveyed. This returns to the variety of opportunities afforded in both the quilting and feminist hackerspaces to explore one's own identity as a maker, which has positive effects on confidence (Fox et al., 2015).

3.3.5 Autonomy

3.3.5.1 Gender Stereotypes and Representation

One of our female participants (GL1) reported being mistaken for a game jam volunteer just because she presented as a woman, which she found discouraging. She problematized

the fact that while many women were public faces of the game jam, the fact that they were organizing rather than participating reinforced technical skill biases.

A frequent joke among quilters was how it was their "expensive hobby" (QS7, QS4). More than one quilter referred to their equipment as "toys": at one point while explaining that sewing machines could cost anywhere into the thousands of dollars, a participant said "*these* are *girl* toys" (QH2), intentionally foregrounding and reversing the trope of housewives being expected to accept and move on when their husbands come home with expensive but unnecessary "toys" with which to perform masculinity. It emphasized that they felt just as entitled to spending on themselves, but this use of language, categorizing complex machinery—that is not easy to learn nor to operate—as a toy and therefore a frivolity, simultaneously downplays the stature of the art, and the significance of their work. In most cases, the quilters we observed not only quilted as a hobby but for the purpose of commission:

> All my quilts I post when I finish them. They all go on Facebook. That's how I've gotten so many more customers... people coming in and wanting me to commission them. (QS7)

In game jam groups, participants side-stepped questions of gender, one participant saying that he thought women would "definitely not" feel excluded, because "it's a pretty game-focused environment [so] there's not much polarizing about it" (GG2). Assumptions of gender-neutrality often obscure a bias towards default male preference (Bradley et al., 2015; Williams, 2014), and from what we heard from the female jam participants above, they had a different experience where gendered expectations hindered their feelings of autonomy.

While feminist hackerspaces are positioned as a material response to masculine techno-culture (Fox et al., 2015), quilting groups express a material response to an oppressive social culture. Within the quilting group, participants surface and play with feminine stereotypes as a form of asserting control over their identities as makers and as individuals bound by commitments to their communities, jobs, and families. However, in the jamming group, burying such issues makes it much more difficult for them to be addressed.

3.3.5.2 Creating space

The spaces in which we observed making activities served to help or hinder participants' ability to achieve their goals. There was an aspect of fluidity and comfort with the quilting spaces (Figure 3.1) that contrasted with the rigidity of the jamming space (Figure 3.2). With the exception of the home-based quilting group, none of the groups observed had

ownership over the space they occupied. However, the guild quilters intimately knew their stomping grounds in the local community centre: at the Sew Social, they warned which outlets were connected to which fuses, so that we knew where to set up our equipment so as to not interrupt power to their irons and sewing machines.

The sense of comfort with the space shown by the quilters allowed them to feel as though they belonged, whereas a lack of ambient belonging cues in the jam environment created uncertainty about who could be there and what they could do. As well as in feminist hackerspaces (Fox et al., 2015), environmental cues in the physical space affected feelings of autonomy. However, we saw as the guild moved between spaces that the higher concept of the community bound them together regardless of the venue that they occupied.

3.4 Discussion

Through our analysis, we found that pleasures and pains experienced by makers in all the spaces studied were related at a higher level to the self-determination theory constructs of autonomy, competence, and relatedness. Participants in gaming and quilting environments displayed a variety of personal needs and desires that we envision on a spectrum: a common desire for relatedness, which can be achieved by working alone among a group, or by directly collaborating with others; wanting to learn and grow, from one's peers or by individual experimentation; and a genuine interest in the creative activity, whether they took pleasure from the process of making it or from the satisfaction of seeing the end result. In Toombs et al. (2014) we were introduced to a rich set of values determined by a study of an all-male group of makers. Among these were the ideas of building confidence and adhocism. Given what is known regarding gendered differences in self-efficacy (Beckwith & Burnett, 2004; Beckwith et al., 2005) and tinkering behaviour (Beckwith, Burnett, Grigoreanu, et al., 2006), we felt it was important to corroborate those done with different demographics. There is no one-size-fits-all solution to designing conditions for successful diversification of a maker group, but we offer some initial thoughts based on the reported themes, separated into three higher-level shifts in thinking that could help maker groups move towards fulfilling a broader set of needs. Following this, we discuss opportunities for designers of maker tools and spaces (3.4.1).

3.4.0.1 Redefining Belonging

While quilters felt that true membership in the group came with continued participation as opposed to simply paying the membership fee, game jammers felt their involvement began

and ended with the jam event. We provide evidence for the diversity in how relatedness is satisfied in different ways for different people, from working alone in the presence of others to directly collaborating with them. For organizers trying to create a lasting sense of community, we suggest evaluating how current events are both structured *and* perceived by participants, and whether they afford opportunities for participants with different needs to feel a sense of belonging to the group.

3.4.0.2 Reframing Failure

The game jams provide one way to fail: openly (unless people decided to leave to avoid this, leading to the very attrition we seek to reduce). This raises gendered issues in willingness to participate and to innovate. We argue that a confident community stems from feeling safe with various opportunities in venues to explore and to fail, and this is supported by investigations of groups like the Failure Club (Rosner & Fox, 2016) which has been designed for women only. Our quilters laughed at and celebrated their unfinished projects, calling them "UFOs" (UnFinished Objects). As was discussed in 3.3.4.1, a maker's personal goals (e.g., learning a new tool) may be thwarted by what they perceive to be the objective of participating in the group (e.g., finishing a game in 48 hours). The game jams that we observed deliberately offered recognition via jam jars for achievements like taking risks, but we found that the predominant culture still conveyed an impression to participants that there was a competition to be won. As maker groups are important to learning and developing one's confidence as a maker, the reframing of failure is central to promoting more willingness to remain involved, even if things are not going as planned.

3.4.0.3 Renegotiating Space

As the gaming environment can display hostility to women (Shaer et al., 2017), it can be tempting to redefine the bounds of the game jam. However, existing members are attached to them for a reason, and the existing communities must be respected, not displaced to accommodate another group (Bardzell et al., 2017). Maker groups provide sites for members to negotiate their identities (Chu et al., 2017; Fox et al., 2015; Toombs et al., 2014), and our evidence shows that a strong sense of community can help makers overcome limitations of the physical space as well. As was shown in our analyses, a desire to create underlined a high level of motivation among the participants. The space, over which they have less control, is the environment created collectively, based on the shared drive and attitudes of the participants.

3.4.1 Opportunities for Design

The presentation of our data has highlighted the rich experiences of individuals during the process of making throughout this study. To move forward, we discuss a number of design opportunities that could promote more satisfying experiences for participants in various maker groups by addressing the three facets of self-determination through design: specifically, how makers interface with their tools, with each other, and with the space.

3.4.1.1 Relatedness

There is a large opportunity to leverage the wealth of knowledge in the CSCW community regarding the use and adoption of collaborative tools, in order to support relatedness. In 3.3.4.1 we discussed opportunities for learning: in the quilting environment, learning from peers was a regularly expected experience, whereas in the game jam environment there were concerns about interrupting, as well as not knowing who to ask about what, and a hindrance caused by the physical space as well as the time constraint (3.3.5.2). To overcome this, game jammers took to the chat tool Discord to communicate with teammates and to put questions out into the void in the hopes that someone could help them. However, this creates an inequitable situation where more experienced jammers are unable to achieve *their* goals if they spend too much time teaching: a problem well-documented in the CSCW literature (Grudin, 1988). There is an opportunity to research the nature of the communication *between* participants to understand where breakdowns occur, what reoccurring problems arise, and how tools could be designed better to facilitate activities of this nature.

Quilters reported a knowledge of implicit social codes (3.3.3.1), and previous work reports explicit social codes contributing to a stronger sense of shared community (Fox et al., 2015). We therefore raise a need for wider adoption of Codes of Conduct, as they not only assist with overcoming the social tensions (3.3.3.1) reported over how, when, and whether to provide feedback or criticism, but can foster a baseline sense of community before makers even arrive at the group, through knowledge of a shared understanding of acceptable behaviour. While Codes of Conduct have increasingly been adopted in the HCI world, for example at its flagship conferences, it is not well understood at this stage what would constitute a healthy and productive code in the context of maker groups.

3.4.1.2 Autonomy

While performance anxiety was discussed in the context of feelings of competence (3.3.4.3), this was also a major barrier to women's autonomy as makers, as they reported a number of concerns about working with people with whom they have no prior relationship. For example:

> Part of the reason why I didn't join a team this time, there's a few reasons, but one of them is that I don't feel like I'd be a great teammate. Like I said, I'm very picky about how the final product turns out, so when I work on group projects it usually leads to me not liking how it's going, but I'm too anxious to say anything, or I kind of, like, start nitpicking about things and annoy everybody. (GG7)

The perceived emphasis on performance in the game jam lends to this unease, whereas quilters were more likely to show up to an event alone, because they knew they shared a common bond with everyone over the love of quilting. Besides de-emphasizing the performance angle, there is an opportunity to circumvent the temporal constraint of team-building in maker groups through design of matchmaking tools to help participants find others with complementary attributes in advance. Such advances have already begun in this community through explorations of algorithmic team formation (Jahanbakhsh et al., 2017), the effect of team-building activities and composition on outcomes (Hastings et al., 2018), and how methods such as "team dating" can help determine if participants would like to work together for a longer period (Lykourentzou et al., 2017). Further exploration in this area would additionally help to level the playing field between those who have pre-existing relationships with other makers, and those who are making the brave step to join on their own. The design of such a tool could draw on further empirical data gathered through this study about what characteristics or attributes makers deem as important to success—keeping in mind that success, throughout this work, has been shown to be a relative term.

Although we highlight the importance of collaborative and communication tools above (3.4.1.1), we recognize that the existing tensions between the demands of novices and the availability of experts can be exacerbated in such an environment. Novices may be acutely aware of this, and turn to lurking as a result of not feeling adequate enough to contribute, or not wanting to 'bother' others on the platform. Contrastingly, some makers may be loath to speak up in a shared collaborative tool, for fear of the lurkers laughing at them, inducing comment anxiety. Previous work in the CSCW space has elucidated a number of insights about the lurker (Goriunova, 2017; Muller et al., 2010), which can be leveraged in the design of a tool that acknowledges these potential barriers and recognizes the potential contributions of such participants to a vibrant group environment.

3.4.1.3 Competence

A repeated message from game jammers was that there was a perceived hierarchy of tools to be used in development, which lent to feelings of legitimacy in the final product. This sense of legitimacy feeds into feelings of competence. For example, when a jammer was asked what skills or characteristics would lead someone to success in a game jam group, they responded:

> For this one it's definitely more technical skills, people who are good at programming, Javascript, someone who's good at programming for the blockchain is definitely useful. (GG5)

Other jammers repeatedly nodded to Unity as the tool that would unlock the ability to jam (despite a number of tools being used), with one participant saying: "If you're great at Unity, you can be a part of any game jam since you already have the main tool" (GG2). Meanwhile, in 3.3.4.3, a female jammer expressed her fear of being a "dead weight" if her tool competence was not meeting expectations, which lead her to work only with someone she knew.

Among the quilters, there was more acceptance that a person's method was their own preference, and those differences were celebrated. To enable those new to making to achieve their goals, we do not recommend the creation of custom tools that would stand in opposition to those perceived as 'legitimate' (Unity, Unreal Engine), as there is a saturated market of such software: this would further contribute to feelings of being "less than." Instead, we encourage explorations of how the existing tools can be modified to be more useable or accessible, to grow confidence while using the tool through methods such as plug-ins, tooltip overlays, or step-by-step revealing of more complex features to reduce feelings of being overwhelmed.

Representation is important to helping makers feel as though they, too, can handle the activity. However, in designing a maker group, one should make conscious decisions about representation. In 3.3.5.1 we heard from a woman who was mistaken for a volunteer at the game jam, because there was a high proportion of female organizers, but the same was not true among the jammers themselves. There should be adequate representation at all levels to reduce the risk that participants perceive tokenization over genuine diversity in the group.

3.4.2 Limitations

The at-home quilting group's confusion with the IMI survey reveals a limitation of using such questionnaires, which may bias younger participants in their construction (Spiel,

2017). The intersection of age and gender leads to a broader limitation of the intersectionality of this study.

I chose to study the game jam and quilting groups due to the similarities in how they operated and their very skewed gender membership despite the difference in medium. However, based on the diversity of our sample, we would be remiss to assume the generalizability of our recommendations to equally benefit *all* marginalized groups, should maker groups implement our recommendations. At the quilting groups, various forms of disability had been accommodated to serve aging participants. Other forms of structural or institutional exclusion were left unsaid: most participants were educated and affluent, and no gender nonconforming or people of colour were present. The factors that make white women feel comfortable and welcome in a space are not universal and should not be taken as such. Instead, this research should add to the growing body of work addressing and understanding the diverse experiences of marginalized peoples and how we might create more open and welcoming environments for all.

The maturity of the game jam and quilting groups may lend to the differences in how well-developed they are (that is, how they might have adapted to accommodate others, how they organize events); the groups investigated had not been in existence for the same amount of time. As discussed in 3.3.4.1, overarching organization emerged as an important factor to ensure longer-term health of the group. Given the different life stages of our participants and the maturity of the groups, this had become established among the quilters but remains an opportunity that we recommend for sustainability and growth of the game jams.

Finally, given the immense diversity of maker environments, it stands to reason that the contexts studied here are not representative of the breadth of maker groups, and that the groups studied here may not be representative of their respective maker cultures. Community-based research has an inherent trade-off between its generalizability and specificity. Given the parallels that emerged between ours and similar work in this space however, we are encouraged by these findings and look forward to future work exploring additional metaphors which could triangulate insights and increase confidence among interested adopters of the recommendations. We also view opportunities for future work in further analysis of the data collected here, focusing on each context in and of itself through the use of the substantial data collected, and/or exploring the use of different angles of analysis.

3.5 Summary

In this chapter, I investigated crafting spaces as an extension of existing work on maker groups, focusing on female-dominated quilting groups in comparison to the masculine culture of game jams. Through fieldwork and thematic analysis as well as questionnaire data on intrinsic motivation, I found that participants' feelings of autonomy, competence, and relatedness were satisfied in different ways across the quilting group, and that the STEM-oriented game jam failed to provide opportunities to engage a more diverse group of people. I offer a number of recommendations to consider how game jams, and by extension, maker groups might be reimagined, boiling down to a shift in focus: Instead of focusing on specific goals to achieve, organizers could put their efforts into fostering longer-lasting community ties through satisfaction of needs.

3.5.1 Chapter Contribution

The purpose of this chapter was to address **RQ1**: *What can we learn from gender-imbalanced maker groups in order to support the diverse needs of makers in STEM-focused environments?* I presented the results of a study that focused on the common goals and structures in maker groups that were dominated by male and female participation, respectively. In doing so, I found that narrower ideas of what constitutes "passing" as a maker in the STEM-oriented environment limited opportunities for makers to achieve their goals, goals which were every bit as diverse as those found in the crafting environment. Accordingly, I recommend maker groups—if and when possible—consider why people might be engaging along the axes of autonomy, competence, and relatedness (and associated themes therein) to determine in what ways their events might support or be conducive to those goals.

To allow for the kind of thinking that will help us to look beyond something as a makerspace/not-a-makerspace to explore new opportunities to support maker communities, I contribute **C1**, an expanded definition of what a makerspace is (subsubsection 3.4.0.3): one that is metaphorical and defined by makers at a grassroots, rather than a top-down level. To support this way of thinking, I also prioritize using language like *maker group* over *makerspace* to foreground makers as individual agents that, together, form communities. In Subsection 3.4.1 the themes of the research coalesce under three buckets highlighting the need to support makers' self-determination. In doing so, I contribute **C2**: *Identifying new ways to support makers' diverse needs using technology.* The lenses explored here serve to support the psychological needs of makers to increase their satisfaction in the long term.

3.5.2 Context in the Thesis

This chapter of the thesis focused on improving inclusivity at the entry point to the STEM talent pipeline, with the underlying belief that diversifying makers and creators will lead to more diverse perspectives and more inclusive product designs. This would, in theory, counteract the effect shown by Beckwith et al. (2005) of how the features of commercial software tools are usually optimized around the preferences of male developers. However, Williams (2014) states the shortcomings of relying solely on improved female recruitment rather plainly: "I don't want to see women missing out on great technologies while we wait for the pipeline of female candidates to fill, and I don't want businesses missing out on being successful in the marketplace by not successfully creating products and services for 51 percent of the population" (Williams, 2014, p. 36).

There exists a group of HCI researchers already contributing to a growing body of research on the role of gender in HCI through examining the design and use of software. De Angeli and Bianchi-Berthouze (2006) were early to acknowledge that gender tended to be controlled-for in usability evaluations, but not much was actually known on whether and how gender differences should or could influence the design of interactive software. The Feminist HCI approach proposed by (Bardzell, 2010) rejects the idea of universality so that these gender differences can be surfaced, and provides theoretical, methodological, design process, and evaluation recommendations. Some research empirically tests hypotheses related to gender differences in the use of problem-solving software, using existing software tools as well as prototypes developed on the back of their findings (e.g., Beckwith & Burnett, 2004; Beckwith, Burnett, Grigoreanu, et al., 2006; Burnett et al., 2011). These hypotheses are developed using evidence from different domains, such as computer science, psychology, education, gaming, and marketing. Williams (2014) summarizes this and related work by others demonstrating that implicit gender-neutrality often obscures a bias towards male users of that software. In past work, I have also shown how ambiguity in design language can lead to generalizations that a potential user will be male (Bradley et al., 2015). To assist teams that want to avoid inclusion of gender bias in their software, Burnett et al. (2016) developed a tool called GenderMag, and validated its usefulness in the field.

While this past work has been invaluable to the pursuit of designing technology that is more suitable for women, the focus has largely been on existing software that has been commercially available for some time (e.g., programming environments and spreadsheets). This rigour has not been demonstrated on emerging technologies that may have the potential to be designed at an earlier stage with a feminist lens. As a part of my PhD research, and design explorations stemming from the findings of this chapter, I identified a gap in the

literature relating to a gender-based analysis or feminist critique of VR technology. Moreover, this technology seemed well suited to addressing the unmet needs of marginalized makers. However, on further investigation I found that, were VR to be used uncritically, it would further exacerbate inequities due to its inaccessibility to people in marginalized groups. In the chapter to follow, I describe why this problem matters, and my contributions towards addressing it.

Chapter 4

Technology for Access, Inaccessible Technology: The Case of Virtual Reality

As we learned in Chapter 3, nurturing the maker community over any one physical space is advisable for improving equity among makers. But what about virtual spaces? As maker groups are often early adopters of novel technologies and a popular site for research, VR technology is already finding its way in (e.g., Blum-Ross et al., 2019; Enkin et al., 2020; Han et al., 2020; Lock et al., 2020; Own, 2018). As potential solutions to address issues raised in the previous chapter, I conducted design explorations using different technologies including mobile apps, chatbots, and using existing platforms such as Discord (and Discord bots) to reduce friction in processes that made ILEs intimidating or otherwise unfriendly to those already likely to suffer from feelings of exclusion (e.g., finding a team or partner, asking questions, knowing how to plan or do self-guided learning leading up to an event). I also considered opportunities for VR to support making. Given the realities of COVID-19, suddenly what it looked like to make was very different. This made VR a promising direction, while also creating difficulties when studying the technologies considered in design explorations: the contexts in which they would be used were fundamentally changed, and the dynamics of making remotely were unknown—these dynamics are explored in Chapter 5. A highlight of the findings in Chapter 5 is an attention to the need to support social connectedness among makers over the practice of making itself. Maker groups are already trying to maintain a sense of social connection using other tools, but are expressing frustration and dissatisfaction. VR is in this case very promising to explore to support maker communities, but the fact remains that the technology itself is inequitably designed, and

particularly inaccessible to women. A feminist methodology threaded throughout this research means that I have chosen to face this problem head-on as opposed to sweeping it under the rug. In the remainder of this chapter, I present my contribution to the corpus of knowledge on gender and virtual reality, specifically how experimental design and reporting of research has perpetuated systematic exclusion that limits who can comfortably experience the benefits of this technology.

4.1 Background

For decades, research into VR has provided evidence that women may be disproportionately affected by the negative symptoms of cybersickness (e.g., LaViola, 2000; Shafer et al., 2017; Stanney et al., 2020), ranging from discomfort to the possibility of an emetic response. Research into cybersickness follows a longer history into simulator sickness[1], which also provides preliminary evidence that women may be more susceptible to the possible negative effects of VR. Despite this long history, cybersickness remains an unsolved problem for VR, and the apparent link between cybersickness and women across VR research has not been systematically studied or validated. With the recent release of relatively low-cost consumer head-mounted displays (HMDs), there is an increased availability and access to VR technologies, both for the public and for the research community. VR technologies and applications impact a wide variety of domains (Esposito, 1996; McGill, Boland, et al., 2015), with early evidence suggesting a range of prosocial benefits (Gillath et al., 2008; Peck et al., 2020). Yet the possibility of negative symptoms remains a consistent and often overlooked concern. Given the persistent unknowns about the safety or risks associated with VR, it is crucial that more comprehensive and/or targeted study design methods and practices are developed to better understand the relationship between gender and cybersickness. With an initial focus on human-computer interaction (HCI), I propose to examine how VR research accounts for the possible gendered effects of cybersickness. I then ask how we might leverage lessons learned from these publications in order to better understand the possible relationship between VR, gender, and cybersickness. If VR is to

[1]The terms *simulator sickness* and *cybersickness* were often used interchangeably over the course of our review, but they are not the same: *cybersickness* pertains to the discomfort felt during or after using a virtual environment (VE), with approximately three times the severity and a different symptom profile to *simulator sickness*, which pertains to simulator environments (LaViola, 2000; Stanney et al., 1997). I also encountered attributions of sickness to both *gender* and *sex* in this review. Given that the standard manner of establishing participant gender is by self-report, I use *gender* in this work to reflect and respect the identity disclosed by participants.

live up to its promise as a technology for 'everyone' (Özgen et al., 2019; Sutcliffe & Kaur, 2000), it is integral to find ways to ensure that it does not exclude by design.

I present a systematic review of literature that comments on the connections between gender, cybersickness, and VR in order to propose equitable study design guidelines for VR. This systematic review is informed by, first, a preliminary review of CHI 2019 VR papers that shows that considerations for participant gender are inconsistent and under-reported. Expanding this search, my systematic review of 71 eligible VR publications (59 studies and 12 surveys) draws on literature across a variety of related fields (health, human factors, psychology, and so on) in order to derive more generalizable recommendations for study design and to better understand the relationship between gender and cybersickness. It should be noted that this systematic review is unlike other traditional systematic reviews. The findings reveal that most VR studies within HCI do not report on gender effects, so I am unable to provide statistical analyses on the topics of interest. This does, however, show the need within the VR community to acknowledge the gendered effects on cybersickness. I argue that with the possibility of a gendered susceptibility to cybersickness, the VR community must consider gender at the forefront of study design. This work reveals a number of confounding factors (e.g., a wide variety of technical specifications, tasks, content), a lack of demographic data, and a bias in participant recruitment, which can make it impossible to identify or ascertain the specific causes or effects of gendered cybersickness. Furthermore, I uncovered a clear bias in inclusion and exclusion criteria, with a lack of data on those who are not able to participate due to the negative effects of cybersickness. Overall, these results are then reinforced by survey papers that repeat these findings, and perpetuated by further research that is informed by these surveys.

In the recommendations (Section 4.7), I argue that there is a need for more consistent study design and reporting. The principles of human-participant research suggest that representative samples of demographically diverse participants lead to more generalizable findings (Kukull & Ganguli, 2012; Peck et al., 2020). Moreover, I suggest that there is a need for this research to adopt more nuanced perspectives of sex and gender, as socially-constructed and/or biological characteristics appear to be assumed or essentialized. While this review confirms that multiple studies claim that female-identified participants are more likely to experience cybersickness in VR, the inconsistencies and the lack of clear study design guidelines that acknowledge and/or address this gender imbalance suggests opportunities for future work. Based on the gaps identified in this systematic review, I contribute preliminary study design recommendations, arguing that gender considerations are necessary at every stage of VR study design, even when the study is not 'about' gender.

4.2 Current Context

Prior to the CHI 2019 review (Section 4.3) and the in-depth systematic review (Section 4.4), I explored the problem space of gender issues in VR that inspired this work overall. In this informal literature review, I observed that publications coalesced into three broad categories:

1. publications *documenting and comparing* gender and susceptibility to sickness (e.g., Flanagan et al., 2005; Park & Hu, 1999);

2. research *investigating* the nature of gender differences that could lead to virtual reality (VR) discomfort, such as differences in path integration and visual dependency (e.g., Cadieux et al., 2010; Fortenbaugh et al., 2007); and

3. *interventions* that attempt to address suspected causes of the discomfort (e.g., Xiao & Benko, 2016).

However, I also observed a misalignment between these three areas in terms of the measures used and the solutions proposed. For example, I found that (1) and (2) do not account for possible gender differences in symptom manifestation or expression (e.g., comparing "nausea" as one universal experience, as opposed to having multiple dimensions which differ in expression and prominence in the context of cybersickness (Muth et al., 1996; Stanney et al., 2003), and (3) proposes universal solutions to cybersickness without validating their effectiveness among diverse groups. While still valuable, as a large amount of participants in VR research are likely to experience discomfort using VR systems (Özgen et al., 2019; Sutcliffe & Kaur, 2000), creating universalizing solutions does not address the specific problems stated in (1) and (2). In this section, I expand on this misalignment by elaborating on categories 1-3, highlighting the issues I identified that inspired the systematic review presented in this chapter.

In tandem with the paucity of research on this topic, and the difficulty of reconciling disparate findings across these categories, there is a lack of engagement with gender as a factor across study design and analysis that could negatively impact understandings of participant experiences in VR. I argue that this lack of consistency and/or attention to the possible gendered effects of cybersickness signals the need for future work. This, in turn, prompted the preliminary recommendations for future VR research.

4.2.1 Documenting and Comparing: Symptom Profiles Differ by Gender

Much of today's knowledge about gendered experiences of simulator sickness or cybersickness—the terms used to describe the combination of uncomfortable symptoms associated with VE exposure—comes from the human factors field, where simulators were adopted for training in aerospace and defence. Stanney et al. (2003) provide a comprehensive overview of what cybersickness—the term used to differentiate sickness from VR versus a simulator—often entails: dizziness, drowsiness, headache, nausea, fatigue, general malaise, and aftereffects including disturbed proprioception and postural instability. The most common theory for why cybersickness occurs is *sensory conflict theory* (Reason, 1978). This theory positions cybersickness as a reflex (such as nausea) to a stimulus (conflicting sensory inputs): e.g., the visual system perceives motion while wearing a head-mounted display (HMD, a VR headset) while the body remains stationary.

In prior literature on gender and cybersickness, I found that symptom profiles are experienced differently by gender. For example, Stanney et al. (2003) presents a study with 1102 participants that found that female participants experienced 15% higher total severity of sickness symptoms. Among other findings, they found that female and male participants experienced different "symptom profiles," that is, the symptoms recorded had a significantly different hierarchy of the experienced severity between sexes. In the order of most to least severe symptoms, women had a *Disorientation* > *Oculomotor Disturbances* > *Nausea* ($D > O > N$) symptom profile, while men had a *Disorientation* > *Nausea* > *Oculomotor Disturbances* ($D > N > O$) profile. In other words, women may experience less nausea than men during experiments while still experiencing *overall* more severe symptoms of cybersickness. Later research continues to find a higher level of total severity in women, but tends to overlook this possible difference in symptom profiles, resulting in the use of measures that do not fully capture what is happening between groups. Essentializing claims about cybersickness are likely to disregard the nuances of these profiles or differences in individual experiences. I contextualize this point with an example in Subsection 4.2.2.

4.2.2 Investigating Gender and Cybersickness: A Need to Document Women's Experiences of Discomfort

Some attempts have been made to distinguish whether women are simply more likely to report discomfort (due to reasons such as socialization or tolerance), rather than experiencing it more frequently. Jokerst et al. (1999) attempted to rule out an effect of socialization, and

in their study found that while the gender of the participant and the researcher did not significantly affect the participant's likelihood to report, female participants had higher symptom scores and reported significantly higher gastrointestinal symptoms in a post-survey. And yet, the authors doubted the validity of female participants' self-reports, with no mention of reasoning behind their doubts, and so they recorded gastric myoelectric activity to quantify levels of nausea. They found no difference between genders on the gastric measure. Similarly, Cheung and Hofer (2002) use physiological measures (heart rate, blood pressure, etc.) and were unable to detect gender differences, and yet because the blood flow measures could not explain the reports, they state that women must be more inclined to report discomfort. Park and Hu (1999) present a study of similar design, with a similar conclusion. In addition to the lack of data to support these explanatory efforts, this view of cybersickness neglects an account of the experience beyond nausea, especially given that nausea is not solely due to gastrointestinal distress.

Moreover, recall that in the female symptom profile, nausea was the least prominent symptom ($D > O > N$, Stanney et al., 2003), and the sensation of nausea does not necessarily induce an emetic response, as would be detected by gastric sensors. "Nausea" is highly complex and contextual, with three distinct dimensions: somatic distress, gastrointestinal distress, and emotional distress (Muth et al., 1996). According to Stanney et al. (2003), while women do report more sickness than men overall, they do not experience more nausea than men, and differences between male and female participants were attributable to significantly higher levels of disorientation and oculomotor disturbances.

Further complicating reports of discomfort is the possibility of self-exclusion. For example, Flanagan et al. (2005) control for a number of factors including willingness to volunteer given a history of motion sickness. The authors propose that a past history of motion sickness induces anxiety which exacerbates negative symptoms. They point out the numerous differences in questionnaires and lab studies in prior work, and cite evidence against the idea that men are more reticent to report motion sickness. Flanagan et al. (2005) also suggest that there is a fundamental flaw in any research involving people who may be susceptible to motion sickness as these people might self-exclude, raising questions about how to better include those who may be most at risk. Taken together, these cases suggest a need to better document gendered experiences of discomfort.

4.2.3 Interventions: A Need for More Attention to Gender

While attempts have been made to mitigate cybersickness in VR, there is a lack of attention to the possibility of gendered effects of cybersickness across study design and analysis. Current research to reduce cybersickness includes examinations of walking in VR (Yamamura

et al., 2020), or examinations of the effects of vertical axis alignment in supine postural VR use (Tian et al., 2020). Yet without specific attention to gender, it is difficult to assess whether such efforts can be generalized, or how findings may relate to the possibility that women are more likely to experience discomfort in VR (Stanney et al., 2003).

Comparing past research findings to contemporary experiences with VR may be necessary to provide more insight into the role that gender plays in these contexts. For example, one opportunity for closer examination is field of view (FOV) in VR. In the early 2000s, research showed that the size of display improved people's path integration ability in 3D virtual navigation tasks (Tan et al., 2004). The authors hypothesized that the induced immersion caused by a larger display would influence participants to use "more efficient" egocentric navigation strategies. Similarly, Czerwinski et al. (2002) argued that a wider field of view coupled with larger displays for navigating 3D virtual worlds improved women's navigation speed performance (note, however, that these were not head-mounted displays). Despite these apparent advantages for navigation, other research showed that a virtual reality display with a wide FOV can induce cybersickness more easily than a display with a narrow FOV (Kooi & Mosch, 2006; Lin et al., 2002). More recent research complicates these latter findings. Xiao and Benko (2016) report that the relatively low-cost addition of sparse peripheral displays to existing headsets expands FOV with the unexpected result of reducing nausea symptoms. In this case, only 6 of the 17 participants were female, and gender was not part of the analysis. While this case benefits from putting the work into conversation with past research into FOV and cybersickness, the same is needed with regard to FOV and gender. For example, Al Zayer et al. (2019) report that restricting the FOV is an effective mitigation strategy for cybersickness among both male and female participants.

While recent efforts to mitigate cybersickness are needed, the lack of direct attention to gender in such cases is a missed opportunity. Recent research, for example, argues that gender differences in cybersickness may be due to default interpupillary distance (IPD) in headsets, which is less likely on average to fit women compared to men (Stanney et al., 2020). If mitigation strategies are to be applied generally, there may be a need to consider how such approaches may have to change for diverse bodies and diverse individual experiences.

4.2.4 HCI Research into Gender Issues in VR

VR research in HCI commonly focuses on experiences in VR (Iskenderova et al., 2017) and the usability of VR systems (Sutcliffe & Kaur, 2000). As such, VR studies in HCI

that include a focus on gender appear to primarily describe experiences *within* VR: for example, gender swapping and avatar use (Reichenberger et al., 2019; Schwind et al., 2017), experiences of harassment in VR (Blackwell et al., 2019; Neyret et al., 2020), or exploring topics like sexuality and heteronormativity via pornography in VR (Wood et al., 2017).

Research on female representation within HCI has focused on the lack of female participants and authors in VR research papers (Peck et al., 2020), and the implications this might have on the field. These implications are vast, and authors note the importance of reporting data on gender and other demographics in order to better understand how each are affected by VR. The authors write, "Demographic information must be included when reporting characteristics of participants, including age, gender, and race/ethnicity, so that readers can accurately interpret the studied population and future meta-analyses of participant demographics can be performed" (Peck et al., 2020, p. 1952). This recommendation has direct implications for systematic reviews such as this one, where inconsistent or missing participant data hinders an ability to perform such meta-analyses.

Research on usability stresses the importance of broad usability for VR to be applicable in educational settings, entertainment, job training, and more (Esposito, 1996; McGill, Boland, et al., 2015). However, while usability in VR often focuses on individual experiences, gender does not appear to be a key factor. Despite the significant efforts made by researchers to generate design recommendations to improve user experience and the usability of VR systems, few papers consider how and why gender may impact user experience.

Although gender *in relation* to cybersickness is not frequently investigated, discussions of cybersickness and the use of measures like the Simulator Sickness Questionnaire (SSQ) appear to be common in VR studies. Within HCI, research on experiences of cybersickness also includes exploratory work that provides guidelines and suggestions on design improvements for VR (Davis et al., 2014). Again, there appears to be a lack of research into how and why gender may impact user experience.

After examining the research on gender within HCI, I was able to further identify the specific questions and gaps within the field. I specifically wanted to focus on how the CHI community, a well-known resource for VR research, reported cybersickness and the level of discomfort experienced in VR. This prompted an exploratory review of CHI 2019 papers, which I used to further develop the questions that were asked during the systematic review.

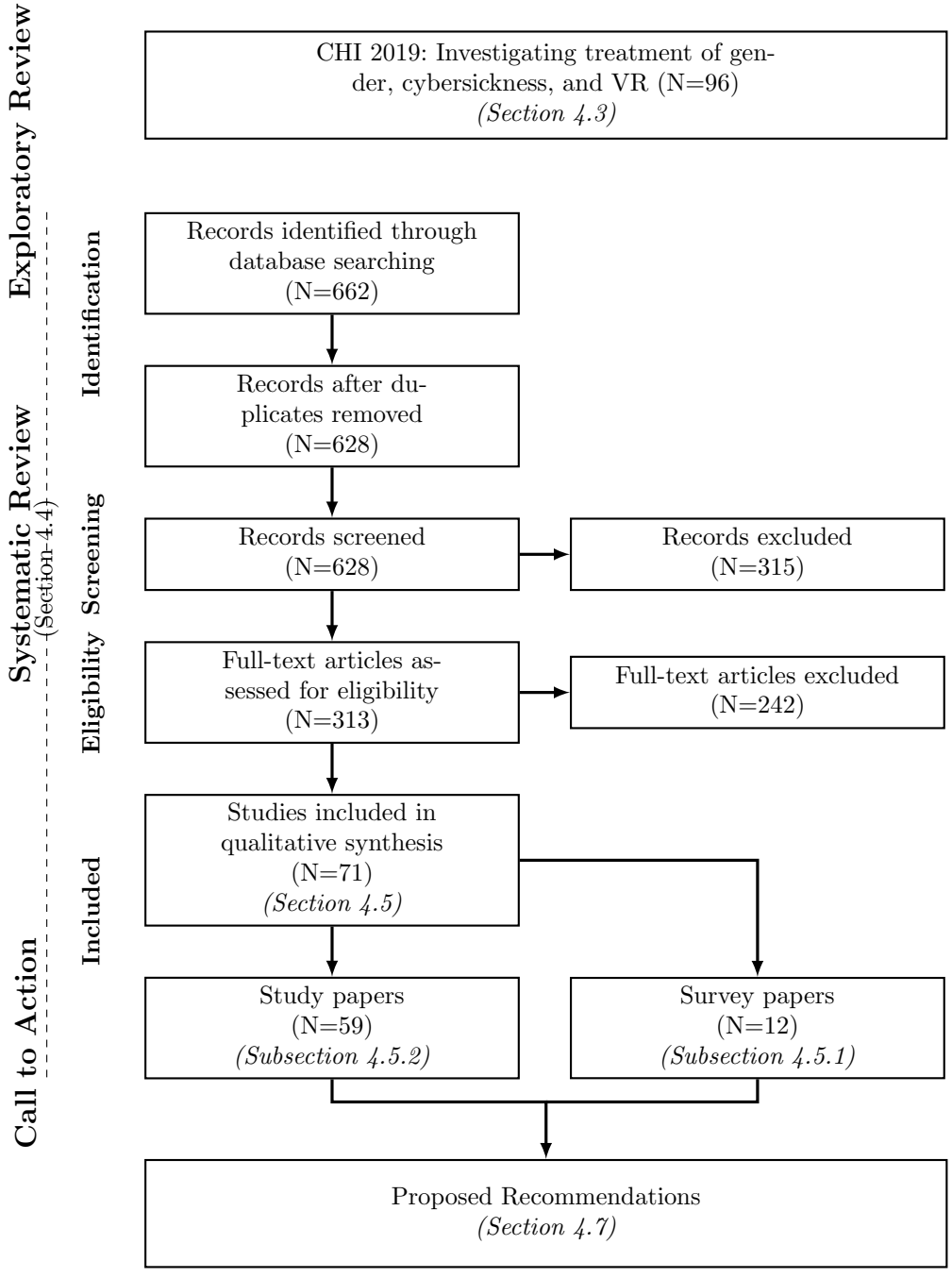


Figure 4.1: Number of results at each stage of the review, as represented in a PRISMA flow diagram.

4.3 Exploratory Review

I began with an exploratory review of CHI 2019 papers to help develop a preliminary understanding of how current research addresses the possible relationship between VR, gender, and cybersickness. As the largest HCI conference, CHI provides a sample of current state-of-the-art research on VR. The overarching finding of this review is a lack of consistency with regard to how data on gender and/or cybersickness is collected and reported, which complicates more in-depth analysis across these studies. I describe the procedure used to select papers and the insights that provided the foundation for the methods that were applied to the systematic review (Section 4.4).

4.3.1 Search Procedure and Selection of Studies

Figure 1 shows the procedure of the review, from the exploratory review to the outcomes of the systematic review. Preceding the systematic review, I focused on CHI 2019 proceedings and papers from the ACM digital library. I used keywords such as "Virtual Reality", "Mixed Reality", and "VR" across paper titles and abstracts to identify eligible papers. I then refined the search to only include those that were directly about VR, excluding papers that were about investigating and/or testing a tool to be used with VR, such as controllers. Other papers that were excluded were those that primarily focused on other VEs, such as Augmented Reality. Two researchers analyzed the proceedings to ensure that only full papers were used (posters and demonstrations were excluded). The results yielded 96 papers.

4.3.2 Insights

The analysis for the exploratory review focused on three overarching questions:

1. Did authors report the gender of their participants in terms of recruitment, and how many reported it in their results?
2. How was gender data collected?
3. Did authors measure, document, or report cybersickness and/or discomfort among participants?

In order to answer these questions, I looked at study classification types, sample size, gender of the participants, use of SSQ, contributions found about cybersickness, and whether the studies tested for differences in gender.

Overall, I found very little consistency across the 96 papers. For cybersickness, only 20 out of the 96 papers attempted to capture some aspect of participants' experience of sickness, and the strategies among these papers varied. 11 used the Simulator Sickness Questionnaire (SSQ), while 9 used other measures: 1 used the Virtual-Reality Sickness Questionnaire (VRSQ), 1 used the Motion Sickness Assessment Questionnaire (MSAQ), 1 used questions from Witmer and Singer's presence questionnaire (Witmer & Singer, 1998), and 6 used verbal feedback. Similarly, the papers presented a range of study types (e.g., user studies, pilot experiments, etc.), and were not consistent in the ways that they reported on gender. These inconsistencies suggest a need for further examination. For example, of the papers analyzed, only 65 reported participant gender, and only 3 reported their results across gender, meaning that it is not possible to identify specific issues or causes between gender and cybersickness within this recent work.

These inconsistencies led to investigating the supplemental information of the papers in the exploratory review in order to determine the demographics of the participants, especially for studies that did not report on gender. The goal was to assess whether one could use the supplemental information to pursue further gender-based analysis. However, of the 96 papers, only 2 provided supplemental information: 1 provided partial supplemental information, and 1 provided the questionnaires used. Broadly speaking, not only the inconsistencies were surprising, but also how little information on gender and cybersickness was reported by authors within the community. Again, this suggests the need for further research to better understand a possible gendered susceptibility to cybersickness.

4.4 Systematic Review: Method

A common theme across the related work and exploratory review is the wide range of fields and the variety of possible applications that are impacted by VR research. Because the possibility of a gendered susceptibility to cybersickness is also a common theme, a strength of this approach is the ability to draw from findings that cross disciplines. To ensure that I reviewed a broad range of research, I used the following databases that have a history of publishing VR research: ACM DL, IEEE, PubMed, SagePub, as well as the University's institutional library databases which include SCOPUS and Web of Science. The search strings used in each database are presented in Table 4.1.

Database	Search string	Results	Date of search
ACM Digital Library	`[[All: "simulator sickness"] OR [All: "cybersickness"]] AND [[All: gender] OR [All: sex]] AND [[All: "virtual reality"] OR [All: "virtual environments"] OR [All: "mixed reality"]]`	191	February 19, 2020
IEEE Xplore Digital Library	`(gender OR sex) AND ("simulator sickness" OR "cybersickness") AND ("virtual reality" OR "virtual environments" OR "mixed reality")`	7	February 19, 2020
PubMed Central (PMC)	`(gender OR sex) AND ("simulator sickness" OR "cybersickness") AND ("virtual reality" OR "virtual environments" OR "mixed reality")`	155	February 12, 2020
SagePub Journals	`(gender OR sex) AND ("simulator sickness" OR "cybersickness") AND ("virtual reality" OR "virtual environments" OR "mixed reality")`	101	February 18, 2020
Institution Library	`(gender OR sex) AND ("simulator sickness" OR "cybersickness") AND ("virtual reality" OR "virtual environments" OR "mixed reality")`	208	February 19, 2020

Table 4.1: Databases reviewed and search strings used for the systematic review.

Using these strings returned a total of 662 records. At this first stage of screening per the PRISMA systematic review protocol (Moher et al., 2009), a group of 11 raters evaluated the records for eligibility based on titles and abstracts. Agreement was calculated at 98.8% between raters after independently rating 83 papers to ensure calibration before proceeding. In this first screening phase, publications were marked as follows:

- *Relevant*, wherein the title and/or abstract refer to the three main concepts of: gender or sex; cyber-, simulator-, or motion-sickness; and virtual or mixed reality;
- *Somewhat*, wherein the title and/or abstract refer to two of the three core concepts mentioned above;
- *Not Relevant*, wherein the title and/or abstract may include a reference to one of our core concepts or terms, but with no relation to the others, or the terms are being used in a different context.

As reflected in the PRISMA diagram (Figure 4.1), 315 papers were excluded at this screening stage (34 of which were duplicates). Of the remaining 313 papers:

- 66 papers met the criteria for *Relevant*, defined as "measures or finds something about the relationship between: gender or sex; cyber-, simulator-, or motion-sickness; and virtual or mixed reality," and were forwarded onwards for full-text analysis;
- 247 papers were deemed *Somewhat* relevant, defined as "needing further examination; may be about cybersickness or simulator sickness, but does not tell us about the sex or gender *relationship* to it; tells us about sex or gender and motion sickness or cybersickness (but is not VR/MR); or uses the key terms in passing but does not contribute new information," these required further investigation beyond title and abstract, and these 247 papers were evaluated based on full-text contents by a group of 11 raters (including 3 of the authors), all with previous familiarity with the project and its goals from the prior screening stage.

Following this full-text analysis, 242 papers were excluded for reasons including: the publication is not in English and a reliable translation was requested but not obtainable by the authors; the research is not about humans; the publication is not a full paper. Finally, we arrived at a list of 71 *Relevant* articles, comprising 59 studies and 12 survey papers.

4.4.1 Phase 1: Data Collection

After narrowing down the set of publications to be analyzed, I along with the supporting authors of this study collectively defined a number of categories to log details from the papers for further analysis based on the studies reviewed. The exhaustive list of categories is as follows: display type; stereoscopic; motion tracking; driving simulator; commercial or custom; study design (between, within, or mixed participants); sample size; number and percentage of female participants; whether gender or sex were the primary focus of study or supplementary findings; whether any non-binary understanding of gender was expressed by the authors; if any gender or sex differences were found; number of dropouts and dropout gender; measures of sickness; independent and dependent variables; participant demographics reported; type of exposure; duration of exposure; exclusion criteria; content (when available); what relationship (if any) was found between gender and cybersickness. We also noted any overall strengths and limitations of the studies as they pertained to answering the questions guiding this systematic review:

1. How does VR research account for the possible gendered effects of cybersickness?
2. What can we learn from these publications about how to improve study design to better understand the possible relationship between VR, gender, and cybersickness?

4.4.2 Phase 2: Scoping

After collecting data on approximately half of the papers, we revisited our categories to discuss preliminary findings. Phase 1 was an attempt to better understand possible factors influencing cybersickness during a study. However, in the review it became apparent that a clear connection cannot be drawn between, for example, headset type and increased cybersickness for women due to the number of confounds and the sheer variety of variables, and/or the lack of standardization and/or reporting across studies. Other categories, such as the number of dropouts, offered limited reports of data, or none at all. Given my intention to offer preliminary study design recommendations, we honed our set of categories again. Categories relating to technology type; exposure; study samples; consideration of gender; and measures of sickness were reported more reliably. We therefore focused on these latter categories for the remaining analysis in an effort to identify more generalizable criteria for studying the relationship between gender and cybersickness in VR. All investigated categories are listed and discussed in Subsection 4.5.2.

4.5 Results

In this section I provide commentary on the current state of research pertaining to gender, cybersickness, and VR. In Subsection 4.5.1, I discuss the survey and review papers, which for the most part complicate understandings of gender and cybersickness by repeating inconclusive findings. In Subsection 4.5.2, I discuss the study-based papers, beginning by identifying a number of possible confounds, before moving to the categories that more directly report on possible connections between gender, cybersickness, and VR. I will contextualize these results in Section 4.6, and their implications in Section 4.7.

Survey papers that qualified per our criteria (12) are summarized in Section 4.5.1 and span from 2000 to 2020. Of these studies, five were published in the years 2015, 2017, 2018, 2019 (noting that our search ends at February 2020). After a discussion of the survey papers (12), in Subsection 4.5.2, I turn to a detailed analysis of the studies evaluated (59), which span the years 1996 to 2019. The oldest paper in the original set prior to screening was from 1994. I begin the analysis of the studies with the high-level results from some of the categories explored in Phase 1 before moving into those that came into focus in Phase 2 (Section 4.4.2).

4.5.1 Survey Papers

Of the publications deemed eligible for the final stage of the systematic review, 12 of the 71 were categorized as survey or review papers, with the remaining 59 classified as studies. In this section, I analyze the surveys and reviews to better understand synthesized perspectives on the possible relationship between cybersickness, VR, and gender. On average, these papers surveyed 246 manuscripts from databases such as PubMed, IEEE, ACM, and Google Scholar, in either a literature review format, theoretical discussion, or systematic review. Each of the 12 papers approached cybersickness differently, with topics including measuring motion sickness (Koohestani et al., 2019), possible correlations between migraine symptoms and cybersickness symptoms (Paroz & Potter, 2017), technology-aided psychotherapy (DeLucia et al., 2013), the optimal visual modality in VR (Stevens et al., 2015), and the representation of female authors and participants in VR research (Peck et al., 2020). While gender and cybersickness are mentioned in each paper, the possible relationship between the two is not always considered, and the possible causes and mitigating factors are inconclusive or overlooked entirely.

The most common hypothesis presented as a possible reason for gendered cybersickness is discussed in 3 of the 12 papers (Davis et al., 2014; Koohestani et al., 2019; LaViola,

2000), which refer to a reported difference in field-of-vision (FOV) of female participants. Women are said to have a wider FOV, which in turn is said to increase susceptibility to simulator sickness in VR due to a likelihood of flicker perception. A simpler, more obvious explanation is presented by Peck et al. (2020), whose analysis of studies from the IEEE VR conferences from 2015-2019 showed both an under-representation of female participants and female authors. To ascertain the possible bias caused by this under-representation, the authors performed a subsequent meta-analysis of 21 papers to assess how female author or participant representation might affect results. The authors conclude that "smaller increases in simulator sickness following VR exposure were observed in studies with a greater proportion of female participants," suggesting that female participants' presumed susceptibility to cybersickness may simply be due to biased study design. While the authors note a number of limitations with this finding (e.g., challenges comparing variables across studies), they offer the reminder that "conclusions drawn from samples with inadequate gender diversity may not accurately characterize simulator sickness in the general population." The remaining survey and review papers Classen et al. (2011), DeLucia et al. (2013), Jones et al. (2004), Martirosov and Kopecek (2017), Mol (2019), Paroz and Potter (2017), Stevens et al. (2015), and Weech et al. (2018) mention gender as a possible factor of cybersickness, but do not discuss how or why a gendered difference might occur.

Overall, however, as with the exploratory review of CHI2019 VR papers, there are discrepancies and unknowns about how gender is understood. For example, for most of the reviews it is unclear whether any consideration is made for trans or non-binary identities. The one paper that mentions non-binary gender identities is the review by Peck et al. (2020), which specifically excludes considerations for non-binary identities in their review of author gender, and excludes the 1 non-binary participant out of the 9,557 participants across 319 studies in order to make comparisons across male and female participants. The authors conclude with recommendations for more representative samples of participants, and more accurate reporting of demographics. My own review confirms that such data gathering and reporting practices are needed across the vast majority of VR research.

4.5.2 Study Papers

In this section, I discuss the two phases of analysis for the 59 study papers revealed in our survey. In the first phase, I identify a number of possible confounds that are often unacknowledged when attempting to extrapolate findings across VR research. In the second phase, I hone the categories of analysis in an attempt to identify more consistent variables.

4.5.2.1 Phase 1: Categories with High Variability

While investigating and analyzing the set of 59 study papers, I began to note the possible confounding factors of cybersickness due to the many variables across system design and study design. The papers examined various aspects of VR; some noted the causes and symptoms of cybersickness as experienced by their participants (e.g., Asjad et al., 2018; Kim et al., 2017; Stanney et al., 2003) while others did not. The studies showed wide variation in terms of system design and study design, including variations in the amount of exposure time, break time, and other variables. The variety of technology used in research on VR creates a large amount of experimental data to disentangle, making it difficult to ascertain how and why cybersickness occurs and what needs to be done to mitigate its effects. Although I do not attempt to hypothesize the causes of cybersickness, it is important to highlight the possible confounds based on this work and other previous literature. By identifying possible confounds, future research can begin to manipulate variables in order to better understand the relationship between gender and cybersickness.

Technology types The variations in terms of hardware, software, and content is not only underreported, but also difficult to assess. From the papers we analyzed, the most common displays used were HMDs (e.g., Jaeger & Mourant, 2001; Nguyen et al., 2018; Pot-Kolder et al., 2018). Other display types include Cave Automatic Virtual Environments (CAVEs) (e.g., Gálvez-García et al., 2015; Keshavarz & Hecht, 2011) and screen monitors (e.g., D'Amour et al., 2017). Some of these display types were used as part of driving simulation experiments (e.g., Gálvez-García et al., 2015; Keshavarz et al., 2019). Driving simulations were seen being used in both HMD environments (Liu et al., 1999) and CAVEs (Gálvez-García et al., 2015). The types of programs used in the 59 studies varied from being either custom-created for the experiment (e.g., Aldaba & Moussavi, 2020; Boustila et al., 2015), or commercially available to the public (e.g., Al Zayer et al., 2019; Clemes & Howarth, 2005). In some cases, the authors chose the display type in order to prevent other confounds such as the weight of an HMD, which could have caused participants to perform fewer head movements (Kim et al., 2015). While all of these types of virtual experiences may be categorized as forms of VR, they each offer significantly different experiences, meaning that generalized claims across these studies is limited.

Exposure and break duration The duration of VR exposure in the papers analyzed varied in the specific type and amount of time participants had to be in the virtual environments. Some studies divided their research into blocks of time where participants were

exposed in short bouts such as 2-10 minute intervals (Mittelstaedt et al., 2019), while others asked participants to complete tasks within the experiment and did not clearly mention the amount of time exposed (Zimmons & Panter, 2003). Experiments ranged from intervals of a couple of minutes (Pot-Kolder et al., 2018) to 20 minutes or more (Kim et al., 2015). Experiments also ranged in the duration of breaks between exposure; some studies reported breaks that lasted a couple of minutes or 10 minutes (Munyan et al., 2016), while others did not report the duration of their break times at all (Foroughi et al., 2015). While differences in exposure time and breaks may be necessary depending on the study design, these examples show that there is too much variation to assess the direct effects on cybersickness results.

Independent and Dependent Variables The studies that were analyzed also varied greatly in the dependent and independent variables they measured. Independent variables included factors such as latency (Wilson & Kinsela, 2017), navigation (Kim et al., 2015), level of joystick control (Rich & Braun, 1996), furnishing of virtual environment rooms (Boustila et al., 2015), etc. Dependent variables ranged from the rate of control (Kim et al., 2015), to simulator sickness (D'Amour et al., 2017), to spatial comprehension (Boustila et al., 2015) and more. Some papers, such as Nichols (2000), call on the need to recognize virtual reality induced symptoms and effects (or VRISE) as a multi-factorial problem. Sex was considered as an independent variable in two studies (Al Zayer et al., 2019; D'Amour et al., 2017), but gender and sex were more likely to be reported as demographic data. There is also a large variety in the way in which gender and sex are considered as part of the demographic data, with no clear consensus in the way gender was collected, reported, or analyzed.

4.5.2.2 Summary

It can be difficult to ascertain how this variety of factors may influence cybersickness, including displays, additional technologies, program type, exposure time, break time and variables studied. There are generally few references to these variables in existing studies, and in this work there is not sufficient control to identify clear relationships between a single factor and susceptibility to cybersickness. The papers analyzed did not report these factors as part of their findings, making it difficult to make clear recommendations on how to mitigate cybersickness. For each of these categories (technology display, custom vs. commercial, exposure time, and break time), there is too much variety to be able to conclusively say what factors contribute to cybersickness. This lack of data is exacerbated

by a lack of reporting on gender. Further research is needed to better understand how these possible confounds may contribute to cybersickness symptoms and onset.

4.5.2.3 Phase 2: Categories with Broad Patterns

In the second phase of analysis, the goal was to provide a more in-depth review across all 59 study papers by identifying categories that might offer more consistent reporting on the possible relationship between cybersickness and gender.

Gender and Sex Perhaps the most obvious category to the topic at hand is how the studies in this systematic review wrote about, treated, and reported on participant gender, or in many cases, sex. Sample sizes ranged from 10 to 1102, with a mean of 122 participants and a median of 50. Reporting on basic participant information was not always straightforward: some papers required reverse engineering to determine the number of women included (e.g., from percentages of women provided across multiple study groups with a given N Tyrrell et al., 2018). This could be attributed to differing disciplinary expectations, however, a lack of clear reporting can lead to confusion: one paper reports a sample of 60 participants with 39 (or 65%) males, but their limitations state that "After careful deliberation, the decision was made to recruit males only due to disproportionate attrition" (Munyan et al., 2016) (in this case, I assume an error in transitioning from reporting on the breakdown of the original 122 participants recruited, to just those 60 remaining post-exclusion). Two papers (Liu et al., 1999; Luks & Liarokapis, 2019) did not report on the number of women in the sample, although one noted that groups were "balanced," which is assumed to be 50%. The average number of women included in these studies was 54, with a range of 0 to 467, and a median of 24. This amounts to approximately 47.5% female representation across all of these studies, noting that inclusion ranged from 0% (all men in one study, Munyan et al., 2016) to 100% (all women, in two studies Ji et al., 2009; Schneider et al., 2003).

Of the studies that were analyzed, none made statements demonstrating any consideration for non-binary or transgender participants either in passing reference or in their approach to data collection or analysis. I also failed to detect any detailed information on *how* gender information was collected by researchers, either through statements by the authors, or implied through phrasing (e.g., "participants identified themselves as..."). I am therefore unable to ascertain whether gender or sex were ascribed by the researchers, or gathered through self-report, and what options were available for participants to self-identify.

Primary or Supplementary When categorizing papers, I used "Primary" or "Supplementary" to denote whether the study foregrounded gender as a factor to be studied (i.e., it was included in their experimental design and/or constituted part of the overall research questions). In "Supplementary" cases, gender was analyzed in post-hoc analyses and/or was not considered a main factor of study. Out of the 59 studies included in this review, only 11 considered gender as a primary factor. The vast majority of papers (45, or 76%) included gender as a supplementary finding. As mentioned above, the three remaining studies had single-gender samples.

Difference found? Of those studies in which gender was a primary focus (excluding the studies with homogeneous samples), most found gender differences in their analysis (e.g., Aldaba & Moussavi, 2020; Jaeger & Mourant, 2001; Pot-Kolder et al., 2018; Rich & Braun, 1996; Weech et al., 2018). However, the proportion of studies finding a difference varies depending on whether "difference" is defined as something for which the authors were looking for with regards to their main research question(s), or if they found differences in other measures: most, if not all, reported gender differences in areas like dropouts and reports of sickness. Four studies reported no differences, but again, included commentary on dropouts and sickness, making it difficult to determine what does and does not constitute "difference found." One study reporting no gender differences also reports having just one female participant remaining after 10 minutes (Nguyen et al., 2018), so making any claims about difference would not be possible given the sample. The vast majority of studies wherein gender was a supplementary consideration reported gendered differences in experience, pointing to the value of including gender as a consideration in VR studies regardless of whether the study is 'about' gender.

Measures of Cybersickness From the data set, 48 out of 59 papers (81%) used the Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) to measure participants' symptoms. Of these 48 studies, 9 used additional supplementary measures to capture sickness data: general questionnaires made by the authors (3), MSSQ/MSSQ-short (4), Body Awareness Questionnaire (1), VIMSSQ (1), FMS (3), malaise rating (1), MHQ (2), SSVAS (1). This means that 39 used the SSQ alone, and 9 used some combination of SSQ plus other measures. Other studies used standalone measures to capture cybersickness information: one study used the MSSQ-S alone (Luks & Liarokapis, 2019); one used MHQ alone (Schild et al., 2012); or verbal feedback alone (Mittelstaedt et al., 2019). Overall, while every one of the 59 studies measured sickness in some way, the differences across these various measures of cybersickness makes it difficult to develop generalizations about

how, when, or why cybersickness occurs across these studies. Comparing and compiling differences across these measures is another opportunity for future work.

Dropouts Dropouts were a concern across all studies surveyed: there appears to be a general understanding that where there is virtual reality, there will be cybersickness, and where there is cybersickness, there will be individuals unable to continue participating. How this reality is handled varies. Some studies (e.g., Kim et al., 2015) reported on the number of participants, their gender, and reasons for discontinuing participation in the study; others reported on only one of or some combination of these values. Cybersickness was the most frequent cause for terminating an experiment, although some other reasons included equipment malfunction, and participants not following instructions. Women were consistently recorded as more likely to discontinue participation in the experiment due to intensity of cybersickness (D'Amour et al., 2017; Graeber, 2001).

Some papers retained the data for dropouts and reported on it to the extent that was possible (e.g., Keshavarz & Hecht, 2011; Kolasinski & Gilson, 1998; Rich & Braun, 1996), providing important context on the full spectrum of participant experiences. One study had one female participant drop out and noted "shortly after exiting the VE [virtual environment], she induced vomiting and vomited three times. This participant reported that she has a long history of motion sickness in both cars and airplanes. During the follow-up call, she reported that she started feeling better about two to three days after the session and stated that her experience in this study was probably [her] worst case of motion sickness ever" (Kolasinski & Gilson, 1998, p. 1513). Others (e.g., Arns & Cruz-Neira, 2004) sought new replacement participants with similar demographics and scoring on any pre-study measures: the implications of this practice are discussed in Section 4.6.

Demographics, inclusion, exclusion The demographics of the participants that were reported varied greatly across studies. All studies except for two included gender as part of their participant sample breakdown (Liu et al., 1999; Luks & Liarokapis, 2019). Age was commonly noted, and the average age pool was composed of college students (e.g., Stanney et al., 1999; Zimmons & Panter, 2003). Papers rarely noted the race or ethnicity of the participants being studied. When race or ethnicity was noted, it was still not tested or discussed (Munyan et al., 2016). The level of prior video-gaming or VR experience of the participants was also commonly noted among studies (e.g., Bessa et al., 2016; Iskenderova et al., 2017; Kim et al., 2015). Although these types of factors were sometimes included, there were infrequent tests to explore whether differences exist between the various demographic data of their participants.

Of the papers that were reviewed, only some noted the exclusion criteria or why they chose the criteria that they did. Some papers noted that participants who dropped out were excluded from final analysis but do not state why participants dropped out, while others mention that participants dropped out because of the cybersickness they experienced (e.g., Matas et al., 2015; Stanney et al., 2003). The inclusion criteria of the papers investigated were factors around how participants might not be able to take part in the study, such as their vision. For example, some studies asked participants to complete questionnaires to investigate if they had normal or corrected vision, or asked participants to complete a vision test (Jaeger & Mourant, 2001; Wilson & Kinsela, 2017). Papers were overall more likely to report on exclusion criteria rather than inclusion criteria, however many papers did not explicitly report these criteria at all.

4.6 Discussion

In the analysis, I focus on the study papers evaluated and discuss the findings in the context of their implications for future research on gender and cybersickness in VR. In particular, I spend time on those variables that presented more identifiable patterns and opportunities for researchers doing studies in VR. When appropriate, I contextualize these factors within broader patterns in HCI research. Although I critique particular examples in the following, it is not my intention to target individual researchers, but rather to provide examples that demonstrate what we view as a systemic issue across the literature we reviewed.

4.6.1 *How* is gender involved in these studies?

4.6.1.1 How is gender treated by the authors?

One thing the CHI community already has to its advantage based on the exploratory review is that it reports fairly reliably on gender breakdown of participants, although somewhat imperfectly: 65 of the 96 papers surveyed in that review (Section 4.3) reported on participant gender. The manner in which participant breakdowns were reported in the review of literature showed inconsistencies as to where, how, and whether this information was even provided. Since the papers in this review represent a variety of domains, I am unable to comment on whether their use of the terms "gender" or "sex" is the result of different disciplinary standards or attributable to other factors, such as the authors' understanding of the gender binary being projected through their reporting. There are existing publications within CHI that discuss implications of, and provide recommendations

for, this type of reporting (e.g., Bradley et al., 2015; Burtscher & Spiel, 2020; Scheuerman et al., 2020). More intentionality is needed in the use of these terms in order to avoid essentializing claims that can add uncertainty around how this data was collected, and what was inferred by the authors as a result. Given that the HCI literature reviewed largely ignored the relationship between gender and cybersickness, I highlight the opportunity to adopt more inclusive understandings of gender in VR studies. For example, Burtscher and Spiel (2020) broadly identify three common social understandings of gender as *essentialism*, *performance*, or *identity*. Although all three conceptions were present in our review, the most common was the essentialist perspective.

In one example of the *essentialist* view, the authors align menstruation with womanhood (Clemes & Howarth, 2005). Despite their focus on this biological process, the authors still use "gender," demonstrating a biologically deterministic view whereby the association of menstruation with a particular sex implicates gender (Burtscher & Spiel, 2020). While research about potential impacts of hormones on susceptibility to cybersickness can add value by examining additional variables, it implicitly positions men as the control group with "normal" experiences in VR, and the essentialized category of women as the deviant group to be ameliorated. Rather than adjusting systems to people, people are forced to adjust to systems. After completing this systematic review, I noticed that this approach is still being applied in 2021. For example, Lim et al. (2021) use an all-male participant pool to eliminate hormonal fluctuations associated with menstruation. They selected participants who were "healthy and easy" to participate in the experiment with the stated goal of clarifying and quantifying factors causing cybersickness.

An example of the *performative* view of gender can be seen in a paper that claims that visually induced motion sickness (VIMS) is more severe and has a faster onset for women (coupled with a 49% dropout rate, compared to 18% among men): despite having tested selected variables in a three-factorial between-participants design, the authors disregarded this outcome, writing "the reason why VIMS is more prevalent in women is not yet understood ... One reason, however, may be a cultural difference rather than a true sex-effect or physiological difference, with females possibly being more open-minded about their feelings than males" (D'Amour et al., 2017). In this case, such a claim undermines what the authors studied, analyzed, and published by attributing their results to stereotypes.

Keyes (2018) highlights how externally defining aspects of participants' self-representation can amplify pre-existing inequalities, and in turn, thwart a person's self-determination by denying their *identity*. There are multiple sources published in and intended for the HCI community to support individual self-determination through thoughtful and informed engagement with gender throughout the research process (e.g., Scheuerman et al., 2020; Spiel et al., 2019), and these understandings of gender draw on decades of research across fem-

inist, queer, and trans studies. However, none of the studies included in this systematic review made reference to gender beyond the binary, nor did they demonstrate recognition of the changing nature of gender itself within a broader social or cultural context. If the option to self-identify was included in study protocols but not reported, then it is not possible to judge whether erasure has occurred. Reporting language can help to clarify that participants have had a chance to self-identify, e.g., "7 [participants] identified themselves as females, and 5 as males" (Bergström et al., 2019). In VR research, there is a clear gap in reporting what options were available to participants, whether or not they were selected, and indicating through word choice who established the gender of participants.

4.6.1.2 Primary vs. Supplementary Framing of Differences Found

When screening the papers for this review, it was not immediately apparent which papers would consider gender a primary focus. We were then surprised at the low proportion of "Primary" papers in our set compared to "Supplementary": while gender effects were framed as incidental findings in the latter group, each of these papers demonstrates a need to consider gender at the forefront of the study design. The search criteria biases the sample of papers towards those that have included gender or sex as a relevant term in their publication, meaning that I have not evaluated papers that make no mention of it at all. Whether or not gender differences in cybersickness were part of the authors' own research questions, I found that the mere act of reporting on gender provides valuable information for other researchers. 45 of 59 (76%) studies in this review considered gender as a supplementary reported result. Of these 45 studies, 26 of them (57%) reported these differences as relating to cybersickness. Had a consideration and reporting of gender been the norm rather than the exception, perhaps a meta-analysis would have been possible for this systematic review. Going forward, I encourage authors to take away an increased awareness of the potential relationship between gender and cybersickness, and to report their findings even when their VR studies are not 'about' gender, so that future meta-analyses may be conducted.

Over the course of this review, I was able to find authors who expanded on the potential impact of other individual factors as contributors to cybersickness. I note this finding to highlight the fact that gender is not likely to explain away all of cybersickness, and that future work should remain sensitive to the complexity of individual differences contributing to experiences in VR as opposed to essentializing based on categories of people. Wilson and Kinsela (2017) contend that while women are reported to be more susceptible to sickness, differences may be due to individual susceptibility. For example, this is demonstrated in Nguyen et al. (2018)'s analysis of the ability to detect curvature redirection, wherein

men on average performed better on detecting curvature gain, but there was high variance *within* their gender groups, leading the authors to question the importance of visual dependence among individuals rather than groups. Chen et al. (2015) also find large individual variation in susceptibility to sickness, while also noting several of the same confounding factors that were considered in this review. While controlling for the effect of susceptibility and citing Barnett-Cowan et al. (2010), the authors determine that gender *was* indeed a contributing factor not to be overlooked. Overall, a high degree of variation within two binary gender categories throws into question whether binary gender is a *good* choice or a *convenient* choice for data collection and analysis, particularly in light of other individual factors emerging such as visual dependency or susceptibility. Given the degree of uncertainty in the data and disagreements across publications, I contend that it is necessary to continue investigating the effects of gender alongside other identity factors on cybersickness. Reporting on this data is necessary within diverse contexts and research settings, and across a range of possible variables.

4.6.2 *What* is being studied?

4.6.2.1 Measures: Can the diversity of cybersickness be adequately, or satisfactorily, quantified?

The most popular measure of cybersickness among all papers was the SSQ. As mentioned in Section 4.5, every study in this sample measured cybersickness in one way or another. In contrast, only 21% of the CHI 2019 papers reported measuring sickness in some way. Regardless of proportions, what I have learned about the vastness of independent differences would suggest that a plurality of approaches would be required to capture these various nuances. A feminist approach to data science reminds us that "what gets counted counts" (D'Ignazio & Klein, 2020); accordingly, we raise concerns about the repeated exclusion of trans/non-binary identities, and the continuing reliance on and validity of the SSQ as such a singularly dominant approach to document cybersickness.

From the sample of papers, it became obvious that susceptibility and sickness co-occurred in the reporting. Authors intended to contribute variables that served as predictors of susceptibility to cybersickness (e.g., Smart et al., 2002); there were studies which stated that women have higher susceptibility than men in the framing of their work (Graeber & Stanney, 2002; Kolasinski & Gilson, 1998; Munafo et al., 2017), implying a trend that "susceptibility" and "women" are tightly coupled concepts. It is therefore concerning that some papers used susceptibility to motion sickness as exclusion criteria for their studies (Munyan et al., 2016), although others required that participants demonstrate some level of

susceptibility (Clemes & Howarth, 2005). The role or relevance of susceptibility altogether was brought into question by Weech et al. (2018) who found differences in cybersickness but not in reports of susceptibility documented using the MSSQ.

There is an opportunity to better identify the *contexts* in which these measures are developed and applied, and what is actually explainable from the outputs. One paper explained that an SSQ score above 20 meant that participants were "sick" (Gálvez-García et al., 2015), whereas the intended interpretation is that the simulator itself is "bad" (Kennedy et al., 1993). "Sick" is a feeling, not a number, despite the necessary efforts to quantify that feeling. Other measures used such as the Motion History Questionnaire (MHQ) and Motion Sickness Susceptibility Questionnaire (MSSQ) both take past experience as predictors of whether participants will be impacted by cybersickness. Rather than filtering for susceptibility, a major stepping stone in cybersickness research would be to move from aiming to forewarn those who are susceptible (e.g., Stanney et al., 2002) to determining what specific design elements (e.g., hardware, software, interaction techniques) are needed for a system that is enjoyable for everyone to use.

Recent research in VR has begun to develop and adopt more targeted approaches to assessing and evaluating cybersickness, including the CSQ (Stone III, 2017) and the VRSQ (Kim et al., 2018). Our review suggests that not only is there an ongoing need to iterate on the tools we use to better understand and mitigate cybersickness, but also a need to examine how these tools are being used, and how gender is considered before, during, and after data collection. The current lack of data on gender that our study demonstrates raises important questions for future research. This includes a need for more generalizable best practices for VR research, as well as a need for practical case studies developed with rigorous attention to how the data is collected, and who is represented by that data.

4.6.2.2 "No one verbally complained"

We noticed a pattern of little qualitative feedback being reported to contextualize participants' experiences. Some authors expressed a level of confusion when SSQ scores indicated high levels of sickness, but "no subject complained" (Asjad et al., 2018) (we find a similar statement in Usoh et al. (1999)). Asjad et al. (2018) state that it was difficult to assess the severity of symptoms, since "no one verbally complained." Short statements like this indicate that authors across our systematic review were not in the practice of including semi-structured, debriefing, or exit interviews. It also indicates that had they taken this step to solicit qualitative feedback, they may have been able to more accurately contextualize their findings using the verbal feedback collected.

In our review, we encountered essentializing claims regarding gender and the expression of cybersickness or discomfort in VR. We emphasize that the value in providing qualitative feedback from participants is not to add further anecdotal evidence to the "women are/are not more likely to express discomfort" debate, but rather to provide the information beyond what a questionnaire is capable of capturing. If the questionnaire (whether the SSQ or another measure) is adequately capturing the breadth of experiences, then this would not be necessary; however, given the number of open questions following this review, it is clear that this is not the case. Questionnaires like the SSQ tell us that people felt sick, but do not tell us how to *mitigate* that feeling. Supplementing quantitative measures with qualitative methods (not only interviews, but observational and other methods) can provide more detail on how, why, and when sickness is induced.

4.6.3 Additional Context: Troubling History of the SSQ

As discussed in Section 4.5, the Simulator Sickness Questionnaire (SSQ) was by far the most popular instrument for capturing experiences of cybersickness. The SSQ was published in 1993, and was derived using factor analyses on over 1000 records of the Pensacola Motion Sickness Questionnaire (MSQ) from United States Navy aviation simulator training data (Kennedy et al., 1993). The MSQ dates from 1968 (Graybiel et al., 1968), a time when women were not permitted in the naval aviation program where the measure was developed (they were not authorized for aviation training until 1973) ("Women's Policy: History & Firsts", 2005). The SSQ was validated with pilots over a 20-month period between 1988 and 1989 (Kennedy et al., 1993). There is little data accessible pertaining to women in naval aviation training at that time, but we do know that the representation of women and minorities in the naval aviation community ranged from 2-3% between 1992-1996, and that prior to 1993, the combat exclusion law limited the assignments of women in aviation (Uriell & Rosenfeld, 2011). As such, a generous approximation would be *at most* a 2-3% representation of "women and minorities" in the validation of the SSQ.[2] The SSQ is therefore designed to capture and represent the experience of simulator sickness overwhelmingly as expressed by men. Despite the pervasive references to gender differences in cybersickness in the sources we reviewed suggesting widespread acknowledgement of this phenomenon, the SSQ continues to be a standard measure. The time has come to ask: why? If it was clear in 1997 that simulator sickness and cybersickness were not the same, and that cybersickness was potentially more severe (Stanney et al., 1997), then it

[2] An unfortunate trend in military documentation from the time of developing these measures is a lack of participant data as would be the standard in modern publications, perhaps due to a shared understanding that at the time, cadets were men, and this would be reporting the obvious.

is decidedly *unclear* why the community accepts the SSQ as a standard measure for VR research to this day.

A recent review by Grassini and Laumann (2020) challenges the argument by Munafo et al. (2017) that the gendered disparities in HMD symptoms are sexist. In the section of their review evaluating simulator sickness in the context of VR HMDs, the authors categorized studies using the SSQ as a measure of participant symptoms (Grassini & Laumann, 2020), excluding those using alternative measures. From these studies, they included only those reporting a total SSQ value, and of the studies with pre- and post-test SSQ values, only *post*-exposure values were used. Cases with modified questionnaires were also excluded. Unsurprisingly, the authors did not find a gender difference in cybersickness in the majority of studies analyzed. An arbitrary focus singularly on SSQ data imposes a biased interpretation of what simulator sickness, or cybersickness, is. Excluded qualitative data tells us what the survey cannot capture. Post-test SSQ scores introduce further bias in only considering those who made it through the experiment. The problem is not with people, who can be conveniently replaced in experiments to maintain a certain sample size when others cannot finish the protocol: to use VR in the home, at school, or at work, you cannot call in and substitute someone with roughly equivalent demographic characteristics to take your place. The results from such studies are inherently biased. The problem is with the technology.

4.7 Recommendations & Limitations

Our systematic review revealed that there is a large amount of information and detail missing about how gender relates to cybersickness, and how to mitigate the cybersickness experienced by women. Our review calls attention to these unknowns, and the need to manipulate these variables to study them more in-depth. In this section, we provide some preliminary recommendations for future VR research. It should be noted that there is still a need for more generalizable best practices within VR research in HCI that take into account the realities of various sample sizes, budgets, etc. As more research and information becomes available on the relationship between gender and cybersickness, these recommendations will need to be modified and updated. However, these recommendations provide a much-needed step towards maintaining consistency, replicability, and effective VR research progression benefiting all genders.

Our preliminary recommendations include:

1. **Clear reporting of demographic characteristics:** Although we focus on the lack

of reporting around gender, it is clear that there is also a general lack of reporting around other demographic characteristics, such as race, ethnicity, and age. More detailed reporting and more diverse participant pools are necessary to ensure more representative and generalizable findings (Peck et al., 2020). In order to ensure that VR is safe for everyone, future work will first need to assess whether reports of gendered cybersickness are due to biological factors, social factors, some combination of the two, and/or misrepresentations due to a lack of data. Simply put, the underrepresentation of women as participants in VR studies Peck et al. (2020) calls existing theories into question.

2. **Broader considerations of gender:** Beyond representation, our survey reveals that there is an implicit lack of reporting around what is assumed (i.e., biologically, socially) about gender. It is incumbent on researchers and reviewers to develop considerations of gender beyond a binary, and to develop up to date practices of reporting on gender that does not essentialize and assume. Decades of feminist, queer, trans and other scholarship offers many examples of best practices, and more recently research in HCI offers domain-specific considerations (Scheuerman et al., 2020; Spiel et al., 2019). Importantly, these understandings of gender must come from within communities that are most impacted by the results, with greater care to work with and/or position them as experts of their own bodies and experiences. A lack of representation from authors to participants (Peck et al., 2020) can lead to biased findings.

3. **Clear reporting of drop-outs:** This includes the reporting of drop-out demographics (such as gender), at what point they ceased participation in the study, and the reasons as to why each participant dropped out (e.g., experience of cybersickness). Having adequate and detailed reports of drop-outs will enable future research to disentangle the relationship between gender and cybersickness, and elucidate underexplored factors related to more extreme responses. As ethical guidelines stipulate that participation is voluntary, in some cases it may be impossible to fully understand why some participants drop out of a VR study. It may also be the case that ethics protocols will specify that drop-out data must be discarded; due to the potential value of this data, there may be an opportunity to reconsider what aspects of the data can be included in cases where participants drop out due to cybersickness. This lack of data must be acknowledged, and should also be a reminder to develop practices to safely account for all experiences.

4. **Study design:** Participant exclusion criteria was not frequently stated in the papers we reviewed, which results in a lack of understanding of why some participants are not represented in research. Documenting exclusion criteria is especially important

to better understand who and what is considered from the outset. Due to the possibility of cybersickness, any study that uses VR must find ways to carefully choose a spectrum of measures that are sensitive to differences in experience. A one-size-fits-all model in system design or study design may not be adequate or inclusive. For example, because of the variety of factors that may cause cybersickness, researchers may need to carefully consider the duration of study conditions as it relates to average time of onset for symptoms (Moss & Muth, 2011; Saredakis et al., 2020), time buffers between conditions as symptom onset can occur within 24 hours of exposure (Stanney et al., 2002), as well as how and when they use between- or within-participants study design to account for adaptation effects (Duzmanska et al., 2018). Future research could provide more detail regarding the content and experimental setup, i.e., diagrams, source code, product information.

5. **Measuring cybersickness:** There was a wide variety in the type of measurements that researchers used to assess cybersickness. Differences across measurements can make it challenging to formulate concrete themes across diverse research areas, but these questionnaires show that cybersickness remains a clear and ongoing problem in VR research. At the very least, future research can make use of a validated cybersickness questionnaire like the SSQ, but also supplement it with qualitative data such as verbal feedback and report differences (and absence of differences) based on gender and other demographics. This is also an opportunity for researchers to critically reflect on the possible limitations of these methods and/or to ascertain whether newer measurements or validated questionnaires may be more appropriate. Nevertheless, documenting cybersickness among participants provides information that, while not always directly relevant to the primary research questions, relates to the broader issue affecting all research in VR. More work is needed to better understand both the onset and post-exposure effects of cybersickness.

A closer reading of the work presented in our review demonstrates that complexity introduced by the study design may limit researchers' ability to derive meaning from their data with regard to cybersickness, which in turn may make it more difficult to extrapolate findings for future work. An overarching recommendation for future research is to adopt an interdisciplinary view that strives to more broadly address some of the key concerns raised by our analysis. As VR impacts so many fields it may be increasingly necessary to search across disciplines to better acknowledge the work that has been done, and the work that still needs to be done.

4.7.1 Limitations

The limitations of our review are broad. Some of these limitations are due to the methodology of conducting the systematic review, while others pertain to the perspective we took while conducting the review itself. In this section, we discuss how the need to contextualize the work reviewed during this project came with its own constraints due to the irregularity in the data collected, and we address the challenges in filling in the missing gaps of the relationship between gender, cybersickness, and VR.

4.7.1.1 Limitations of our method/approach

Search bias In our methodology, we intended to select papers that had gender as part of their work. Our approach therefore creates its own bias within the sample of papers that we based our review on. For example, a number of papers had near-gender parity, but this is likely due to our choice of gender as inclusion criteria rather than what is representative of VR research more broadly. The same can be said of our inclusion of cybersickness and simulator sickness. As both cybersickness and simulator sickness were part of our search strings, a high number of the resulting papers therefore measured these concepts in some way. Compared to the CHI 2019 papers from our exploratory review, it is unsurprising that our systematic review yielded many more papers that were about cybersickness and/or simulator sickness.

Databases A meta finding related to our technique is in the instability of the databases themselves. Using the university library, with the same search string on the same day, would yield different results (in terms of the number of records). Library staff could only offer that the results not showing up were duplicates of the same records from various sources. Similarly, we had to adjust our search methods to suit different databases, and small changes would yield different results. This brought into the foreground the things that remain out of researchers' control when trying to collect data through systematic reviews, which we felt was worth reflecting on for other authors who may perform similar techniques in the future.

4.7.1.2 Limitations of our perspective

Our findings emphasize a lack of data with regard to the relationship between gender and cybersickness, and the lack of consensus and possible confounds in the way VR research is

reported. However, in our attempt to highlight these unknowns, we inadvertently reinforce the concept of binary genders through our focus on the comparisons "between" genders. The direct causes behind the potential difference between the susceptibility of cybersickness among different genders might not even be due to underlying biological differences. Research has noted that the true causes are still unknown, and although biological aspects such as hormonal cycles are a possible factor, as we discuss, there is still not enough evidence to validate these findings. There are also an abundance of other factors beyond gender that we are unable to address that face similar problems. For example, elderly participants are often excluded because they are also said to have an increased susceptibility to cybersickness compared to younger participants. However, there are still some studies that choose to include senior participants, and the relationship between age and susceptibility did not appear to have a clear consensus in our review. Similarly, race and ethnicity are often overlooked, and like gender there is anecdotal evidence that such demographic characteristics may also have an effect (e.g., Ji et al., 2009), though we stress that it is important not to extrapolate results based on limited findings. Lastly, participants with disabilities are often excluded from VR research. For example, locomotion studies in VR that involve a treadmill or walking around a room, might assume or require an ease of physical mobility. Additionally, low vision is a common reason for exclusion from VR studies (Smart et al., 2002). Each of these factors underscores the need for more diversity within participant samples, and to increase the demographic pool of participants as a whole within VR research.

4.8 Summary

Our systematic review is motivated by studies that report a gendered susceptibility to cybersickness across VR research. After conducting an exploratory review within CHI 2019 proceedings and papers, we conducted a broad, interdisciplinary review of research that comments on gender, cybersickness, and VR. Our work reviews survey papers as well as study papers, and we identified a number of confounding factors as well as under-reporting across categories with a direct impact on gender and cybersickness. We identified several gaps in the research pertaining to gender, as well as other demographics and factors such as dropout, exclusion criteria, and study design. We found that papers in our review primarily treat gender and cybersickness as a secondary aspect of their research and do not analyze the data or provide meaningful recommendations for mitigating the effects of cybersickness. Our analysis contributes insight into a decades-old problem in VR research, as well as preliminary recommendations for how to conduct future VR research. Our overarching

recommendation is that considerations for gender and cybersickness are important at every stage of VR research, from study design, to data collection, to analysis.

4.8.1 Chapter Contribution

The purpose of this chapter was to address **RQ2**: *What systemic barriers exist that prevent successful adoption of novel technologies to support the needs of diverse makers, and specifically women?* At the beginning of this chapter, I discussed initial explorations to determine how and in what ways different technologies could support unmet needs of marginalized makers. However, the accessibility of these technologies also needs to be understood to determine whether they are useable for marginalized groups: otherwise, we run the risk of further exclusion through inappropriate solutions.

In answering RQ2, I contribute **C4**: *Demonstrating systemic bias in virtual reality research that inhibits the HCI community's ability to develop equitable experiences.* Although virtual reality technology offers an excellent means to provide the types of experiences needed to support makers working on their projects, and more pertinently, to support social connectedness when they cannot meet, the technology remains biased in ways that disadvantage those who are already marginalized in maker communities. Through conducting a systematic review of the literature, I have offered guidance to HCI researchers using VR in their studies to prevent perpetuation of patterns of exclusion and erasure that are related to women having experiences that are at times physically intolerable.

4.8.2 Context in the Thesis

The knowledge gained in this chapter informs opportunities for design of VR for making and for makers. VR has already entered the world of making, and its applications for social interaction are already widely explored in HCI and CSCW research. This trajectory will continue, given major acquisitions such as Facebook's purchase of Oculus. In light of these findings, it is of utmost importance to begin the design process with the issues I have presented in mind: more descriptive reporting of who participated in the studies (and who did not); details around drop-outs; sensitivity to and inclusion of more accurate gender data; an awareness of how gendered cybersickness effects can be compounded through study design; and acknowledging that cybersickness is a major component of experiences in VR for many people, not just for women.

Cybersickness is not a challenge that will be overcome overnight; it is a complex, interdisciplinary issue. This does not mean that we should not begin exploring what VR

for makers could look like. As I describe in the chapter to follow, makeshift solutions to maintain social connections are not meeting the mark for makers at this time, and so the opportunity remains to work towards improving this experience. When we study VR for social connection in future work, it is necessary to build in the aforementioned considerations in study design, as well as building in design components like the ability to take breaks. Importantly, we must design in affordances that provide a *first-class* experience for people who are affected by the technology's current inaccessibility. This is in direct opposition to the rhetoric of "quitters" and "survivors" that we heard in systematic review papers, where people experiencing cybersickness were positioned as less-than. Instead, this would be an asymmetric experience for VR and non-VR participants who could participate using e.g., their desktop computer, and enjoy the same benefits.

Chapter 5

Making Technologies Work for Makers: Research and Design Guidelines

In Subsection 3.4.1, I identified pathways for designers to explore how to support improved autonomy, competence, and relatedness among makers. This came with an understanding informed by this work that foregrounding the maker community over the maker *space* would assist with informing possible solutions intended to benefit community members. Makers' relationships to physical spaces were a theme throughout our interviews, and comfort levels varied wherein an existing level of confidence allowed crafting groups to creatively overcome the limitations of their space, whereas in the STEM environment a willingness to negotiate space was hampered by unease around how their actions might be perceived by others. In essence, feelings of belonging facilitated a sense of ownership over their surroundings, or exerting actions indicating a sense of ownership served as a way to perform belongingness.

At the time of the initial research, physical space did not factor much further into analysis as this was seen to be a fixed, taken-for-granted aspect of how maker groups assembled. Of course, this all changed in March of 2020 with the first pandemic-related restrictions on public gatherings. Suddenly, the *environment* in the HCD model (Figure 1.1b) was removed, or rather, replaced by an unknown. How would these communities adapt? Would they adapt?

I foreshadow in Chapter 2 and illustrate in Chapter 4 the risks of hamfisted technosolutionism, particularly when working with marginalized groups. Newspaper headlines in the early days of the pandemic celebrated fab labs and hackspaces rapidly pivoting to 3D print

personal protective equipment (PPE) and specialized parts for ventilators. These groups represent the normative makerspace in line with the neoliberal libertarian ideology dominating hacker culture rhetoric (Toombs, n.d.), jumping to provide technological solutions themselves, displaying the simultaneous hedonization of technological production springing from the initial attraction to the *democratization* of technological production that these spaces offered (Tanenbaum et al., 2013). The gendered divide between making and craft might be construed as fading into the background in this frame, but it is still there. Sewing groups and crafters contributed to the effort by sewing masks, gowns, and ear-saving accessories for front-line staff needing to wear masks for long hours. This coordination took place through stereotypically feminized platforms like Facebook and was framed as care work, as grandmas with sewing machines "doing what they can."

Disregarding the problematic continuation of these narratives in the public discourse, what was notable to me after having spent extended periods of time among these communities was that nowhere in these narratives were makerspaces positioned as sites with value beyond an economic, productive value; the closest approximation was a brief discussion on the devastating impact of the loss of public library facilities to individuals experiencing homelessness and low-income populations. My observations confirm and extend to maker culture specifically what Akah and Bardzell (2010) had started to document, that is, that *making* itself constitutes part of people's identities.

People affirm their values and their identities by making marks in the world. Agency requires being an agent acting upon something, thus making is a process of enacting one's agency—and a particularly cross-cultural, historically embedded, traditional one. Losing access to maker groups precludes the ability to participate in those identity-affirming processes. Burt and Atkinson (2012) report on the relationship between craft and wellbeing, and I offer the additional angle of identity construction as an important component of that mental wellbeing, in addition to extending the applicability of these benefits to spaces framed in the narratives of maker or hacker culture.

In the remainder of this chapter, I provide more detail on my research with maker groups in a post-pandemic world, and its implications on designing for these groups. I weave this and the work leading up to this into intimations for a methodological practice seeking to foreground the aspects of relationality, identity, wellness, and care in research that is sensitive to, and working for, improved equity for its participants.

5.1 Purpose

This chapter serves to answer the research question: *What responsibilities, ethical and methodological, do we carry as designers and researchers looking to design, develop, or appropriate digital technologies with, in, or for maker communities?* In this chapter, I weave together reflection and looking forward to propose methodological guidelines for working with and for maker communities. It presents a messy reality of communities and individuals in a state of change. It shows them doing their best with what they have, a point of pride for makers worldwide. Viewing these spaces through the intersecting HCD lens and a methodological lens of action research (Hayes, 2011) also reveals tensions in the relationships between people, their making practice, and their spaces or communities, tied to the underlying politics and values of these communities which are entangled with the social, political, and economic systems in which participants are situated.

5.2 Participants & Methods

Between July of 2020 and April of 2021, I conducted observations and interviews in group and individual settings with members of a hackspace, a sewing group, and two game jams. During this time I also volunteered at a youth hackathon for high school students and at a game jam, and I took part in occasional virtual social hours where participants worked on their own craft projects. A total of 8 makers participated in interviews lasting on average one hour: three from the hackspace, two from the sewing group, and three from the game jams. Of these participants, four self-identified as women (1 hackspace, 1 jammer, 2 sewers), and four self-identified as men (2 hackspace, 2 jammers). None self-identified as gender-nonconforming or any further genders, nor did any participants choose not to share their gender.

The purpose of these interviews was twofold: to build on the themes in Chapter 3 by using a similar, slightly modified protocol, and to discuss how makers were coping with the transition to remote making. The latter aim was achieved through using the Brief COPE scale (Carver, 1997).

Brief COPE Inventory The COPE inventory (Carver, 1997) is a 28-item scale used to explore how a study participant has been coping with stressors in their life. The sample protocol for introducing the scale, as written by Carver (1997), is as follows:

> These items deal with ways you've been coping with the stress in your life since you found out you were (insert stressor here). There are many ways to try to deal with problems. These items ask what you've been doing to cope with this one. Obviously, different people deal with things in different ways, but I'm interested in how you've tried to deal with it. Each item says something about a particular way of coping. I want to know to what extent you've been doing what the item says. How much or how frequently. Don't answer on the basis of whether it seems to be working or not—just whether or not you're doing it. Use these response choices. Try to rate each item separately in your mind from the others. Make your answers as true FOR YOU as you can.

I have modified the above quote by adding *(insert stressor here)*, as the example provided has to do with undergoing an operation. The scale has been validated with a number of groups, such as breast cancer patients, and people recovering from Hurricane Andrew. Passmore and Mandryk (2020) have demonstrated the use of this scale in online contexts to explore how game players cope with instances of discrimination.

Participants respond to the questions on a scale of one to four, where:

1 = I haven't been doing this at all
2 = I've been doing this a little bit
3 = I've been doing this a medium amount
4 = I've been doing this a lot

Importantly, the scale does not provide an "overall" coping index or score. It also does not break into adaptive or maladaptive composites to describe how "healthy" a person's method of coping may be, or whether it is emotion- or problem-focused. The author of the original scale recommends looking at each subscale separately and how it might relate to other variables: the sample size here ($n = 8$) means that the scale served as a useful jumping-off point for discussions with makers, but I did not conduct statistical comparisons between subscales due to low power. The 14 subscales of the COPE inventory are listed in Table 5.1.

5.3 Insights

In this section I present a summary of the data collected from my research with remote makers, before moving on to discussions about how we can move forward to serve these groups. I position the data shared here as generative rather than summative, meaning that its intent is not only to provide a snapshot of the state of maker groups while displaced due to COVID-19, but also to advance our knowledge of, and explore opportunities for, supporting makers who may otherwise be marginalized by the infrastructures at play in the process of adapting to new spaces, both physical and virtual.

5.3.1 On Coping

COPE Subscale	Average Response	Standard Deviation
Acceptance (A)	3.7	0.4
Use of Instrumental Support (IS)	3.3	0.8
Planning (P)	3.3	0.9
Humour (H)	3.2	0.7
Use of Emotional Support (ES)	2.9	1.0
Self-Distraction (SD)	2.6	1.2
Active Coping (AC)	2.6	1.2
Positive Reframing (PR)	2.5	1.1
Venting (V)	2.4	1.0
Religion (R)	1.6	1.1
Behavioural Disengagement (BD)	1.4	0.5
Self-Blame (SB)	1.4	0.4
Substance Use (SU)	1.1	0.2
Denial (D)	1.0	0.0

Table 5.1: Results from the 28-item Brief COPE Inventory (n=8)

Per Passmore and Mandryk (2020), *discrimination* is a threat against individuals' inherent legitimacy and agency along social categories of identity, such as culture, gender, ability, age, and so on (Berjot & Gillet, 2011; Crenshaw, 1991). We affirm our identities by performing them (Butler, 1988), thus inaccessible opportunities preclude the ability to enact our selves. At the beginning of this chapter, I discussed making as an activity of making the self, that is, of constructing one's identity through participation *in* and making a mark *on* the world. Hence my initial reaction and primary concern for makers during the pandemic was that the inability to continue in making-as-usual would be emotionally detrimental based on what I had learned and seen in Chapter 3. As this can be classified as a denial of identity—and a positively affiliated sense of self—the potential negative impacts would align with those associated with discrimination, spanning impacts on mental health, physical health, and behaviour (Krieger, 1999; Luthar, 2015; Pascoe & Richman, 2009). These effects are, of course, compounded to those already culturally or historically marginalized.

In general, makers responded fairly consistently to the COPE inventory, although its use was complicated by the compounded events of losing access to their maker groups

because of the pandemic. They reported constructive ways that they were coping with stressors, including continuing to engage in making projects at home when possible (e.g., P7, P8).

Figure 5.1 displays results from participants differently from what was presented in Table 5.1, in that it separates out responses by participant gender (men and women, as self-reported by the participants). In this view, we can see that women are leaning more heavily on acceptance, humour, venting, and planning, whereas men are leaning more on self-distraction, and use of emotional or instrumental support (while also showing high levels of acceptance). Maker groups are a place where all of these things can occur, satisfying people's unique needs differently through social connection and engagement in activities. Seeing the differences in how women and men approach coping in this limited sample lends support to the arguments in Chapter 3 that an inclusive, supportive makerspace culture should not follow a "one size fits all" model: not only should they provide ways to pursue autonomy, competence, and relatedness, but they should also provide the context for emotionally healthy engagement based on the contrasting needs of individuals as shown here.

My assumption when discussing coping in these interviews was that we would be discussing makers' relationships with making itself. In particular, if making provided a sense of stability and comfort, then was it a healthy relationship to lean on during a time of uncertainty? Were they able to *use* making at home as a way of coping with outside stressors (the pandemic) that were out of their control? For makers that depended on physical spaces for access to tools, materials, and working on larger projects that were not possible within the home, what would the impacts be for them? This, I hoped, would lead to identifying further opportunities to incorporate technology to support the act of making, as well as bolstering the argument that specific sensitivity and care should be paid when working with maker groups, given the role that making plays in their well-being.

What I heard from makers, however, was that continuation of *making* was not a major concern as once thought—what was most impacted by remote work, and where the sense of loss was acutely felt, was the sense of social connectedness previously afforded by gathering in the physical space. I had conceptualized this portion of the research as exploring the convergence of *Task* and *Environment*, but as ecosystems do, underlying connections in this system had been brought to the surface that are not so easily captured in a simple diagram: this problem is very much a *Human* one, and thus pulls our focus into the centre of the original diagram of my research space, illustrated in Figure 5.2. In the sections to follow, I discuss what opportunities and challenges this presents for researchers, designers, and practitioners in maker groups themselves.

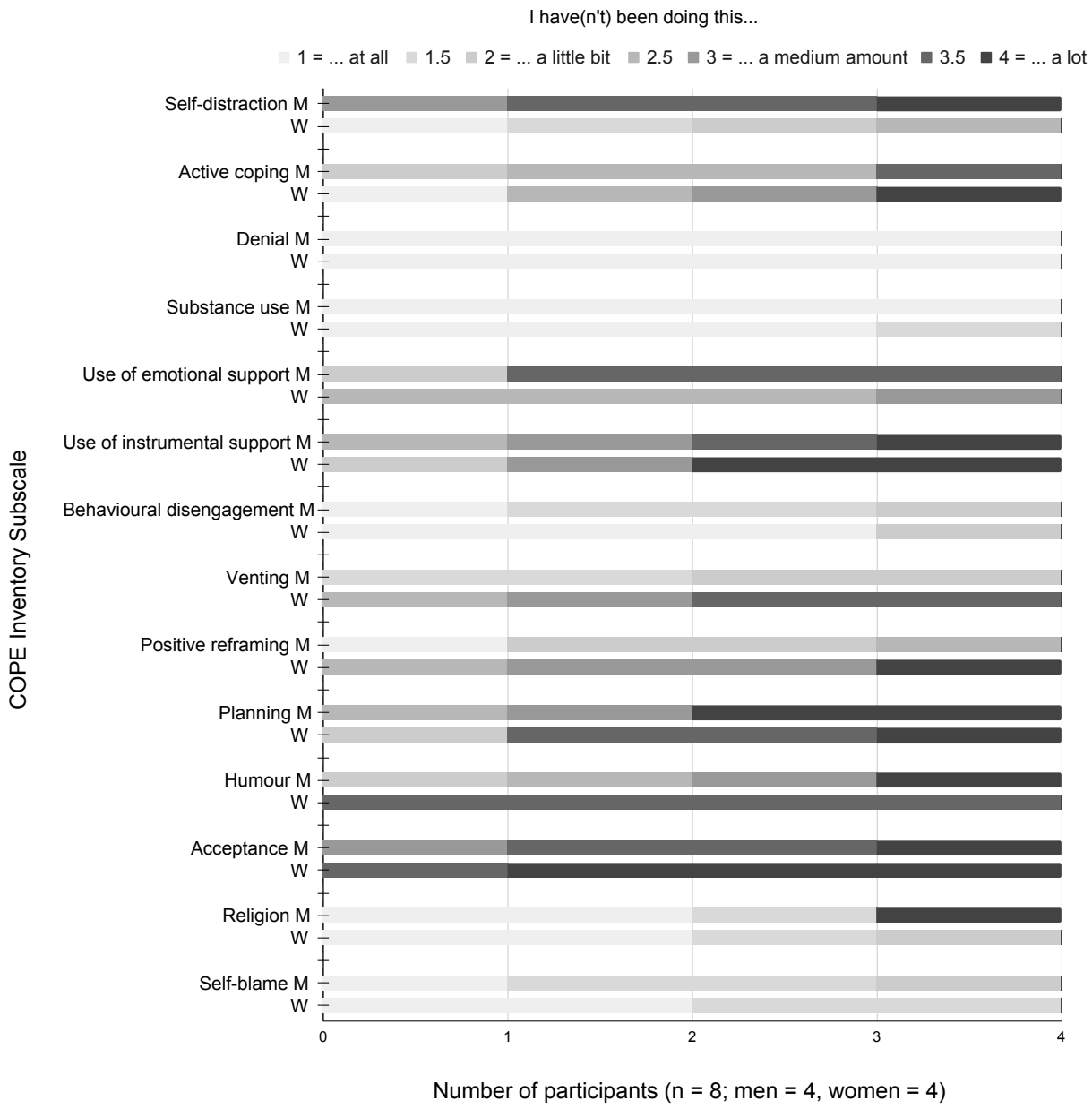


Figure 5.1: Responses to the COPE Inventory compared by gender across each subscale. Each subscale has two questions, so each score is an average of those two responses.

5.3.2 Limitations

In this chapter, I heard from a more diverse variety of makers than in Chapter 3, in terms of their geographic dispersion, the size and composition of their groups, and their groups' interests. However, these groups all reflect a sampling bias in that they had managed to adapt to meeting online, in one way or another. I did not hear from those groups that had tried, struggled, and/or failed to migrate to a virtual environment: reflections on their experiences, needs, and efforts would provide the perspectives of those who have effectively been marginalized through no longer being able to access their communities and exercise their maker identities in the group setting.

5.3.3 Summary of Findings

The exploratory nature of this work was to better understand the relationships that people had with making itself: how were they coping with limited access to their maker groups? And, in the bigger picture, how did making factor in to how they were coping with the global pandemic: had their attitudes or behaviours towards making changed? As it turns out, this research turned to *adapting* over coping: a major challenge for these groups in adapting to changes in working remotely was the maintenance of the communities themselves. Groups were affected differently based on the inherent privilege and politics of access to infrastructure based on the composition of the group's membership, compounding existing social inequities brought to light by the pandemic. These engagements with makers were rich and served to surface tensions between mak*ers* and mak*ing*: when the ecosystem of human, task, and environment shifted, it supported my earlier findings (Chapter 3) in showing that the overall health of the community is related to the well-being and support of its members. Given the insights from this new context, I describe opportunities in the research space applicable for researchers and designers in HCI and CSCW to support makers towards improving equitable outcomes of these communities.

5.4 Opportunities for Design and Research

5.4.1 Introducing technological solutions

Historically, epidemiological research shows that health, well-being, social power, coping, and identity are highly interrelated or inseparable (Krieger, 1999; Pascoe & Richman, 2009). These relationships are also highly contextual. As such, a maker's ability to cope

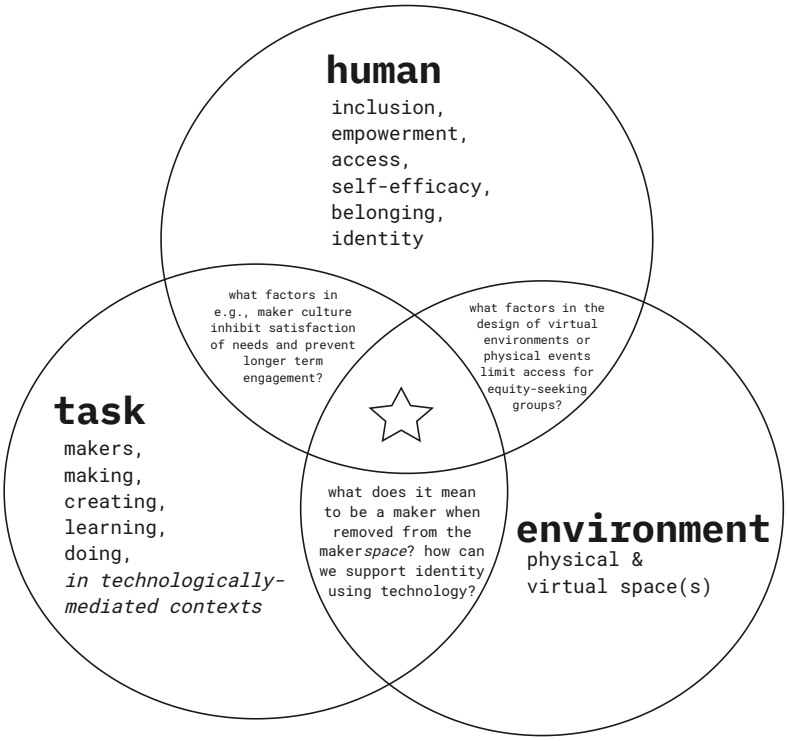


Figure 5.2: A shift in the role of Environment in the HCD model highlights the need to consider the intersection of all three elements

with a shift to remote making, thus avoiding the potential negative impacts of these changes in access, are tightly coupled with concepts like social power and privilege. For example, due to their position of relative privilege, P3 described the shift to working online as a non-issue, because their workplace made available Zoom teleconferencing licenses which could be used to host their weekly meetings virtually. In contrast, P5 describes a more labour-intensive process of identifying an online platform that would meet the needs of their group. The ethos of hacker culture had influenced its own set of requirements to seek out a tool that supported the principles of open source development, and that reflected a counter-culture to corporate Zoom-ification (and a rejection of surveillance capitalism).

Recent research on collaboration using augmented reality (AR) demonstrates how such technologies can be used to balance inequalities due to dominant peers or unequal access to resources (Radu et al., 2021). Using VR is an attractive choice to address feelings of social

presence: P2 has ceased attending their group's socials because the online solution was frustrating, rather than satisfying, the need to connect. However, as discussed in Chapter 4 this technology comes with its own (gendered) issues. In the same way, the hacker ethos that influenced the choice of the platform Discord for P5's group meant that the gendered politics of that culture was ported in with the tool: P1 reported having previously enjoyed their weekly socials, but now that they are online, it is not possible to choose who you can and can not interact with—in the physical space, it was possible to walk to different areas, or walk away from people.

As demonstrated through these examples, the impacts of technology choices can occur across intersecting or compounding axes of identity such as gender and class. Designers looking to introduce technologies to support these communities need to be aware of the exacerbation of existing inequities that can occur based on these underlying currents of privilege and oppression.

5.4.2 Infrastructuring maker groups: For stakeholders

Providing two separate sections of advice for researchers and for organizers of maker groups perpetuates an ongoing problem that feeds into a divide between these groups. In order to create more equitable infrastructures for maker groups, I highlight the need for tighter coupling between these two sets of stakeholders that have investment in these groups, whether these investments are research or practice-related.

Given the increased interest in the HCI research community in makerspaces over the past several years, it was challenging to build trust and gain access to maker groups, both for the purposes of this chapter and for the research presented in Chapter 3. In fact, P5 shared a story that due to a market research firm having gained access to maker groups by masquerading as doctoral research, a number of hackspaces had decided to officially cut off any further involvement with research, legitimate or not. This leads to inequities in who gets to research these spaces as well: social or professional connections, as well as "looking the part" both played a role in my personal success making connections with certain maker groups. Researchers are not exempt from the politics of privilege even when that is what they set out to study, and thus statements of positionality can help to situate what was learned from which standpoint.

Harrington et al. (2019) explore more deeply the challenges researchers and communities face when that trust has already been damaged through inequitable research and design engagements, where academics take but do not give back. What Harrington recommends are quick turnaround times, immediate outcomes, and real tools to prevent research

abandonment. In the context of maker groups, this means ongoing relationships to improve outcomes for all stakeholders by iterating and receiving feedback, in turn, increasing buy-in and mitigating the distrust stemming from researchers coming in, extracting information, using makers' time, and having nothing to offer in return. Research abandonment compounds feelings of isolation that I discuss below, caused by other barriers to resources that would empower maker groups.

Access to research In fact, researchers already have access to a number of answers that makers seek. One group reported challenges in generating a Code of Conduct to be adopted by their group, due to loud dissent from a few existing members concerned about "tone policing" and "freedom of speech." (Meanwhile, the group had lost several women who had felt uncomfortable in the space due to a lack of such a policy.) The corpus of HCI and CSCW literature documents examples of successful, diverse models of makerspace organization, but they are shrouded in keywords and jargon, hidden except to those knowing to look in the ACM Digital Library or Journal of Peer Production, and are locked behind paywalls. Again, power and privilege will impact who gets to benefit from the fruits of our academic labour if we do not build into our praxis to deliver results that are useable *to* makers themselves, in a reasonable timeframe. Through a feminist care ethic approach to research I advocate for this notion of reciprocal uplifting.

Access to each other When I asked in interviews whether maker groups were associated or affiliated with other like-minded groups, the answer was no. A lack of networking between maker groups introduced another barrier should they want to work from successful examples or share their experiences. The impression is then given that they are reinventing the wheel when this is not necessary. To continue with the same example, a Code of Conduct is not new nor innovative. What makes them *feel* complicated are the existing power dynamics within a group and how public narratives of "democratization" and a DIY ethos can be weaponized by in-group actors to imply that a step towards a more inclusive culture necessitates a step away from the (counter-)cultural foundations of the group. There is an opportunity in CSCW research to explore how maker groups currently connect and how these systems are, or are not, working for them. There is power in numbers, and a concerted effort among makers to put forward more progressive policies will be backed by confidence and support if they know they are not acting in a vacuum.

Access to infrastructures In a demonstration of infrastructures as politics, participants pointed to existing foundations that exist to "support" maker communities but not for the

purposes of learning or sharing as mentioned above. These groups, like the FabFoundation[1] have an appearance more akin to multi-level marketing schemes. P5 said that the choice to name their group a hackspace was likely a factor in it having a narrower appeal, but was under the impression that calling it anything else would require membership to one of these larger foundations. For example, the FabFoundation has certain requirements for what equipment should be available in order for a space to call itself a Fab Lab. In order to be a Fab Lab, not only do you require the funds to purchase said equipment, but lab managers should be trained at Fab Academy at a cost of around $5000 USD.[2] Requirements like these run counter to the definition of a makerspace as was developed in Chapter 3, as one defined by the presence of makers, people performing making. They gatekeep who counts as a maker and who does not. They foreground the branding reflecting the economic framing of making, as opposed to supporting communities by connecting them to learn from one another.

5.4.3 I Want to Believe: UFOs for Design Futures

A privilege of working with a variety of maker groups was getting to know their own vernacular. When I first heard the term "UFOs" among quilters, the group shared a knowing look and a sly smile. Then, one took me to a closet to show her collection of UFOs: unfinished objects.

In that context, UFOs were both a point of pride and of embarrassment, but giving them their own nickname made them a peculiar, ever-present, beloved part of quilter culture. Objects may be unfinished for a number of reasons: you didn't like the pattern, the colours weren't working out, you lost interest, you started another project instead, you got bored—there is no end to the list of reasons why something might become a UFO. As in any makerspace, projects are undertaken for different reasons, and producing a polished outcome need not be the main goal. As was discussed in Chapter 3, a fixation on the product limits the possibilities for rich outcomes from taking part in the process. Rosner and Fox (2016) focus on the legacy of craft and the centrality of failure in creating more feminist spaces, and in this section I return to this idea of reframing failures (subsubsection 3.4.0.2) for empowerment.

When interviewing remote makers, I began to probe *the ideal*: irrespective of any practicality, feasibility, or realism, how would you ideally want to engage with your maker group now? Going forward? However, makers often would get hung up on the things they had

[1] https://fabfoundation.org/

[2] https://fabacademy.org/apply/fees.html

tried to do and that had failed, or on aspects of the social or cultural realities that would inhibit these dreams from being realized.

I believe, and makers believe, in a more equitable future for their spaces. However, they don't always know quite how to get there, and face challenges of access to research, other groups, and infrastructures as highlighted above. Adding to this, each group has specific, situated needs, and makers' ability to imagine the role that technologies might play varies. For this reason I embrace the UFO as an accessible means to ideate possible futures for maker communities. Rather than trying to imagine something perfect, something that will work for every member in the group, something future-proof, the UFO acts as one slide in a flip-book, a part of an exquisite corpse, one patch in a quilt.

In using the UFO as praxis, my goal is also to side-step embedded inequities in the history of participatory design (PD). For example, even though PD was first positioned to balance dynamics between designer/researcher and participant(s), Harrington et al. (2019) discuss how "blue sky" approaches to ideation can be exclusionary to communities that have historically faced systemic discrimination: engaging in design processes without constraints can then exacerbate existing inequities by leading to infeasible solutions that frustrate those who are already underserved. It also seeks to address some of the concerns that come with using PD approaches with participants that have different values and perspectives, associated with age and diverse standpoints, as evidenced in Lazar et al.'s (2021) study of the formation of an older adult-led makerspace. This is important to consider as the makers throughout this thesis represent an incredible range of identities.

5.4.3.1 UFOs in Practice: Speculative Making

Throughout this work, I have pointed to ways that technology could be incorporated to support more equitable making environments, while also pointing to limitations (big and small) along that path. Makers themselves have limited what they conceive as possible futures due to the situated politics of space and place and their relation to social institutions. Braybrooke and Smith (2020) discuss how liberation from these webs of contingencies and context will require resisting the urge to meet in the middle at an acceptably "neutral" makerspace idea, rejecting the worry of agitating the normative group. This opens up the opportunity to enact justice through writing one's own futures. Through sharing UFOs within or across maker groups, and patching them together where they connect, we begin to see a theoretical quiltwork of commonalities in the goals and aspirations of these communities. What is necessary as a part of the discursive process with UFOs is identifying what parts are left out, and why. Below, I compose a few UFO scenarios to demonstrate possible futures towards more equitable making using VR.

- Sandy, an HCI researcher, makes a meaningful contribution to her field by extending the literature on VR and making, since it currently exists primarily in non-HCI venues, e.g., applications for education. In doing so, she designs a VR application to support remote making, since whether or not there is a pandemic, there will always be people who cannot physically access the space: thus, she frames her contribution in terms of accessibility and supporting social wellbeing, two areas that are underexplored for makers, especially in HCI.

- Betty is looking forward to meeting with her quilting group soon. She puts on her VR headset and is transported to a familiar scene, with the group sitting on couches around a coffee table, all working on their own quilt blocks. Lauren suffers greatly from cybersickness and so she joins them, too, using her laptop where she is also able to hear, speak, see, and move freely, to be equally included in this weekly ritual with her friends.

- Mellissa is passionate about game development and wants to take the leap to participate in her first game jam, to meet other game developers and to challenge herself. However, she doesn't know where to start. Thankfully, the jam organizers have gone above and beyond after they read a 2019 CSCW paper suggesting that to support women interested in participating they should help to address worries about familiarity with the space, worries about skills being "enough," and knowing how to connect with people ahead of time. She puts on her VR headset to get a virtual tour of the space and... *crack*. Mellissa is Black. The "flexible" headpiece on this commercial HMD does not accommodate her hair. Instead, she navigates to the 3D virtual tour hosted online on her desktop computer, so she can avoid looking like she's lost when she arrives on the first day.

These UFOs are written as samples to demonstrate what they might look like as part of a larger ideation process where participants write their own stories, and stories for their own spaces. Following up on these through reflective exercises is necessary to discuss what is *not* there as much as what is there. From there, we can also work to understand the things that groups feel are so insurmountable that they opted to leave them out of the UFO (hence, it is unfinished). We also are able to envision what a world would be like were those barriers are removed. Using the *what is not* (the reality) as a starting point, and *what could be* (the UFO), researchers and participants can begin mapping opportunities for improved equity in makerspaces and virtual reality.

5.4.4 Limitations

In Subsection 5.4.3 I proposed a method to push forward stalled conversations around imagined, equitable futures that was inspired both by the unfinished objects shared across the maker groups studied, as well as alleviating concerns around producing an "ideal" or "finished" product that comes along with purposeful speculation. My future work includes workshopping this method with different makers, including those who *have not* successfully migrated to a virtual environment, and iterating on the procedure over time.

5.5 Summary

In this chapter, I described research conducted with maker groups during the COVID-19 pandemic, when making together in person was not feasible. In doing so, I uncovered a tension between makers and the relationship to making: that the loss of the makerspace was not as severe a loss as the connection to the maker group itself. I discussed what implications this has on opportunities for introducing technologies to support makers, and considerations for research in this space moving forward. I adopt a concept from the early stages of my research and, in the spirit of maker culture, re-appropriate it as a methodology, using the UFO to map opportunities for improved equity in makerspaces and VR.

5.5.1 Chapter Contribution

The purpose of this chapter was to address **RQ3**: *What ethical and methodological considerations do we have to take into account as human-computer interaction researchers when working to design, develop, or appropriate digital technologies with, in, or for maker communities?* To begin answering this question, I probed more deeply the connection between making and identity, to explore what making means to makers particularly when they lose access to the maker space.

One outcome of this exploration is **C3**: *Unearthing tensions between maker/making and an elevated importance of social connectedness.* In other words, these findings expand the research space for those seeking to research or design for and with maker groups. I have positioned supporting the social community for makers as a matter of wellness, given the role that making plays in identity. As such, I emphasize the need for researchers to exercise care and recognize their position as part of the making ecosystem. I embrace

the culture of experimentation and failure in proposing the UFO method for community-based participatory research with maker groups (**C5**), as a means of empowerment through speculation and leveraging the DIY spirit of these groups.

5.5.2 Context in the Thesis

The knowledge presented in this chapter paints a picture of maker groups when they are removed from the makerspace. Once distributed, it is possible to see infrastructures that might otherwise have been invisible limiting factors in these groups' ability to proceed towards more equitable engagements. I have also shown how in adapting to remote making, implementation of new tools for connection have caused the cultural politics of these technologies to come with them—with their own implications for how welcome makers feel in these new, virtual spaces. Thus the exclusionary elements of these tools compound for makers that were already marginalized in their groups. Given the limitations identified around access to research, access to other maker groups, and access to appropriate infrastructures, it is a challenge for maker groups to become empowered to make prosocial changes even when the motivation is there.

The embedded contexts of history, culture, society, and politics are all undercurrents creating tensions in how makers, and maker groups, see their futures. The UFO technique seeks to liberate from these limitations by allowing makers to do what time and time again seems to hold them back: leaving things unfinished. Not looking for polish. Not compromising. They are both utopian and messy, and intentionally so. I look to a future where constellations of UFOs will provide the kinds of real-world scenarios needed to inspire and drive forward research to make virtual and physical spaces more accessible to all.

Chapter 6

Conclusion

In this chapter, I provide a brief overview of the contributions of this thesis and their overall relation to addressing the three broad research questions posed in Chapter 1. These research questions were:

RQ1. What can we learn from gender-imbalanced maker groups in order to support the diverse needs of makers in STEM-focused environments? To answer this first question, I present a study in Chapter 3 that eschews socialized or gendered connotations of what is and is not a makerspace, instead focusing on the common goals and structures of two genres of maker events that inhabit the spaces of game development and craft, specifically quilting.

RQ2. What systemic barriers exist that prevent successful adoption of novel technologies to support the needs of diverse makers, and specifically women? In tandem with determining how and what technologies could support unmet needs of marginalized makers (as per RQ1), it is necessary to identify how appropriate these solutions are: are they useable? Are they accessible? Or do they bring with them their own set of embedded biases? VR technology presents this very issue, and is explored in Chapter 4.

RQ3. What ethical and methodological considerations do we have to take into account as human-computer interaction researchers when working to design, develop, or appropriate digital technologies with, in, or for maker communities? In Chapter 5, I reflect on the changing nature of maker communities in response to the

global environment, and the changing relationships between makers, making, and their communities. The relationship of the researcher is implicated in this dynamic, and I offer a methodological approach to help these communities move forward, together.

To address these research questions required a range of approaches, and the scope of my research is presented in Chapters 3, 4, and 5.

In Chapter 3, I addressed **RQ1**: *What can we learn from gender-imbalanced maker groups in order to support the diverse needs of makers in STEM-focused environments?* I presented the results of a study that focused on the common goals and structures in maker groups that were dominated by male and female participation, respectively. In doing so, I found that narrower ideas of what constitutes "passing" as a maker in the STEM-oriented environment limited opportunities for makers to achieve their goals, goals which were every bit as diverse as those found in the crafting environment. Accordingly, I recommend maker groups—if and when possible—consider why people might be engaging along the axes of autonomy, competence, and relatedness (and associated themes therein) to determine in what ways their events might support or be conducive to those goals.

To allow for the kind of thinking that will help us to look beyond something as a makerspace/not-a-makerspace to explore new opportunities to support maker communities, I contributed **C1**, an expanded definition of what a makerspace is (subsubsection 3.4.0.3): one that is metaphorical and defined by makers at a grassroots, rather than a top-down level. To support this way of thinking, I also prioritize using language like *maker group* over *makerspace* to foreground makers as individual agents that, together, form communities. In Subsection 3.4.1 the themes of the research coalesce under three buckets highlighting the need to support makers' self-determination. In doing so, I contributed **C2**: *Identifying new ways to support makers' diverse needs using technology.* The lenses explored here serve to support the psychological needs of makers to increase their satisfaction in the long term.

In Chapter 4, I addressed **RQ2**: *What systemic barriers exist that prevent successful adoption of novel technologies to support the needs of diverse makers, and specifically women?* At the beginning of this chapter, I discussed initial explorations to determine how and in what ways different technologies could support unmet needs of marginalized makers. However, the accessibility of these technologies also needs to be understood to determine whether they are usable for marginalized groups: otherwise, we run the risk of further exclusion through inappropriate solutions.

In answering RQ2, I contributed **C4**: *Demonstrating systemic bias in virtual reality research that inhibits the HCI community's ability to develop equitable experiences.* Although virtual reality technology offers an excellent means to provide the types of experiences needed to support makers working on their projects, and more pertinently, to support

social connectedness when they cannot meet, the technology remains biased in ways that disadvantage those who are already marginalized in maker communities. Through conducting a systematic review of the literature, I have offered guidance to HCI researchers using VR in their studies to prevent perpetuation of patterns of exclusion and erasure that are related to women having experiences that are at times physically intolerable.

In Chapter 5, I addressed **RQ3**: *What ethical and methodological considerations do we have to take into account as human-computer interaction researchers when working to design, develop, or appropriate digital technologies with, in, or for maker communities?* To begin answering this question, I probed more deeply the connection between making and identity, to explore what making means to makers particularly when they lose access to the maker space.

Through this exploration, I contributed **C3**: *Unearthing tensions between maker/making and an elevated importance of social connectedness.* I expanded the research space for those seeking to research or design for and with maker groups. I have positioned supporting the social community for makers as a matter of wellness, given the role that making plays in identity. As such, I have emphasized the need for researchers to exercise care and recognize their position as part of the making ecosystem.

One way to enact this care and use a researcher's positionality as one towards liberation and justice is to employ new methods of design futuring. To this end, I contribute **C5**: *Taking C1-C4 into account, using a design futures approach to inform a methodology for working with maker groups.* To reflect the researcher's position as a custodian of care, a stakeholder, and a part of the makerspace ecology, I re-appropriate the makers' concept of unfinished objects, or UFOs, as a method to speculate and co-create possible futures for more equitable engagements at the intersections of making and technology.

Throughout this research, a consistent theme was optimism and gratitude. Makers are resilient, adaptable, collaborative, curious, and vulnerable, too. The knowledge shared in this dissertation is used to map out new paths and opportunities for using technologies to push back on the systemic biases that lead to exclusion, and demonstrates how using a feminist lens can help HCI researchers to avoid compounding exclusion through technosolutionist approaches that bring their own biases. Taking part in this ecology of makers, technologies, and both physical and virtual spaces implicates the researcher as an agent of change—using this research, change for the better.

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