Handmade Future: A Field-based Inquiry of Innovation through Making and Craft

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**Abstract**

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This project analyzes the impact of mediated discourse on the skills, materials, and tools of innovation through a multi-method, three-part study of "making" practices— a growing method of Do-It-Yourself technology design that engages students, hobbyists, and experienced engineers in the building of technological artifacts outside of corporate hierarchies. Making integrates material skills (e.g. sewing, woodworking) and digital fabrication tools (e.g. 3D printing, laser cutting) to produce physical prototypes. These hybrid forms of construction hold significant promise as an inclusive method of innovation, acting as a pathway for women's participation in technology design. However, if public conceptions of making neglect the contribution of craft and handwork, the potential for innovation will be reduced. This project contributes to existing

scholarship in communication and science & technology (STS) studies by elucidating the mechanisms through which media produce symbolic value for technology industries and technology practices. Across this three-part project, I argue that when we expand popular narratives about the tools and practices of technology production, opportunities are also expanded to recognize the diverse contributions—both presently and historically—of people on the peripheries of STEM communities.

First, this project identifies the values and ideals of innovation that are created through public discourse about making; paying specific attention to the material practices that are framed as central to innovative work. In my thematic analysis of *Make:* magazine and its short-lived sister publication *Craft:* magazine, I identify both making and crafting as activities that are meant to transform the world through hands on, material engagement. However, I argue that makers and crafters take significantly different points of intervention – with makers innovating through disruptive products and crafters innovating through subversive processes. Second, this project identifies the influence of media discourse on the practices of makers through one year of field study in a university makerspace located in the Pacific Northwest region of the United States. Through ethnographic observation, I develop an empirical understanding of how hands-on construction is leveraged as a wellspring of innovative thought. I describe two central ideals of maker learning – Doing It Yourself (DIY) and the power of tools – and how they contribute to idea generation, prototyping and technology design. However, I argue that there are limits to these ideals, especially when the power of tools fails to connect the practices of soft (textiles, fabric) and hard (electronics) materials. Third, this project uses a collaborative design workshop to intervene in media discourse and broaden public conceptions of innovation. Through exploring an understudied moment of engineering history, these workshops provide an opportunity for participants to build experiential understandings of technology production. I argue that through incorporating methods of design, communication scholars can build new, feminist histories of innovation—helping to address issues of representation in the absence of remarkable personal narratives.

*For my dad, who made me a maker.*

*And for Sam, who makes me so happy.*

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Being (nearly) finished with a PhD puts you in the surprising position of being asked for advice about getting a PhD. My answer to almost any question is the same: *mentorship is everything.* Looking back over my time in graduate school, I have been so *so* lucky to be mentored by advisors and colleagues who have helped me grow as a scholar, at every step and new start along this path.

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**Handmade Future: A Field-based Inquiry of Innovation through Making and Craft**

Every surface in the University of Washington "CoMotion" makerspace is covered in tools. There are workbenches with vices and soldering irons, and a bank of glossy white Macintosh computer monitors. On a wire rack, a dozen 3D printers hum quietly as they pull from spools of brightly colored filament. In the "ideation station"—a seating area meant for brainstorming—a table is barely visible under a sheet of butcher paper and a spread of loose color pencils. There are laser cutters and sewing machines. There are racks of tiny compartments filled with screws and capacitors, and a pegboard hanging straightedges and hammers.

CoMotion is just one of an estimated 1,400 active makerspaces in the United States, supporting 135 million adult "makers" (Bajarin, 2014; Lou & Peek, 2016). Part art studio, part computer lab, part woodshop—makerspaces are an open area where potential innovators can share knowledge, learn new skills, and access expensive and regulated tools they wouldn't have at home. Among the many promises of makerspaces—increased innovation, collaboration and creative thinking—is the challenge of including women in these activities. At stake, is a generation of potential innovators. As Anne Balsamo (2011) observes "those who engage in technological innovation are designing the culture of the future." In makerspaces, people aren't just *using* technology, they are learning to invent technology through their tinkering. This means that those who can substantively participate in these spaces are building the ability to design objects that reflect their experiences, perspectives, challenges and goals.

Making is a deliberately expansive term: a verb that includes all types of creation and construction. In makerspaces, the practices used by makers draw on varied traditions; from open-source computing cultures to "low-tech" artisan communities (Hunsinger & Schrock, 2016; Rosner & Fox, 2016). Though incorporating a wide variety of tools and skills, it's hoped that makerspaces can empower people of all types to repair, tinker with, and invent new technology. Academic institutions across the United States are building makerspaces as a means of exposing a wider range of participants to the fundamentals of science and engineering. Despite these inclusive ideals, maker communities are still plagued by the same gender disparities that characterize technology fields as a whole (Faulkner & Mcclard, 2014).

Through a focus on the skills and tools of making, this project considers the material challenges faced by women in Science, Technology, Engineering and Mathematics. Attempts at broadening women's participation in technology design have largely operated from liberal feminist perspectives that focus on equal access as the key to ending gender imbalance in the sciences (Rosser, 2005). This is especially evident in makerspaces, where administrators are confident that no-cost, open door policies remove the most significant barriers to women in technology design. Yet, my field research indicates that the enthusiastic narratives surrounding the expansive possibilities of making are accompanied by a lack of clarity about how they can be realized. On one hand, making offers wider access to the tools of technology design and production. On the other, the potential of the spaces remains inaccessible to those who cannot meaningfully integrate their knowledge into the routines and toolsets present in makerspaces. Technology design is intensely reliant on genres of knowledge: types of expertise that have been dominated by men through historical divisions of labor (Wajcman, 2009).

How are the practices of makers shaped by the stories we tell about innovation—the accounts, both contemporary and historical, of technology design processes and accomplishments? Science and technology studies are characterized by close attention to the contingent nature of scientific ideals, paying particular notice to the negotiated actions of the scientists and technologists who contend with these ideals in their daily work (Daston, 2009).

Yet, sociologist Pierre Bourdieu (1993) argues that research into fields of production must look beyond structures and practices within the field, to the symbolic production of the field itself. That is to say: how does communication *about* the field create professional boundaries and shared understandings of what it means to participate in the field? With this project, I widen the scope of inquiry into innovation culture. I look beyond the observable behaviors of innovators, and bring attention to how the value of innovative activities is produced externally—through public commentary and media writing. Communication provides a methodological tool kit for analyzing the mechanisms of field delineation, to understand how technological tools and practices become valued contributors to innovation or merely peripheral hobbies.

**Making Matters Work**

On a November morning in 2016, the Higher Education Makerspace Initiative convened the first ever, international symposium for academic makerspaces. Going by HEMI (spoken aloud as one word), the organization's name recalled the high-performance engine. A hemi is powerful. It makes things move. The symposium had been convened to "rapidly and broadly infuse makerspaces" in universities and colleges. I was observing as a part of my fieldwork, based in the makerspace on my university campus. Seven of HEMI's eight board members were mechanical engineering professors—hailing from prestigious private universities such as Yale and Stanford as well as public engineering powerhouses like Georgia Tech and UC Berkeley. Educators, administrators, and researchers all gathered together in a lecture hall on the Cambridge campus of the Massachusetts Institute of Technology (MIT). Just inside the doors was a bazaar of tables promoting digital fabrication tools from symposium sponsors Tormach, Shopbot and Othermill.

The symposium's keynote speaker was Dale Dougherty, publisher of *Make:* magazine. Dougherty's talk was focused on making as a driver of innovation in education. But, he opened with a brief reflection on history. He discussed Tim Berners Lee and the origins of the World Wide Web, and Richard Stallman and the free software movement. These technology communities had an ethos of "openness, transparency and collaboration" that he wanted to bring to physical world. With his business partner, Tim O'Reilly, Dougherty founded *Make:* magazine to apply the values of open source software to hardware. Even the magazines name was inspired by a Unix utility. Taking this perspective, making was a practice predicated on electronics, computers and hardware.

Dougherty's keynote was a narrative that I accepted as an obvious truth at the beginning of this project. The tools and material practices he emphasized in his trajectory were also emphasized at my fieldsite – an academic makerspace focused on supporting innovation – and in the most widely available media accounts of making. In publications such as *Forbes* and *Fast Company,* the business press celebrated making as a form of self-motivated, entrepreneurial innovation (Upbin, 2008). To them, makerspaces held the potential of transforming local skills into business enterprises (Tierney, 2015). With an overarching focus on the capacities of digital fabrication tools, those conversations draw on a perspective popularized by Christopher Anderson (2012) in which making represents "the next industrial revolution." Digital fabrication machines like laser cutters, 3D printers and CNC milling machines blend traditional fabrication tools like saws and routers with digital automation and computer software—giving inventors direct access to the tools of design and the tools of manufacturing. Despite the expansive activities that could be represented by a term like making, texts such as *The Maker Movement Manifesto* closely aligned the practice with digital fabrication methods. After the manifesto's imperatives of "share" "give" and "learn," makers are instructed to "tool up" (Hatch, 2014). Digital fabrication tools dominate the beginning of the equipment list.

However, as I became immersed in maker culture, it soon became difficult to identify any singular lineage as the basis of the maker movement. Early issues of *Make:* (and it's short lived sister publication *Craft)* made little mention of digital fabrication, instead focusing on the possibility of innovation through material, hands on work. Ten years before Dougherty gave his history of *Make:* at the academic makerspace conference, he'd been on the cover of *Forbes* celebrating the "Do It Yourself Revolution." In his interview, he described *Make:* as emerging from a wider cultural moment in which there was renewed attention to DIY. This included electronics-based communities of computing and hacking—and an upwelling of crafting, re-cycling, up-cycling, mending, modifying, repairing and artisanal creativity. The early issues of *Make:* and *Craft:* magazine often acknowledged they were part of something much larger and more diverse, in gender and in practice, than only open source software[1]. Yet, by 2015, the dominant narratives that informed my understanding of making had hardened around digital fabrication tools as the driver of innovation.

What might be lost when understandings of innovation fail to include tools and practices outside of computing and engineering? Craft knowledge has played a foundational role in computing innovation. It provided the metaphors that created the first computer algorithm (Lovelace, 1992) and the design of the first software program (McMillan, 2015). Both of these accomplishments drew on craft expertise—leveraging the skill sets associated with textile production, historically feminine work (Barber, 1994). Like making, craft is a broad and contested field. Popular conceptions of craft involve the artisanal and the handmade. Yet,

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[1] Around the time that *Make:* was first published, a survey was conducted that found only 1.1% of developers in Open Source computing were women (Ghosh, Glott, Krieger, & Robles, 2002)

scholars have argued that craft isn't oppositional to industrialization or machine-driven processes (Adamson, 2013; Pye, 1995). Richard Sennett (2008) defines craft broadly through the quality of work. "Craftsmanship" is a thoughtful and skilled transformation of objects. Common to these understandings of craft is material engagement. With this in mind, my attempts to definitively separate "craft" from "making" become increasingly difficult. Where are the boundaries between craft and making? What value is attached to these terms? How are they marshaled in institutional visions of innovation – and what conditions of possibility do they enable or preclude?

This project answers these questions through an interdisciplinary approach that combines interpretive, empirical, and design methodologies in a three-part research study. First, through a evaluation of media accounts of "making," I trace the themes, tropes and narratives that frame contemporary understandings of invention and its associated tools, practices and participants. Second, I examine the impact of how making is framed, through observation and interviews with a range of people who have an investment in making: students, university administrators, STEM professionals, tinkers and hobbyists. Triangulation between texts, conversation, and observation makes it possible to build a holistic understanding of the mechanisms by which media narratives have material outcomes—producing visualizations and ideals, which impact the choices and strategies of technology builders in situ. Third, this project explores the capacity for feminist design methods to tell new stories about invention. Focused on an underexplored aspect of engineering history, this portion of the project invites makers, designers and historians to a workshop that intervenes in media narratives that often elide the contributions of craft to the innovative thinking, not to mention skillful making, associated with high-tech work.

**Sociomaterial Analysis of Innovation in Making.** Technology innovation work is a complex interplay of social and material forces (Pacey, 1983). For designers and makers, actions are shaped by the availability of tools and materials—as well as an actor's skills and knowledge. Science and Technology (STS) scholars have consistently argued that studying technology requires analyses that can account for the inseparable nature of material objects and human action (Hughes, 2004; Orlikowski, 2009). Understanding how technologies are produced requires examining the "beliefs and circumstances" of creators and users, as well as the physical design of artifacts (Lievrouw, 2014). This project advances this agenda by broadening the objects of sociomaterial inquiry in studies of innovation—beyond high-tech computation, to consider the vital and constitutive role of craftwork in invention.

In particular, this project focuses on the innovation work performed in academic makerspaces. University based makerspaces are part of a larger movement in American education to create a better and more prepared scientific workforce. As a training ground for applied engineering, makerspaces work to address the scientific "skills gap"—a dearth of people who have the education and skills needed for engineering professions (Hanc, 2017). In universities, computer science and engineering students flock to these spaces. They collaborate across disciplines and mechanical, electrical, and chemical specialties. They work in teams to build aerospace or biomedical prototypes for course assignments and research assistantships. Yet, many makerspaces on college campuses are specifically designed to be "open-access," welcoming students regardless of major. Students from across the humanities and social sciences are given access to tools and lab space that would ordinarily be off limits to students outside of STEM majors. Here, they learn digital skills and are exposed to scientific concepts—with the hopes of building the creative thinking that is wellspring for invention. By inviting more people into the world of scientific tools, makerspaces aim to make more scientific thinkers and inspire more scientific innovations.

Makerspaces have the capacity to bring diversity to the scientific community, offering opportunities that may help address the persistent gender and racial disparities that plague STEM fields (Landivar, 2013). Borrowing a term from basic chemistry, one respondent in my pilot research referred to experiences in makerspaces a kind of "activation energy"—the initial spark required to create transformation. Influenced by the constructivist ethos, administrators believe that these types of positive experiences are an opportunity for people to overcome their entrenched beliefs about their own scientific aptitudes (Papert, 1980). While institutional narratives often focus on makerspaces as a method of engaging a greater "diversity of thought" (as opposed to diversity defined through the identities of participants), I bring an attention to gender equity as implicit in this aim (Jandhyala, 2017). Based on what I've observed in the multiple domains that inform this project, I believe that greater gender inclusion in making will require moving beyond a patriarchy of practice to building meaningful connections to women's modes of creation, which are routinely undervalued.

## Three-Part Research Design: Production, Reproduction, Intervention

With empirical data from ethnographic observation and interpretive data from textual and historical sources, this projects produces an in-depth understanding of the material practices essential to what feminist media scholar Anne Balsamo calls "technological innovation culture" (Balsamo, 2011). In techno-cultures of innovation, groups of people collaborate in order imagine and produce new technologies. With the project, I look beyond evaluations of ideation strategies to consider 1) the role of media narratives in shaping conceptions of innovation in the American public 2) the reproduction of media narratives by the material practices of budding technology designers 3) interventions into media narratives using a guided, feminist design workshop. This reciprocal framework allow me to see how media impacts innovation culture, but also the way that innovative industries are cultural in themselves (Hesmondhalgh, 2007).

**Chapter 1 - Production: Social Construction of Making**

In the most basic sense, making is a practice: it's something people do, a form of action (Couldry, 2012). Yet, practices aren't just comprised of activities but also ways of thinking and talking about those activities. Communication scholar Robert Craig (2006) defines a practice as a "coherent set of activities that are commonly engaged in and meaningful in particular ways, among people familiar with certain kinds of culture" (p. 38). Practices are made of skills and techniques: actionable and particular ways of doing. But, more than that, the discourses around an activity—the expressions of norms and established standards—make it meaningful. Both interpersonal and media discourses contribute to the meaningful frames built around particular technological practices.

Science and technology (STS) scholars working from a social-construction of technology perspective have demonstrated the many ways that the social world shapes our understanding and use of technologies (Bijker, 1997; Kline & Pinch, 1996). Media, such as newspaper reports and advertisements, "educate the public" about the potential applications and proper functions of new technologies (Fischer, 1992). In doing so, these discourses help establish the norms of use that later appear self-evident. Within emerging technology industries, media discourse helps to legitimize new industrial structures (Gregg, 2011; Marwick, 2013; Neff, 2012). And, they distribute expertise within industries—framing different practices as legitimately technological (Marvin, 1988) or creative (Banks, 2009) along lines that are often gendered.

Studying media publications aimed at Do-It-Yourself electronic hobbyists is a window into the narratives that have framed digital practices since the introduction of the first programmable computer. Making, in particular, has been defined by the "intellectual infrastructure" of magazines, meet-ups and online forums (Morozov, 2014). *Make:* magazine has both captured and helped to define a high-tech, innovative, and economically valuable vision of making. *Make:* is often credited with coining the term makerspace (Cavalcanti, 2013). However, some makers see *Make*—and its publisher O'Reilly Media[2]—as simply capitalizing on a community that existed independently. As one participant explained: "*Make:* is a brand embedded in the movement they claim to have started."

In this chapter, I trace the emergence of the maker movement through early issues of the flagship publication, *Make:* magazine. *Make:* begins in a larger cultural moment in which cheap electronics, environmentalism, hacking and crafting were all flourishing. These influences combine to create an understanding of "making" that is based in repair and modification. Dominant discourses about innovation often emphasize novel inventions and the origins of artifacts, while overlooking renewal and recombination (Jackson, 2014) Yet, the formative issues of *Make:* magazine embed repair and modification practices within innovation, ultimately presenting them as a source of new ideas. I argue that *Make:* depicts a disruptive vision of innovation, in which hands-on work is a method of engaging users in thinking beyond the limits of industries. I then move to discuss *Make:* magazine's sister publication *Craft:* magazine. *Make:* and *Craft:* differ considerably in the mindsets they encourage. The crafter's vision of innovation is more akin to "making do" than how contemporary discourse defines "making." I argue that *Craft:* depicts a method of challenging the boundaries that separate craft from technology making—while also opening opportunities for insight and critique of industrial production

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[2] In 2013, *Make:* was split off from O'Reilly Media to form an independent brand (Make Media) headed by Dale Dougherty (O'Reilly, 2013). For consistency, I refer to O'Reilly Media as the publisher of *Make:* throughout this project – as O'Reilly was the publisher of *Make:* during the volumes that comprise my primary dataset.

processes. These commitments emerge *from* crafters material engagements, which are windows into how things are made and how things could be made better. Visions of making that don't include craft also fail to include the profound critical thinking that can emerge from material engagement. The crafters mindset becomes the source of a responsible approach to innovation, accounting for the at times destructive impact of productive activity.

**Makers in the Media Data Set.** The "Makers in the Media Data Set" is made up of the first twenty issues of *Make:* magazine and all (ten) issues of *Craft:* magazine. In 2005, at the burgeoning of making as a phenomenon, technology publisher O'Reilly Media began producing *Make:* magazine. It ran as a standalone publication for two years, before *Craft:* was introduced in 2007. Importantly, the last issue of *Craft:* was published in 2009—narrowing one of the central voices of the maker movement to the types of DIY displayed in *Make*, rather than *Craft*. The data set covers the entirety of the *Craft:* archive and all issues of *Make:* that ran during the time *Craft:* was being published. Additionally, the data set includes the first two years of *Make:* – prior to the publication of *Craft:* – and the final two issues of the 2009 year.

Each issue of *Make:* and *Craft:* magazine follows a basic structure similar to other magazines: front, feature, and back. Issues are between 150-200 pages in length. The front of the magazine contains editorial columns by regular contributors and profiles of makers or crafters. The middle feature section contains three to five featured projects. These are usually referenced on the cover, and contain significant full-page images and deeper storytelling. The back contains about a dozen instruction sets: DIY tutorials ("Make Cool Stuff!"), primers ("Soldering and Desoldering") and catalog-like reviews of tools. The back also contains a series of reoccurring one-page project reflections.

Analysis was performed on the first four issues of both *Make:* and *Craft:* magazines in their entirety, about 1600 pages in total. This set represents the first year of issues for each magazine, which was published quarterly at the time. For subsequent years, I focused on the front and feature content. This was a strategic choice. The profiles and columns in the front of the magazine focus on exemplars – or "alpha makers" – that acts as models or ideals. One of the primary aims of *Make:* is to act as a showcase for these exemplary makers[3], so that amateurs could learn from observing them. Publisher Dale Dougherty writes in the inaugural issue "becoming a maker is a lot like learning how to be a better cook – you can follow or improvise on the work of experts" (Make, Volume 1, p. 7). Expert figures often directly discuss the practices and perspective that define making and crafting. Through their personal narratives, alpha makers declare their perspective on the value of creating and thinking with materials. The featured projects then put these ideas into action.

Analysis of the Makers in the Media Data Set was conducted using grounded theory to identify emergent themes, tropes and narratives (Charmaz & Mitchell, 2001). Thematic analysis traced the figures, technological lineages and associated types of knowledge that depicted as central to making. Data coding was guided by questions about the patterned depictions in maker media: How does one participate in making? Where does making occur? Who is considered a maker? Using these questions, I performed "constant comparative" coding across the texts (Glaser & Strauss, 1967, p. 101). Simply put, constant comparison utilizes a process of open coding, re-coding, and memo writing to produce categories. The themes I identified were used to

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[3] The editorial process for the content of *Make*: and *Craft:* meant balancing the "alpha maker" with amateurs, enthusiasts and beginners. Primarily, the editorial team wanted activities that average people could actually do. For example, in an interview I conducted for this project, editor of *Make:* Mark Frauenfelder described an elaborate process of in-house testing when they received submission to ensure their feasibility.

produce a cultural history of making—demonstrating the way technology innovation processes are the product of specific contexts and socially defined (Gillespie, Boczkowski, & Foot, 2014).

**Chapter 2 - Reproduction: Enacting Maker Ideals**

Although popular narratives often depict invention as the product of a geniuses and light bulb moments (Isaacson, 2015; Johnson, 2014), in reality innovation is both socially situated and incremental. Innovation occurs through "collective activity" (Becker, 2008)—within organizations and through the repetition of industrial practices. Practices are not idiosyncratic human actions, but rather part of a repertoire (Couldry, 2012). Media work practices are especially reliant on routines and are particular to groups of people (Bechky, 2006; Dunbar-Hester, 2014). Attention to making practices illuminates the entwined nature of the social and material; the way that the prototype one makes is bound up in the skills they know, where those skills come from, and the materials they have available.

Cultural production perspectives offer a way of studying technological artifacts through analyzing the individual actions and institutional arrangements that produce them (Havens, Lotz, & Tinic, 2009; Kellner, 1995). Developed by communication scholars, this perspective draws heavily on sociological field studies which see cultural work as a balance of forces—as makers consider their creative possibilities and institutional constraints (Bourdieu, 1993). Creative possibilities are constrained by cultural value and by the availability of information. The discourse around innovation, and makerspaces in particular, shape these notions of value and frame the practices young people use to design technology. A production study of makerspaces surfaces the possibilities and limitations available to budding technology designers. How does the prominence of digital fabrication enable some users and constrain others?

In this chapter, I explore the CoMotion makerspace: an on-campus organization seeking to broaden participation in innovation through access to tools. The CoMotion makerspace has a unique institutional arrangement and is overseen by the university department responsible for managing commercial endeavors produced from university research. Here, hands-on construction is seen as the initial step in innovative thought. I identify two central ideals of maker learning: Doing-It-Yourself (DIY) and the Power of Tools. I describe how DIY and access to tools contribute to idea generation, prototyping and design. However, I argue that there are limits to these ideals, especially when the power of tools solely lives in digital fabrication. Through failing to connect expertise in hard (hardware, electronics) and soft (textiles) materials, the makerspace misses significant opportunities for interdisciplinary collaboration and innovation – the ultimate goals of the makerspace.

**Fieldwork in Academic Makerspaces.** The social life and practices of makers was "investigated, experienced and represented" using a combination of field research methodologies (Emerson, Fretz, & Shaw, 2001, p. 353). Interviews were used to gather in-depth data on the perspectives of makers and those responsible for encouraging making in an institutional context. Participant observation was used to provide a complete picture of making practices, allowing me to witness activities that occur at this particular site, even those that didn't seem important to participants and worth reporting in interviews (Hesmondhalgh & Baker, 2011). The field research data was placed alongside the textual themes from the "Makers in the Media" data set, providing a comparative context for understanding what is observed during fieldwork. Put simply, blending these methods allowed me to ask: what is it that people say about making, and then what is it that they do?

Field research data was produced through long-term, situated research in which I observed making in its natural setting: makerspaces. Through the practice of participant observation I was be able to record the "everyday practices" of makers—their ways of doing and modes of operating (de Certeau, 1988). Participant observation allowed me to go beyond the realm of language to observable demeanors, attitudes and actions (Hesmondhalgh & Baker, 2011). Fieldwork is especially well suited for developing a deep understanding of work: both the complexity and the routine aspects of actions, knowledge and skill (Smith, 2001).

This project is based on one and half years of participation observation at the CoMotion makerspace at the University of Washington. This space is self-described as "a collaborative innovation hub." Observation began with a pilot period of three months, shortly after the space was opened in autumn 2015. I continued observation between winter 2016 – winter 2017. During this time, specific attention was paid to a weekly event called "Crafting & Making" that was instituted in order to involve more women in the space through expanding the thematic focus of workshops to include craft-based forms of making such as sewing, beading, and paper circuitry. Across the more than two year time span I observed the space, I witnessed both how the concept of "making" was initially instituted in the space as well as how this concept has evolved over time.

Academic makerspaces are a key place to observe how people produce technology *and* how ideals like "innovation" and "entrepreneurship" are reproduced through education. Schools are a primary site where cultural values about work are institutionalized and passed on (Willis, 1977). Situated in the technological hotbed of Seattle, Washington—home to Microsoft, Amazon, and a Google campus—the University of Washington's "CoMotion" makerspace is a local context for me to observe a national phenomenon. Research here engaged me in observing a specific community, imbedded in the technological world where I operate. Furthermore, the University of Washington has a unique institutional arrangement that explicitly dedicates the space to developing innovation. In additional to the previously discussed promises for STEM education, the makerspace at the University of Washington is seen an opportunity to generate lucrative patents. The space is embedded in the center for commercialization, which handles the rights and management of all intellectual property produced at the university.

Qualitative field data was produced through ethnographic fieldnotes and subsequent in-process memos (Emerson et al., 2001). These notes were guided by an attention to the tasks performed by members of the space, how their design activities were organized, and how their design outcomes were evaluated. Analysis utilized grounded theory and was informed by process theory—a focus on “the particular context within which participants act and the influence that this context has on their actions” (Maxwell, 2013, p. 30). Rather than focusing on variables, this perspective identifies the processes between people, situations, and events and how they influence each other. In using this perspective, I sought to understand how the context of the makerspace influences the act of making technology. Fieldnotes were supplemented by material documents and ephemera collected throughout the research period, in the form of event flyers, postcard collateral for visitors, and the instructions and packaging for prototyping materials.

Participant observation was supported with informal interviews with 50 makers, makerspace mentors, and administrators. These interviews were performed using an active interview method, that utilized a process of open “main questions” expanded and evolved with participant responses (Holstein & Gubrium, 1997; Rubin & Rubin, 2012). Interview protocol was in the form of an interview guide, which followed a flexible order and adaptable phrasing (Lindlof & Taylor, 2011). Opening questions included information about the individual’s educational background and fabrication background: what is/was your major in college? How did you learn to sew/weld/use graphic design software? Then, we talked through the fabrication process for the project they're currently working on: what tools did you use? How did you select them? The interview progressed to more conceptual questions, asking the participant to describe what a makerspace is, what activities typically occur there, and how a makerspace may or may not differ from others sites of making (e.g. art studio, wood shop). Lastly, I asked about their familiarity with and perceptions of the maker movement.

Additionally, I conducted four in-depth background interviews: three interviews with makerspace employees who significantly contributed to the organization of the space and one interview with an administrator at CoMotion Headquarters. Because it is funded by the university's center for commercialization, the CoMotion makerspace is embedded in a complex institutional structure that oversees intellectual property generation and commercialization for the University of Washington. Informal interviews were also conducted with both the current and former Operations Manager of the CoMotion makerspace. The objectives of makerspace administrators were contextualized within media reports from the local Seattle technology press and the CoMotion website.

The particular case of the University of Washington was understood through site visits and observation at a broader network of academic makerspaces and craft spaces that provided context for shared themes and comparison. This included observations at:

- The multi-university conference The International Symposium on Academic Makerspaces (iSAM), at the inaugural meeting in 2016 (Boston, Massachusetts) and in 2018 (Palo Alto, California).

- The Institute of Making at the University College of London and an informal interview with their MakeSpace manager.
- The Invention Lab at the University of California, Berkeley as a visiting researcher.
- The Textile Arts Center in New York City, New York and informal interview with their Director of Operations.
- The Vintage MakerSpace in Tucson, Arizona, a makerspace that engages in “pre-electric” forms of making.
- Participating observation at a meeting of the The Mended Way in Seattle, Washington a repair workshop.
- Two workshops hosted by visiting designers, Hannah Perner-Wilson and Irene Posch. Perner-Wilson and Posch are central figures in the academic movement integrating craft with making.

**3 - Intervention: Making Through Craft in Innovation History**

Communication and media studies contribute illuminating and underutilized frameworks for analyzing the social world of science and technology. Understanding the enacted practices of technologists requires an understanding of how these practices are given meaning—the mechanisms by which they become valuable and legitimate, or merely peripheral. Media discourse shape public perceptions of how innovation takes place and who participates in innovation. Rather than treating these as separate perceptions, this project considers how definitions of technology production are entwined with opportunities for participation in technology fields.

The third component of this project challenged existing narratives around technology production by recording and enlivening an underexplored moment of innovation history through a critical fabulation workshop. Developed by my collaborator on the workshop, Daniela Rosner (2018) “critical fabulation” is an analytic technique that occurs alongside acts of building, creating and repair. This portion of the project considered how collaborative acts of making attune researchers and participants to the social and institutional relationships that are materially entwined with technology design. Through interacting with artifacts and processes from the technological past, participants gathered experiential insights about the way artifacts “inhabit” organizations. Technology is a product of organizational processes, decisions and practices that shape their final form. And, technology also sets organizations “into motion”—building networks of labor required for developing, producing and maintaining innovations (Daston, 2004).

As the previously described textual and field research components demonstrate, innovation discourse has the power to shape the activities of innovators. Here, I intervened in that process. This workshop—titled *Making Core Memory*—extended my focus on making as a brand and cultural phenomenon to consider making as a means of critical scholarship. Historical moments of engineering can act as a reflexive mirror, to consider and intervene in contemporary technological culture. *Making Core Memory* built upon inquiries into maker organizations (e.g. maker media and makerspaces) and then engaged artifacts in critical fabulation to expand understandings of gendered technological production.

In this chapter, I present the case study of the Apollo Guidance Computer’s woven core memory, a history that is told through a collaborative weaving workshop. In an appeal to the tactics of design, this critical fabulation opened an indeterminate past to illuminate the networks of labor called into the being by technological artifacts. As a method of intervention, making became a means of interactive storytelling – producing the narratives for broader publics that communication researchers see as essential for challenging ideologies (Jungnickel, 2015; Sayers, 2016). Rather than simply reading scholarly accounts of the Apollo Guidance Computer, participants were given an opportunity to experience the labor processes that transformed software code into hardware. I argue that these methods can also build new, feminist histories of material practices—helping to address issues of representation in the absence of remarkable personal narratives.

**The Case of the Apollo Guidance Computer.** Using a creative combination of participatory design methods, *Making Core Memory* explores one of the most significant engineering accomplishments in modern history: The Apollo Guidance Computer. Building the Apollo Guidance Computer (AGC) required the invention of a compact and highly reliable form of information storage—essentially producing the worlds first portable computer (McMillan, 2015). The solution was a technology called "core rope memory." Core rope memory uses wires running through and around magnetic ferrite core to create the 0s and 1s that make up binary code (Mindell, 2008). The method used for manufacturing core-rope memory was extraordinarily similar to weaving. Women sat on either side of a metal matrix loaded with ferrite core. They passed a needle, threaded with wire, through the cores in the pattern of the software code. The Apollo engineers jokingly called it the "LOL Method"—for the Little Old Ladies who did the work (*Moon machines*, 2008).

Handwork is often considered traditional, thus antithetical to modern computing. Yet, the woven wires used for Apollo were not a quaint work around, they were the right tools for the job. The threaded patterns minimized the number of circuits used, the number of components that were used, and "packed them as tightly as possible" (*Computer for Apollo*, 1965). Through highlighting weaving as a means of technology making, participants began to expand the repertoire of skills they consider to be technological. Histories of innovation look different when the definition of technology changes, remaking contemporary understandings of the people and practice that are essential to innovation.

**Making Core Memory Workshop.** The *Making Core Memory* workshops engage makers, designers and technology historians in creative acts that counter widely held assumptions about who and how one participates in technology innovation. In this workshop, participants collaboratively wove a "core memory quilt." Each participant received a kit (called a "core memory patch") that contains a loom, beads and yarn that are symbolic of the ferrite cores and wires used in the original form. Participants performed a weaving practice that is similar to that of core memory production. Completed patches were placed on an electronic quilt, made of fabric, conductive thread, and an Arduino micro-controller. Placing the patch on the quilt triggered a recording of historical information about the core memory weavers from engineers who worked on the Apollo Guidance Computer.

To date, the *Making Core Memory* workshop has been held five times with over fifty participants. Workshop participants have been from a variety of communities: technology historians, critical librarians, design educations, and information scholars. Importantly this workshop was also held at the University of Washington "Maker Summit" in direct conversation with the research site of my fieldwork. These participation figures reflect workshops in which I've been present. As a collaborative project, the *Making Core Memory* workshop has been held a total of eleven times, with over hundred participants, hosted by different configurations of our research team.

## Making and Communication Studies

The making of technology isn't only a question of communication because there is a communicative element—i.e. media representation—depicted in communication mediums like magazines and news reports. It's a question central to the discipline because these activities build the hardware and devices that act as the intermediaries that make communication possible: computers, broadcast technology, and telephones. Wilbur Schramm, often credited as the founding father of the discipline, defined communication as the "relationship built around the exchange of information" (Schramm, 1983). This project expands the scope of Schramm's definition beyond considering the human relationships built around the exchange of information, to also consider the material relationships humans engage in while constructing media technologies that enable information exchange.

Feminist scholars of technology remind us that understanding the design processes through which technology is made is essential for understanding the capacities of technology, the values it embodies, and its role in the social world. As Lucy Suchman (1994) observes: "the design of technical systems is … an inscription of knowledges and activities into material forms." Furthermore, beyond being merely reflective of culture, technology is made through material culture. Metal, clay and fabric are material. They are the raw stuff that artifacts are made of. Yet, what they become isn't simply determined by the material capacity to be soldered, molded or sewn. What is being made is always shaped by the skills and knowledge of the maker—and these are products of larger socialization processes, which encourage and inscribe values into tools and processes.

The promise of making, as an inclusive method of technology design, is bound up in our ability to recognize it as a deeply gendered practice. Discourses that separate making from craft do so through aligning craft with a set of materials and methods – namely the "soft" domain of fibers, fabric and thread[4] – that are historically associated with women. Craft becomes easily identifiable as a gendered practice. Alternately, making remains seen as all encompassing and "gender neutral." As is the case in many realms, the masculinity that is continually embedded in making becomes invisible (Kimmel, 1993). It becomes the default. This means that discourses that celebrate *making* are continually distributing value to *a particular subset of making activities* – namely hardware and electronics. Today, at least, these activities are socially coded as male.

The entwined nature of gender and craft contribute to a deeply felt ambivalence about craft practices, especially for women makers. For example, in Sarah R. Davies (2017) foundational book *Hackerspace: Making the Maker Movement,* her chapter on exclusion in makerspaces almost immediately addresses the controversial position of electronic textiles practice within maker communities. As the term indicates, electronic textiles (or "e-textiles") combine circuitry with fabric-based techniques, such as sewing. Davies writes that while some makers positioned e-textiles as a method of inclusion in makerspaces, others felt e-textiles "essentialize women as uniformly interested in (and only competent at) particular, 'softer' technologies, rather than things like coding, metalwork or electronics" (p. 99). Davies' analysis rightly brings to light the real limitations created by boundaries and binaries that confine the contributions of women to a single set of material practices. Yet, the discussion of e-textiles also surfaces the way that being associated with craft may diminish women's credibility within maker culture. As one maker wrote, attempts to increase women's participation through craft activities are a situation where their "knowledge and capacities are undermined." (p. 93). At times it seems

[4] The understanding of fiber as soft and electronics as hard is itself a gendered binary, with solder being soft when hot and modern carbon fiber being ten-times strong than steel ("How to knit a sports car," 2019).

that it is craft that genders makers, reinforcing the marginal status of women in a culture where they are already underrepresented. I worry that the rejection of e-textiles is based, at least in part, in a desire to distance one's work from anything thing that is seen as a peripheral alternative to the core of technology innovation.

As social historians of technology demonstrate, the value of work is intimately connected to both *who* performs that work and perceptions of *what* the work requires. In his article on the gendered cultures of computing professions, Nathan Ensmenger (2015) illustrates a trajectory for computer programming that begins with low-status labor performed by women and ends with high-status labor performed by men. Programming was initially feminized labor. It was considered repetitive, routine, and soon to be automated. Yet, as programming increased in importance and pay, it was reframed as creative and challenging (Ensmenger, 2015). Similarly, Mar Hicks (2016) observes the way that even the concept of "technical skills" changed in gender association during the early history of modern computing. Originally, it was women who performed programming tasks. Programming was technical work, defined in opposition to the intellectual and creative work of designing systems. As software programming became more highly valued, technical skills did too, and technical jobs were reassigned to men (Hicks, 2016). The social histories by both Ensmenger and Hicks are clear case-studies of the way that *communication* about technology work produces a gendered system of value for essentially the same practices.

With my project, I analyze the way that communication distributes value across a range of material practices, ultimately constraining the creative possibilities for budding technology designers. The peripheral position of craft limits makers to electronics-based materials, practices, and mindsets that are easily recognizable in contemporary culture as contributors to technology creation. However, this is at odds with what I identify as the underlying project of making—as an expansive intervention into prescriptive, formal modes of innovation and design that are limited to traditional immaterial engineering and the generation of intellectual property.

Across my sites of investigation, proponents of the maker movement celebrate making as a wellspring for innovative thinking and innovative ideas. Rather than arising from a particular skill set – say, knowing the fundamentals of circuitry – innovation ultimately arises from hands-on material interaction. It arises from Doing-It-Yourself. In *Make:* magazine, DIY is positioned as an orientation to the material world in which the objects of everyday life can be modified, upgraded and transformed. In the academic makerspace community, DIY is positioned as an alternative to exclusively theoretical ways of building knowledge. Taken from these perspectives, innovation results from working with your hands and working with physical things, and those engagements are not limited to merely hardware. One can really engage in this way *with anything*. Yet, the discursive move that separates making from craft also positions craft as outside of Do-It-Yourself activity, separating craft from innovation. This division has an enormous consequence for *who* is seen as an innovator, and *whose material practices* are counted as valuable wellsprings of innovation.

Throughout the chapters that follow, an attention to craft within making brings to the foreground of my analysis a set of participants (women) and a set of practices (based in "soft" materials) that are persistently defined as just outside of dominant definitions of making. Taking craft as an object of study also attunes my analysis to the qualities of craftwork (e.g. repetition) that feminize labor across techno-cultures of innovation, and making in particular. I use a three-part structure that first traces how definitions of making are *produced* – through media texts – and then *reproduced* by makers, through their creative activities. Lastly, I challenge these definitions through mobilizing making as a method of *intervention*—co-creating a new history of innovation work in which women and weaving are central to technology building.

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## Chapter 1 - Production: The Social Construction of Making

In 2006, the high-technology beacon *Wired* magazine published its first “How To” issue – heralding the “New Age of DIY.” The cartoonish, ring-lit, inaugural cover features comedian Stephen Colbert sawing into an iPod. But, the following year it would feature someone a bit closer to the Do-It-Yourself movement: Martha Stewart. For the 2007 issue, Stewart smiles from a sunshiny cover: blonde, in a daffodil-colored button-up and holding a pastry bag as she decorates a 2-foot tall cake shaped like a Nintendo Wii. Inside, she is interviewed by the editor-in-chief of *Make:* magazine, Mark Frauenfelder. They discuss their shared beliefs that creating and building things gives people a sense of ownership, control over their environment, and self confidence. Later, *Wired* proclaimed Martha Stewart the “original maker” (Gustin, 2011).

As editor of *Make:* magazine, Frauenfelder was a natural choice as the interlocutor for a cover story on DIY. *Make:* magazine was created two years earlier, and in eight issues had begun to catalyze – or, at the very least, publicize – a swelling of interest in a self-sufficient approach to a world where information technologies were rapidly permeating almost every aspect of daily life.

In technical terms, *Make:* magazine sought to bring an open-source ethos to hardware. Basically since the inception of software, the open source community had fought for and maintained viable alternative to the proprietary operating systems of Macintosh and Windows (Stephenson, 1999). Distributed communities of passionate users created products like Linux and later GNU, pro-bono. Their creations remained open and free; they could be transformed and updated by anyone with a computer and a coding skill set. But, the same wasn’t true for hardware.

Technology historians are quick to remind us that the first personal computer – the Altair8800 – was a DIY machine. Publicized with a half-page ad in the magazine *Popular Mechanics*, interested parties could send away for a kit that contained the parts and step-by-step instructions for assembling a personal computer (Ceruzzi, 2003). Though not immediately revolutionary, the Altair inspired a group of interested Bay Area hobbyists that became known as the "Homebrew Computer Club." In popular histories of Silicon Valley, the Homebrew Computer Club is *the* source of the personal computer we know today (Isaacson, 2015)[5]. Inflected with the Californian spirit of resilience and utopia, alumni from the Homebrew Computer Club went forth and planted the seeds of the computer revolution. Most notably, member Steve Wozniak co-founded Apple – a company that, by 2005, had locked up its hardware preventing any fixing or modification from users. The second issue of *Make:* magazine features publisher Dale Dougherty's experience trying to repair the audio jack on his daughter's iPod. The warranty-voiding process involved heating the casing with a hair dryer to melt the glue and then literally prying it open.

The story of the iPod is a compelling metaphor for *Make:* magazine's intervention into the way technology companies were locking up their products, and locking up users in the process. Somewhere along the way, hardware had lost the Do-It-Yourself spirit. Creating and repairing things shouldn't just be left to paid experts. Across *Make:* magazine's inaugural issues, reinstating DIY in technology culture is their primary intervention. For example, in the coffee-table book commemorating the first year of publication, *Make:* describes themselves as

[5] Walter Isaacson's (2015) *The Innovators* has been heavily criticized in history of computing scholarly communities for furthering an individualist narrative of innovation that overlooks significant aspect of technology innovation work, especially maintenance. However, I use his work here – and at other times in this project – not as ground-truth evidence of a historical event, but as evidence of *how* a history narrated to the public.

celebrating “the creativity and resourcefulness of the DIY movement” (Make, Volume 4, p. 183). Yet, statements like this make it clear that *Make:* emerges from a larger cultural moment in which the Do-It-Yourself spirit was flourishing. Part of that was indeed technological, but beyond the world of electronics was an “exploding craft movement” (Craft, Volume 1, p. 9).

Martha Stuart is like a binary star to *Make:* magazine and the maker movement, revolving around a shared commitment to DIY and occasionally colliding. In 2009, Frauenfelder and Stuart meet again when he appears on the Martha Stewart Show to showcase a few of his “fascinating inventions” – including a VCR he’s hacked to automatically dispense cat food. In 2010 she devotes an entire episode to the Maker Faire, a yearly gathering of makers from across the country – an event that she co-sponsors[6]. In 2014, Stuart even collaborates with Makerbot to create a custom line of 3D printing filaments in her signature colors: a turquoise that graces her Macy’s product line, the same buttery yellow from her *Wired* cover, and “jadite” – inspired by the highly collectible, depression-era, milky green glass that Martha and her daughter Alexis are largely credited with re-popularizing among modern vintage fans.

In their shared 2009 episode of the Martha Stewart’s show, Stewart and Frauenfelder contend with the boundaries of crafting and making. Frauenfelder states that the goal of the magazine is to show people that anyone can be an amateur inventor – it doesn’t require special skills. One can just take things they already have and improvise. “Not all these projects are *pretty,”* Stewart interjects. “That’s the difference between Mark and Martha. I try to get mine to look pretty. But, mine don’t quite do what yours do. They aren’t so mechanical”[7].

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[6] Maker Faire is like a technology parallel to Martha’s own “American Made” awards, which highlights products made in the United States by “Makers Across America.”

[7] The Martha Stewart Show (2009, May 19). Retrieved from https://www.marthastewart.com/248221/fascinating-inventions-part-1

As a viewer, Stewart's division between the pretty and the mechanical gave me a momentary cringe. It feels so gendered. Pretty is a decidedly feminine adjective. For people, it is used to describe the appearance of women and girls. For objects, it distinguishes between what is useful and what is decorative. Brought together, "pretty" subtly distinguishes between who is active and who is passive ("just sit and look pretty") and what is important or unimportant. These divisions play out in technology organizations too. Working in San Francisco, I heard designers declare, "Our job isn't just to 'make it look pretty.'" They expressed that design was more than a surface treatment. Design improved the experience of users and communicated the brand. It was functional, and "pretty" wasn't.

Yet, contextualizing Stuart's statement with her interview in *Wired* tells a slightly different story[8]. In the brief Question-and-Answer style article, Frauenfelder returns to the same division. He asks what geeks (presumably, the *Wired* community) can learn from Martha Stewart. "It's about using your hands and your mind to make things work better." She meditates on prioritizing: simplifying, learning new techniques and consolidating steps. "Making things go faster – but not worse." In her words, you hear the way that elegance gets lost in the geek-driven push towards efficiency.

Stewart's reflection on the contribution of craft highlights divergent definitions of what it means to make something "work better." Both makers and crafters are focused on improving the material world through Do-It-Yourself activity. In *Make:* magazine, maker's activities are largely focused on what can be accomplished through creating and modifying artifacts. It doesn't so much matter the form they take: the construction can be quick and somewhat careless. A timer switch can be made with silly putty (Make, Volume 1). A hinge can be made with a paper clip.

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[8] *Wired* (2007, July). Retrieved from https://www.wired.com/2007/07/ff-howto/

Creations are only as good as they need to be to get the job done. This job might be as a solution to an unusual problem or to just scratch an "itch" of curiosity. Makers execute singular, wild ideas and test the limits of what is possible. It's here, on the edges, where innovation emerges (Dougherty, n.d.).

The editorial voice of *Make:* magazine is impelled by the idea that making, as a practice, is a physical manifestation of a particular way of thinking. The "makers mindset" transforms both amateur users and professional designers into innovators. Within *Make:* magazine, the contributors recurrently claim that user's have a right to modify their things. These are largely acts of customization, emerging from individual needs and enthusiasms (Make, Volume 2, p. 7). For users, innovation begins in personal pursuits and is eventually capitalized on by businesses (Make, Volume 4, p. 15). On the other end of production, professional designers and engineers can also benefit from making. The inventors and scientists profiled in *Make:* magazine cast off the expectations of risk-averse corporations. Rather than refining what already exists, professionals can follow their passions to truly new ideas. They innovate through disruption.

An alternate perspective on innovation is captured in *Make:* magazine's short-lived sister publication called *Craft.* Here, crafters expand the applications of materials and patterns. They bring deeply personal sensibilities to the expressive content of their creations. The publication is radical. While reflecting on material things, contributors to *Craft:* also reflect on questions of creative labor and environmental impact. They challenge the boundaries between science and art, art and craft. Crafters innovate through subversion.

For crafters, innovation isn't in what a project accomplishes, but lives within the process of creation. Crafters innovate through exploring unusual materials, novel techniques, or through questioning the traditional expectations associated with craft. Things that "work better" are better aligned with goals of their creators – and these goals often have less to do with functional outcomes. It would be unfair to say that craft projects are useless. Rather, they challenge a narrow understanding of "use" that exists purely in the application of an object. Crafting is useful as a method of engaging with – and potentially even changing – where things come from.

If developing the maker mindset is a primary goal of the maker movement, the divergent understandings of innovation in *Make:* and *Craft:* create wildly different approaches to changing the world. Making things "work better" is an intervention. As discrete practices, making and crafting illuminate different opportunities for change. For makers, the world changes through the things we create. For crafters, the world changes through *the way* we create those things.

The conceptual distinction between *Make:* and *Craft:* become meaningful when seen in light of the concrete differences between these publications. Each vision of innovation attaches to a particular set of materials – and a particular representation of the people who engage in their associated material practices.  Buried within the textile-based, women-driven voice of *Craft:* is a more responsible, deeply engaged form of creation that too often gets lost in maker discourse demanding open technologies and open information.

Recently, Garnet Hertz' critique of the maker movement, "The Maker Manifesto," has gained wide spread attention. Specifically aimed at the vision of making put forth by *Make:* magazine, Hertz reimagines the Maker's Bill of Rights. Rather than a call for the physical and informational openness of technological artifacts, Hertz calls for a change in perspective on what the maker movement stands for. He critiques exuberant celebrations of digital fabrication, declaring "the worlds key problems won't be fixed by simply adding 3D printing, open source and the Arduino." He avows a more socially conscious stance for technology making, pledging "I take responsibility for making objects and the impact that have on people, society and the environment" (Hertz, 2018). Although I believe these critiques are well founded and needed in the maker movement today, I explore the origins of both *Make:* and *Craft:* to illustrate the way that this current instantiation isn't totalizing or incapable of change. In this chapter, I describe the ways in which a more socially engaged, materially pluralistic version of the maker movement has already existed in *Craft.*

Through Doing-It-Yourself, both makers and crafters engage in creative activities that are meant to transform the world. However, I argue that makers and crafters take significantly different points of intervention. Early issues of *Make:* center the capacity of open technologies to produce innovative outcomes. Makers will ultimately change the world through creating new products, inspired by acts of modification, hacking and repair. Alternately, the voice of *Craft:* centers the impact of materials on the significance and the experience of making. Crafters will ultimately change the world through changing where things come from, inspired by the reflections enabled through extended engagements of making with their hands.

**Making Media**

In January 2005, O'Reilly media released the premier issue of *Make:* magazine. The issue touted "181 pages of DIY technology." Inside, the creations were both extraordinary and attainable. There was a look at backyard monorail systems, a guide to soldering, and a step-by-step tutorial for building an aerial photography rig from Popsicle sticks and a kite. Dale Dougherty, *Make:* magazine's publisher wrote the inaugural editorial letter. "More than mere consumers of technology, we are makers" he begins. "Some of us are born makers and others, like me, become makers almost without realizing it."

Both Dougherty, and his business partner Tim O'Reilly, began as makers of books. They majored in classics and English, respectively. Neither is an engineer (Corcoran, 2008). Yet, since the emergence of personal computing in the 1980s, O'Reilly media has been a dominant source of how-to technical guides. Today, books like "Learning Python" and "Programming Perl" are still instantly recognizable fixtures of student desktops and professional reference shelves. By their very nature, the manuals produced by O'Reilly Media positioned programming as a learnable skill. It's hard to imagine other domains of scientific expertise being the topic of a "manual" – the word in itself conjures images of the household guides that explain the basic functioning of cars and appliances. O'Reilly deliberately emphasizes these practical connotations through their titles. Along with introductory primers, they have "*cookbooks*" for programming languages like Java and C++. They're packed with "practical *recipes*," with step-by-step instructions and sample code. O'Reilly technical manuals are far from laymen's guides. They are visually austere and straightforward in voice. But, as manuals, they imply that programming is at least simple enough that you could teach yourself – and was useful enough that you should.

As technical publishers, Dougherty and O'Reilly have not only been proximate to the colossal transformations in computing and digital communication over the last forty years. Their perspectives have framed public and academic understandings of these transformations. Dougherty is often credited with coining the term "web 2.0" to describe the highly participatory online environment that emerged after the first dot-com bust (O'Reilly, 2009)[9]. The term remains a widely utilized marker to describe the emergence of personal websites and blogging. Within communication scholarship, 2.0 is even used to describe "interactive upgrades" to research methods for studying these participatory environments (Andrejevic, 2009).

[9] See also: Dale Dougherty's biography on the O'Reilly community webpage. "He coined Web 2.0 in 1993." https://www.oreilly.com/pub/au/26

Taken together, both O'Reilly's technical manuals and the celebration of web 2.0 reveal a completely consistent philosophy on digital technology. Websites weren't a static place for institutions; they could be made by people to connect to one another. Software was a tool like any other. If you knew how it worked and how to use it, you could make it work for you. O'Reilly summarized their history with a single line: "We didn't get to sell books; we sold a movement." Their real product was the Do-It-Yourself perspective.

It should come as little surprise, then, that they would apply their DIY thinking to hardware. Dougherty and O'Reilly had built a media empire on the idea that the digital world of computers – software and websites – could be created and modified by users with the right knowledge. Could the same be true for the material world of circuits and logic boards? As Dougherty and O'Reilly tell it, this is where *Make:* magazine begins. Their origin stories follow a reoccurring narrative that begins with recognizing a change occurring in American culture and the foresight to give it a name. The "maker" was part hacker, part crafter, and part environmentally concerned recycler.

## ***Make:* Magazine**

### The Spirit of the Times

According to Tim O'Reilly, "making" was a confluence of four shifts in the United States – one material, and the other three social. In an interview with *Forbes* magazine, he tells journalist Elizabeth Corcoran (2008) that *Make:* magazine emerged from "drawing connections between a set of distant dots." Corcoran summarizes these as "the profusion of powerful, cheap electronics; a deft software hacking community; crafting as popularized by Martha Stewart; and the growing green rage." Each of these is evident in the voice that emerges from *Make*: magazine in their first two years of issues.

**Cheap Electronics.** Materially, electronics were widely available, powerful, and cheap. On one hand, this trend had wreaked havoc on the country's Do-It-Yourself spirit. In an interview conducted for this project, the founding editor of *Make*: magazine Mark Frauenfelder describes a lost world in which technologies were built for repair.

> "In the 1950s, the color TV was $10,000 – so when a TV broke you pulled the parts out. There was infrastructure to test and replace it. The TVs were made to be maintained and kept, and you were responsible for running it, that's how you were trained. Now, I don't need to do that because new TVs are the solution. They're really cheap."[10]

From Frauenfelder's perspective, DIY had declined because the infrastructure and the impetus for fixing had disappeared. But, in the mid-2000s something had culturally started to change. With a shift in mindset, the cheap and disposable became the raw material for creation.

The creative potential of cheap electronics is especially evident in a critically minded project designed by Natalie Jeremijenko, who is featured in a 8-page "Maker" profile for the second issues of *Make:* magazine. Jeremijenko and her students find discarded robotic dogs in thrift stores like Goodwill or on eBay. Then, they install microcontroller computers and a sensor that measures the amount of toxic compounds in the air. The hacked robotic dogs effectively "sniff out" pollutants in landfills or other public sites. In reporting on the project, technology writer Cory Doctorow describes the toys as "cheap-ass-rough-and-ready robotics platforms."[11] Electronics are something to build upon. Jeremijenko writes that using toys for low-cost adaptations "exploits the markets of scale for commercial toy production." They turn throwaway toys into activist instruments.

**The Green Rage.** Projects like Jeremijenko's overtly address the environmental impact

[10] Mark Frauenfelder (2019, February 26). Personal interview.

[11] Jeremijenko's project must represent something particularly salient to the early vision of *Make*. The project is included in both the first and second issue: first by Doctorow in his monthly column and then in the profile. Jeremijenko was also a member of *Make: Magazine's* technical board and a speaker at O'Reilly's Emerging Technology Conference (ETech) the previous year.

of mass production and disposal. Yet, in *Make:* magazine*,* the ethos of the environmental movement typically manifests more subtly in projects that reuse objects that would have otherwise been thrown-away. Discarded objects don't just deserve our attention because they take up space in landfills and give off noxious fumes as they decompose. When one discards an old computer or a single use-video camera[12] they also abandon the creative potential of that object. An old wetsuit can become a padded laptop case (Make, Volume 2, p. 42). A shopping cart can become a chair (Make, Volume 7, p. 41).

In *Make:* the idea of *"*waste" is more often about usefulness. This shows up commonly in conversations about repair. Frequent contributor Mr. Jalopy asks, "When your covered wagon broke a wood spoke did you throw away the whole wheel? The whole wagon?" (Make, Volume 4). Damage is rarely total. Often breakdowns are in a single component, while the rest of object is still fully functional. A broken spoke has no impact on the wagon. In this example, there is an unnecessary volume of waste: a whole wagon rather than a single spoke. But, there is also a waste of potential. The wagon could have gone on being useful – as a mended wagon, or as something else.

Early volumes of also *Make:* feature a variety of "high-trash" or "trash tech" projects that use components from outdated or discarded devices (Make, Volume 3, p. 105). These often draw upon a kind of steampunk aesthetic creating artifacts that are both nostalgic and futuristic. For example, there is a digital clock made of recycled motherboards and an electronic "deco-industrial" brass horn. The components are found and repurposed items, transformed with hand tools and "preserved from a disposable past" (Make, Volume 3, p. 25; Make, Volume 6, p. 21).

[12] Apparently, single use digital cameras and digital video recorders weren't uncommon in the early 2000s, in the transition between film and digital photography. They are both featured as "platforms" for *Make:* magazine projects.

Projects like these are so bespoke and so specialized. They don't contend directly with environmental issues through everyday acts of re-use. And, they aren't scalable as future products. High-trash projects are opportunities for ingenuity. Through these projects makers engage in creative, speculative acts of combination that are "artistically satisfying." Yet, *Make*: also contends with more mundane practices of modification and repair in their editorial voice.

From the perspective of *Make:* magazine*,* both technology users and technology producers had contributed to a culture in which people no longer engage creatively with their things. Users had become lazy and careless consumers. But, producers had engineered this orientation through designing objects that were physically incapable of being modified or repaired. In the premier issue of *Make,* Dougherty writes about his palm-pilot: that the "design pre-supposes you will eventually replace the entire device, not just its battery" (Make, Volume 1, p. 119). Technologies like these can't be fixed. They can't be upgraded through our actions. They're upgraded through buying a new device.

Throughout the early issues of *Make:* I was struck by just how often the projects they feature are resourceful mash-ups of other technologies and household items. The practices are more akin to my vision of hacking, than the "making" I'd come to know through my observational research. At my field site, one of the participants made this distinction specifically, telling me "hacking is about coming up with a clever, non-intuitive solution to a problem. Makers work from the ground up." Making means *making something new* there. Yet, Dougherty himself has been careful to distance making from invention, saying that most people who make things "don't identify themselves that way." Rather, he harkens back to the image of the "tinkerer" – the person whose life is enriched through having the skills the work-on and transform the material world. Underpinning *Make:* magazine is an encouragement that people become tinkerers and a demand that technologies enable tinkering.

**Hacking.** In Volume 4, *Make*: magazine publishes the "Maker's Bill of Rights" written by magazine contributor who goes by the name Mister Jalopy. Today, the Maker's Bill of Rights is one of the most recognizable symbols of the maker movement. The bill has almost nothing to do with from-the-ground-up making or with invention. It appears as a full page graphic in an article about the right to repair (Make, Volume 4, p. 157). Discussing the maintenance of his 2000 Chevy, Jalopy criticizes companies who manufacture enclosed technologies. Objects that can't be repaired trap users within cycles of consumption.

These commitments are deeply influence by the open source movement, which is probably the most recurrent touchstone of their early interviews. In separate interviews in *Forbes,* both Dougherty and O'Reilly talk about the role open source enthusiasts played in the development of software and chart a similar path for the world of circuit boards and microcontrollers (Corcoran, 2008; O'Reilly, 2009). Dougherty forecasts in Volume 2: "We've seen this happen with open-source software, open source hardware is next."

Reparability is made up of two, interlocking faculties. An object can be repaired if it is (1) designed in such a way that users can replace components and (2) the user has the knowledge to do so. Both of these faculties are imperatives for the open-source computing community, which calls for both physical openness and the openness of information. Dougherty writes in Volume 3:

> "To be maker friendly means to provide access to good information about the product. Makers really want the details, and more importantly want access to the product itself. Makers want to look inside and see the moving parts. They want to do the unexpected, such as make repairs and improvements and harvest components." (p. 7).

The "Makers Bill of Rights" lays out 17 design tenants that enable "open" technologies, which broadly fall into three categories. First, technologies should be physically open. Users need to be able to get inside their devices. At the most basic level, "cases should be easy to open" and they should not be "tamperproof." Once inside, the components should be standardized. They shouldn't require expensive or specialized tools. Products that use esoteric screwheads, for example, may technically be accessible but typically remain closed because users don't have the needed equipment. An article on Torx (a specialized screwhead) in Volume 3 called this strategy "security through obscurity" (p. 147). The set of physical tenants can be summarized with the tenant "screws better than glues." Screws can be unscrewed and re-screwed, using widely available standardized tools. Glue is permanent, or permanently broken.

Second, technologies should be informationally open. Users need to be able to understand their devices or access information to learn about them. Parts should be labeled. Schematics should be included. Documentation should be available online "in perpetuity." [13] The availability of detailed information is fundamental to maker's abilities to learn and create. Within DIY computing cultures, informational access is just as important as physical access. Corporations limit the power of users through locking technologies shut *and* locking-up proprietary information. Articles in *Make:* critique products like Lego Mindstorms for being too opaque: "there never was enough technical information about how they really worked." They celebrate robotics clubs for having their work "completely documented on the web" (Make, Volume 3, p. 43). Documentation is a pathway for *truly* understanding a technology, and a way of spreading the knowledge around.

[13] It's also worth noting that Maker Media practices what they preach. The entire back catalog of both *Make:* and *Craft:* is available for digital purchase and download in non-proprietary PDF format, an absolute rarity in magazine publishing.

The Maker's Bill of Rights is directed at technology producers, especially corporate manufacturers. Yet, this idea of openness is an ideal for the behavior of makers too. In his book *The Maker Movement Manifesto*, Mark Hatch (2014) includes as one of his principles "you cannot make and not share." Rather than a cautionary maxim, this statement captures maker's natural compulsion to seek an audience for what they know and what they've created. *Make*: magazine embodies this imperative, as creators openly share how-to instructions for their original creations. As Doctorow writes, the mission of *Make:* is "all about making cool stuff out of other stuff and sharing it with the world" (Make, Volume 4). Sharing means more than just showcasing, it means making creation and adaptation possible for others.

*Make:* magazine fundamentally contributes to the goals of open technologies through being an informational resource. The magazine provides a series of "patterns" – both literally and metaphorically. Every issue of *Make:* features step-by-step instructions for projects that are feasible for beginners. And, each issue also features profiles of skilled "alpha makers," which act as patterns (or exemplars) for what is possible with a maker mindset. Both these types of content act as a method of instruction. Tutorials teach technical skill sets through project construction. While executing instructions to accomplish their goals, makers also learn fundamentals and abstract concepts that can be applied to other problems. Referencing a 1977 work by Christopher Alexander, Dougherty reflects that all DIY projects are comprised of "adaptable solutions to problems that occur over and over again." He views *Make:* as building a "pattern language" that allows readers to "build on the ideas and insights of others who hack, tweak, and tinker" (Make, Volume 2, p. 39). The interviews take this one step further. From my interpretation, the alpha makers act as archetypes – not meant to transform readers into experts but instead model an *approach* to particular project or problem.

As someone who wasn't immersed hacking or making, I initially understood the importance of openness in terms of proprietary ownership. For example, in the third issue of *Make:* there is an article challenging readers to design a widely available, inexpensive screen reader for people who are visually impaired. The author Fernando Botelho is blind. He states that the machine must be open source because corporations can increase the price of their products at any time. Corporations can even discontinue them completely (Make, Volume 3, p. 40). Cory Doctorow makes the same argument about iTunes being able to set the price for digital music. The author of the recurring "homebrew" computer column terms these "vendor lock-in schemes" (Volume 4, p. 192).

However, there is also a broader sense of ownership at work here. In Frauenfelder's *Wired* interview with Martha Stewart they discuss this vision directly.

> FRAUENFELDER: One reason people like projects is because it gives them a sense of control over their environment and technology. It gives them ownership.
>
> STEWART: That's why I say "you own it if you made it." You don't own the pie if you buy it. You just don't. Doing projects really gives people self-confidence."

It's difficult to imagine that Stewart is raging against big bakery corporations having copyright control over ingredients and setting the price of pies. I have to think she means that the person making something *feels* ownership – a sense pride and contribution; that they possess a degree of creative power.

Ownership is about who we become through making. The Maker's Bill of Rights is written to demand that companies design objects in a way that enables fixing. Yet, taking *Make:* magazine as a whole, it becomes clear that *the act* of fixing is perhaps as important as the outcome (an object being fixed). *Make:* isn't just written for tradesmen specializing in machine repair or restoration. It's written for tinkerers and hobbyists. Things should be fixable, and *you* should fix them.

**Craft.** In his recounting of *Make:* magazine's founding, Tim O'Reilly recalls a conversation with Dale Dougherty in which he pitched a magazine that would be the "Martha Stewart for Geeks" (O'Reilly, 2013).[14] From its earliest days, *Make:* was conceptualized as a publication that would bring a technical-bend to the Do-It-Yourself knowledge repository. While Martha Stewart's DIY activity was often focused on domestic advice (Click, 2009) both publications shared a hands-on, creative spirit that is inherently one of craft. In his column for Volume 13, Dougherty discusses making as a craft directly. He quotes chef Simon Hopkins, who defines craft as "anything that is produced with the hands and sense to put together a complete picture" (p. 10). Making, Dougherty says, "is about creating that kind of picture with the technology at hand" (Make, Volume 13, p. 10). As I'll discuss later in this chapter, the independent craft movement was blossoming in wider American culture, impelling Do-It-Yourself activity beyond the realm of geek-dom[15]. Yet, in *Make:* craft remains mostly a subtle ethos – typically used to elevate skilled handwork, rather than the soft material practices that go on to define *Craft:* magazine.

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[14] Using this phrase to describe *Make:* is also attributed to Hacker historian and *Newsweek* columnist Stephen Levy. The team at O'Reilly uses this clout to advertise *Make's* sister publication, *Craft:* magazine, in their online store, the Maker Shed.

[15] To be sure, Do-It-Yourself can also be traced to the culture of open source computing. In his book *Hackers*, Steven Levy (2010) discusses the "Hands On Imperative" as central to the hacker ethic. "Hackers believe that essential lessons can be learned about the systems—about the world—from taking things apart, seeing how they work, and using this knowledge to create new and more interesting things." Cultural historian Fred Turner (2006) traces a similar spirit across early Silicon Valley, in which the *Whole Earth Catalog* existed as a repository of tools for materially building an information-rich world.

## Making: Innovation through Disruption

With a word like disruption, “disruptive innovation” conjures shake-ups and unsettlings. The term, first coined by a Harvard Business School professor, is ubiquitous throughout Silicon Valley to describe technologies that cause a point of breakage within the trajectory of an industry (Tiku, 2018). These disruptions usually come from new ideas – easier, simpler, smarter, cheaper – that displace more established companies and products. Throughout the early issues of *Make:* magazine*,* making is a positioned a source of the lithe, individual ideas that are precursors to industry disruption. Making transforms both experienced engineers and amateurs into innovators who are capable of seeing beyond the constraints of precedent.

### Amateurs: End-User Improvement

More than just ethical ideals, openness and resourcefulness are important to makers because they enable user innovation. Traditional models of innovation position users as recipients of innovation. Engineers and designers bring new ideas to life, and everyday people integrate them into their daily practices. Users can accept or reject the products of innovation. Users are rarely positioned as a source. But, common knowledge also tells us that people are creative. Users employ objects in unexpected ways, they put them to new uses and occasionally create something entirely new in the process.

The creative capacity of users is a foundational tenant of social constructionist perspectives on technological innovation. Scholars working from this perspective argue that designers and users jointly establish new technologies. Early social constructionist scholarship positions the power of users in selection. Users helped to determine the form of objects through interacting with various designs, as different groups choose particular models or artifacts based on their particular needs (Bijker, 1997). Later scholarship captures more transformative practices from users. In their seminal article on the social-construction of the automobile, Ronald Kline and Trevor Pinch (1996) demonstrate the ways in which the introduction of cars into rural American life also led to a series of user innovations. The powerful engine of a car was used for driving – and for towing a harvester and for running a washing machine. Today, we might call these "hacks." Automobile producers had ambivalent feelings towards the modification practices that drove sales but also challenged the intended (and warrantied) uses of their products.

More recent scholarship highlights the ways that modification practices are a legitimate source of new ideas and new products. In *Democratizing Innovation,* Eric Von Hippel (2005) establishes a vision of innovation in which "lead users" develop products for their own use that are also on the leading edge of product markets. Through using a word like "democratization," Von Hippel invokes the way that open technologies put the power of innovation into the hands of more people. Because they can be modified, open technologies hold within them the potential to respond to the needs of small groups and even single users. As Dougherty observes, "When a system is open and easily modified, it anticipates adaptation to a variety of uses that were never considered in the project's original design" (Make, Volume 3).

Early issues of *Make:* recurrently emphasize the value of personalization. Corporations can't possibly design for every individual, so why not let users do this part themselves? Acts of personalization also have monetary potential. Dougherty and Von Hippel share a belief in the power of "lead users" and "alpha makers[16]" as signals for the path of industries. Publisher Tim O'Reilly (2009) credits much of his own professional success to watching what he terms "alpha geeks." Alpha Geeks are risk-taking enthusiasts who have the technical skills to make technology work for them. In *Forbes*, O'Reilly charts how open technologies and ambitious,

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[16] While I think it's unintentional, the similarity between the term "alpha maker" and "alpha male" evoke a gendered, masculine image of technical mastery.

adventurous and informed users lead to profitable business ventures.

> "The alpha geeks exercise an idea or gadget, pushing it past its current limits, reinventing it and eventually paving the way for entrepreneurs who figure out how to create mainstream versions of their novel ideas" (O'Reilly, 2009).

Open technologies incorporate a greater number of minds in the innovation process – generating ideas that can be adopted by companies and then manufactured for the masses.

From the first issue of *Make,* passionate hobbyists have been pointed to as a neglected source of innovation. In a design brief discussing the potential of open source cars, the author praises vintage automobiles for their "modularity and flexibility"— design values that, he believes, have disappeared from modern engineering. The design of modern cars inhibits improvement and maintenance performed by owners. And, in turn, modern cars also inhibit the potential of innovation that arises when maintainable machines and knowledgeable maintainers are brought together. "Do you want to see innovation is the hybrid electric automobile market?" the author posits. "There's an R&D department composed of millions of people in millions of garages around the world" (Make, Volume 1, p. 46). This instantiation of the corporate abbreviation for research and development (R&D) extends the boundaries of innovation. It includes networks of people working outside of car manufacturing and legitimizes the knowledge produced by those tinkering with old cars and sharing information in auto-tech chat groups. More over, it implicitly ties auto companies lagging development to their modern designs.

In both scenarios, making is an answer to the failure of corporations to produce adequate solutions to a problem – or, corporations' failure to care about that problem at all. User innovations mobilize individual's interests and needs, allowing makers to personalize existing technologies. But, sometimes modification isn't enough. In his call for a screen reader aiding those who are visually impaired, Botelho writes: "The magnitude of the challenge requires much more than an incremental improvement of what's now available" (Make, Volume 3, p. 40). Accessibility and automobile emission are colossal problems that require solutions that are truly divergent from what currently exists. Open source isn't the solution itself. Rather open source is a platform through which solutions – new technologies, new innovations – are created.

**Experts: Risking it for New Ideas**

Beyond activating the creative potential of everyday users, making also activates the creative potential of professional engineers and designers. *Make:* magazine puts forth a perspective on technology industries that frames them as slow, unwieldy and risk-averse. Certainly great ideas can come from in-depth research, informed by theories. But, makers engage in a different type of creative process that brings forth truly original thought. They do the imperfect, hands-on work of "enlightened trail and error" (Make, Volume 4, p. 33). These material engagements are incredibly productive for innovation because they help designers let go of the minor, iterative improvements that define corporate research and design.

Dean Kamen is a quintessential example of the expert maker. Kamen is most famous for inventing the Segway and now leads his own design firm called DEKA. In his profile in Volume 4 of *Make,* Kamen describes his perspective on design, stating: "Engineers are taught to think and work in a risk-averse way; let's avoid making mistakes, let's only do what has been documented to work. Well that's great, but it will never result in significant innovation." Kamen advocates for the importance of failure, and especially for failing while doing. Industrial R&D processes limit creators to understanding and figuring it out on paper before they "get their hands dirty" (Make, Volume 4, p. 32). But, Kamen argues, this method will only ever lead to outcomes that are similar to what already exists – rather than something new, divergent, and truly innovative.

The expert maker disrupts the tired habits of engineering and design through integrating the spirit of DIY into their practice. Their material engagements and personal passions are a source of new ideas, as they experiment at the margins of the field. One such demonstrative figure is Ed Storms, a retired Los Alamos physicist researching cold fusion, a phenomenon that is accepted within mainstream physics to be impossible. Storms feels that the energy industries in the United States "simply are not willing to explore new ideas readily" which is why the most innovative research is being done abroad—or by solitary experimenters working in their garage. From Storm's perspective, maverick makers set the agenda for innovation:

> "Anything truly creative in science is usually done on a small scale by people outside of the mainstream of academia or the government. Entrepreneurs, little companies. And then, if it works, it grows. It becomes Microsoft" (Make, Volume 3, p. 34)

Here Storms describes the exact mechanism of innovation put forth by the editorial voice of *Make:* magazine. It begins with enthusiastic tinkerers materially engaging with existing technologies to create something new, and then it becomes potentially profitable when it is produced at scale.

Ultimately, the narratives of *Make:* magazine position making as a method of reinventing technology design practice, liberating the creative capacity of people on both ends of the product. Making transforms end-users and experts into a source of new ideas, incorporating more minds into the engine for change. DIY becomes a method for working outside the mainstream – acting beyond mere consumption or risk-averse research. The maker is the tinkerer; at home, exploring a curiosity they can't put to rest.

## *Craft:* Magazine

### The Spirit of the Times

In 2007, the craft spirit that influenced the founding of *Make:* magazine splintered off into a standalone publication. *Craft:* was initially conceptualized as a special, thematic issue of *Make:* but it arrived at a time when enthusiasm for crafting was exploding. Throughout the early 2000s, young women in the United States were re-popularizing traditional activities like baking, canning and sewing (Matchar, 2013). *Craft:* consistently acknowledges a wide DIY "renaissance" through out its tenure (Craft, Volume 1).

Contributors to *Craft:* position the magazine within a cultural moment that is regularly and self-reflexively considered within the pages of the magazine. An article titled *Why Making Stuff is Fashionable Again* is featured in the first few pages of the inaugural issue. "Why now?" Jean Railla asks "Why after feminism, the industrial revolution, and the pervasiveness of the Gap?" (Craft, Volume 1, p. 12) In this quandary are three forces that are seemingly oppositional to craft making. Feminism liberated women from domestic housework, the industrial revolution liberated people from working with their hands, and commercial establishments like The Gap made it easy to buy things without much work at all. Was craft reemerging despite the current state of things, or because of them?

Narratives of craft as "women's work" are both resisted and reclaimed within *Craft:* magazine. The magazine features projects created by both men and women—many of which challenge the accepted conceptions of craftwork. Contributors are often quick to highlight how the work they're profiling differs from more traditional forms with phrases like "it's not your mother's crafts" and "there's nothing Martha Stewart about this" (Craft, Volume 2, p. 40). Yet, there is also a reoccurring sense that celebrating the work of crafters was a statement against the hierarchies of art and design. Practices like crocheting and wool work had been "consistently neglected" and relegated to the class of "housewife art" (Craft, Volume 1, p. 45). *Craft:* magazine aimed to highlight the way craftwork was artistic—and, as I'll discuss later in this chapter, mathematical and innovative. In *Why Making Stuff is Fashionable Again,* Railla partly credits the success of feminism for "opening the door for all of us to value typically feminine art forms" (Craft, Volume 1, p. 12). Women were reclaiming their own value and the value of their creations.

Beyond questions of contemporary feminism, craft is conceptualized as a political response to globalized production defined by factory labor, environmental degradation, and corporate profit. Because crafters make things they might have otherwise bought, craft becomes a method of "voting with your wallet" (Craft, Volume 1, p.12). Contributors to *Craft:* magazine recurrently position craft in opposition to American habits of buying, using, and throwing away. One article, written half-ironically in the style of sermon, describes consumerism as an alluring trap "Our lives conspire to keep us from acts of creation. We are well bred consumers." Another critiques the American Dream, sardonically symbolized by two car garages and pottery barn couches (Craft, Volume 2, p. 12). In both these narratives, craft is a rejection of these dominant ways of growing up and living life. "Crafting is politics with a little p … a form of resistance against the disastrous reality that is contemporary America" (Craft, Volume 2, p. 12).

The publishing of *Craft:* coincided with a global economic recession. "Folks are broke," a magazine interviewee says bluntly. Yet, contributors often reflect that what had grown out of necessity had become something more. Tina Barseghian, *Craft:* magazine's second editor-in-chief, directly addresses new readers drawn to the magazine by the tumultuous economic climate in her editor's letter for the tenth (and ultimately final) issue of the magazine. "To those of you just joining us – welcome to the joys of crafting! Not only does it save you money and exposure to creditors, it's extremely fun and gratifying" (Craft, Volume 10, p. 11). This journey is familiar in *Craft:* narratives. Though people came to crafting as a method of getting by, it had become a method of thriving. *Craft:* is filled with discussions of the pleasure and meaningfulness that people find in making things by hand.

From the perspective of O'Reilly Media*, Craft:* magazine was conceptualized as a partner publication to *Make:* magazine—containing the more "crafty" submissions the editorial team had been receiving. *Craft:* submissions were defined through the materials of the projects and their visual appeal. Materially, projects in *Craft:* were "softer" (Make, Volume 7, p. 10). DIY projects existed on spectrum, with "soft" projects involving paper, yarn, and clay on one end and "hard" projects involving wires and metal on the other (Make, Volume 7, p. 10). In *Craft's* opening editorial letter, Carla Sinclair uses the materials of an electric tank top[17] to illustrate a negotiated boundary between the two publications.

> "This project definitely has the elements of a MAKE project – it involves soldering, LED technology, and programming. But there are also craft elements that don't quite jibe with MAKE's harder-edged sensibility. It required a sewing machine, sewing skills, fabric and a pattern."

Sinclair also highlights that *Craft:* and *Make:* diverge in their attention to form. A *Make:* project is defined by functionality; it is evaluated in terms of what it accomplishes or solves. But, a *Craft*: projects must be as "aesthetically attractive as it is useful" (Craft, Volume 1, p. 9). In this, we hear echoes of Martha Stewarts concern over whether inventions were "pretty" when

[17] It's worth noting that Leah Buechley designed the electric tank top, making it an especially meaningful cultural artifact. At the time, Buechley was a PhD student and was in the process of designing the sewable minicomputer called the "LilyPad" (Birch, 2014). The LilyPad is a wildly popular version of the ubiquitous Arduino in which makers use conductive thread to build circuits. It has been discussed as a powerful pathway for women's participation in innovation (Buechley & Hill, 2010). Buechley has been publically critical of the maker movement in recent years, which will be discussed more in-depth on Chapter 3.

Frauenfelder appeared on her show. For example, one of the featured projects in Issue 7 is a guide to building a set of “stylish portable speakers.” As a project that involves materials like batteries, jumper wires, tilt switches and audio amplifiers it would be right at home in the pages of *Make.* The speaker unit is housed in a minimalist cardboard pyramid. The shape – with the speakers separated on different sides of the pyramid – allows one speaker to be covered by a built in sliding door that will switch both speakers on and off. The angular cardboard housing is elegant, practical and an opportunity for ornamentation, all aesthetic elements of craft. The second step suggests customizing the speakers with “decorative paper or fabric” or painting it like a canvas.

Craft, as a category, is an intermediary that changes through comparison. When seen alongside making, craft is defined in opposition to functionality: through an attention to the visual elements and aesthetic qualities of a design. However, when seen alongside another pole – the world of art – craft is “utilitarian,” it is useful (Craft, Volume 2, p. 40). Contributors to *Craft:* explicitly discuss the boundaries between art and craft, with craft fulfilling the functional position. For example, in discussing the creation of vintage daguerreotype photographs the resulting image is art – but the photographic plates, emulsions and the case are all built for a purpose. They are craft. Although the division of art and craft is a complex and ongoing debate beyond the purviews of this project, I make this point to illustrate that crafting is never wholly separate from the qualities that define making. Distinguishing the two takes narrative work. The entwining of the functional and the decorative give craft a holographic quality. When turned into the light, the picture changes. Sometimes *Craft:* magazine turns craft towards the high-tech practices that easily cast the image innovation. And, other times, it claims the traditional, the feminine and the forgotten as method of innovating anew.

**A Seat at the Craft Table**

Although *Craft:* is marketed through the potentially gendered language of being a "sister" publication to *Make,* the editors didn't conceptualize the magazine as a women's publication. The editorial process was focused on the qualitative difference between projects. *Craft:* projects were softer and more artistic. Yet, that doesn't mean that the material boundaries didn't create gendered spaces within each publication. In the simplest terms, this is evident just by looking at the covers. Of the 22 issues of *Make:* that I read for this project, only two had women on the cover[18]. Alternately, while half of the issues of *Craft:* featured only objects on the cover, of the five issues featuring people four of them were women. Inside, *Craft:* is like a parallel universe in which the majority of the publication's editorial board, contributors and columnists are women.

When I asked her about the number of women represented in *Craft:*, Sinclair recalled that the early gender-divide between *Make:* and *Craft:* magazine always bothered her[19]. She actively recruited men as contributors, but women were the ones most often pitching her. The publications were wrapped up in larger patterns of expertise she concluded. "I think maybe it was a cultural thing about the kinds of skills and what kinds of things we do. It's a system thing." She went on "girls are more likely to be at the craft table."

Looking beyond demographic representation means seeing the way that the material criteria that separate hard from soft also genders the work of innovation – and our understanding of what innovation entails. For example, in the fifth volume of *Craft*, three of the featured projects were made with fabric—a modern heirloom quilt, a party dress, T-skirt (a skirt made of a t-shirt) – and one was made with glass. The issue of *Make:* published at the same time featured an air canon made of PVC pipe, a wooden toy music sequencer and a vibration-dampening

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[18] One of these was a sexy magician's assistant in a negligée (Make, Volume 13).
[19] Carla Sinclair (2019, March 13). Personal interview.

system made with a cardboard box, epoxy, and a breadboard circuit. The material criteria that separate soft from hard reinforce a gendered image of the maker and crafter. All three of the fabric-based project features in *Craft:* were written by women, and all of *Make*'s featured projects were written-up by men.

Both *Make:* and *Craft:* magazine were motivated by the idea that tool-based activities could encourage makers to start thinking about things differently. One of the reoccurring themes within *Make:* magazine – and the maker movement more broadly – is a recasting traditional hand tools as tools for innovation. An article in Volume Six describes famed Italian architect Michele De Lucchi who spent most of 2005 prototyping model homes with a chainsaw[20] (Make, 6, p. 16). The article is mostly focused on why tools like the chainsaw are valuable for design practices: they work an individual scale and they're intuitive. Low-fidelity tools allow for free thinking creativity, not unlike working with a pencil. De Lucchi's lesson from the chainsaw is that small explorations are the source of new ideas. Designers must separate themselves from "big resources" that make people "anxious to avoid big mistakes." These types of insights could arise from engaging with any level of lo-fi, simple tools – yet within *Make:* they're typically tied to the world of pocketknives not sewing scissors.

**The Maker Mindset and Making Do**

One of the primary claims of the maker movement is that making is a "mindset." Rather than being defined by a particular expertise – like a woodworker, welder, or seamstress – making is a way of interacting with the world. Dale Dougherty defines the maker mindset as orientation to new technologies in which "makers give it a try; they take it apart; and they do things that the

[20] "No fussy stickler for mere handicrafts," De Lucchi also added details using a laser cutter and water jet. In this description we see a fairly rare example of a hyper-masculine performance of making that denigrates craft.

manufacturer did not even think of doing." Dougherty argues that this playful process leads to business applications, and ultimately to innovation. The maker mindset transforms consumers into creators and engineers into inventors.

The maker mindset is also celebrated as the source of a greater cultural shift, away from an unquestioning consumerism and towards a more inspired relationship to things. Within the realm of *Make,* this ethos is most evident in Frauenfelder's perspective. In his book *Made by Hand,* Frauenfelder (2010) is wholly focused on the feelings of self-determination and care that emerge from making. He explores beekeeping and brewing kombucha. His interaction with "technology" is decidedly non-digital. Yet, discourses of responsibility are largely absent from *Make:* magazine. Rather, anti-consumerist themes are used in *Make:* to motivate arguments for material freedom. Corporations lock up their technologies, impeding self-determination and innovation.

The crafter mindset is never specifically defined. However, there is substantial discussion about how crafters approach the world. Most saliently, crafters are people who "make the most of their resources[21]" (Craft, Volume 1, p. 133). Practices of using (and often reusing) materials are framed as the root of creative thinking within crafting. For example, within *Craft:* there are handful of articles about weaving and crocheting different things from plastic bags. Crochet artist Alexis Berge describes this it as such:

> "If your going to make a basket out of rattan that's sold to make baskets, it doesn't push you towards *a new way of thinking about basket-making*. Unconventional materials present unusual challenges … and opportunities." (Craft, Volume 3, p. 8, emphasis added)

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[21] This definition comes from a refreshingly non-western discussion of folk art: "Folk artists in Mexico are a shining example of what being crafty is all about. They make the most of their resources" (Craft, Volume 1, p. 133).

Through using what is available, crafters not only engage in environmentally friendly and economical practices of re-use. They innovate.

For both publications, DIY is celebrated as a method of invigorating original thought. Using alternative materials is a wellspring for new types of thinking—through encouraging and activating the maker mindset. Yet, the goals of these activities are quiet different. In *Make:* re-used objects are platforms for invention. They inspire a maker mindset that ultimately results in new ideas for new products. In *Craft:* re-used objects of are a method of rethinking processes. They inspire new ways of doing.

The crafter's vision of innovation is more akin to "making do" than how contemporary discourse defines "making." Making do is a construct central to cultural studies scholarship, first introduced by French theorist Michel de Certeau (1988) in his book *The Practice of Everyday Life.* For de Certeau, making do is defined as a "way of using" (p. 35). Making do, as a phrase, gestures towards a kind of optimism and resourcefulness. Those who "make do" make the *best* of what they have; they make something from what they've got. Recent scholarship from Human-Computer Interaction scholars had made a similar connection, arguing that "making do" as an idea illuminates acts of repair and reuse in a way that the ground-up connotations of "making" often obscure (Ames et al., 2018). However, this work doesn't appeal to how making do operates within cultural studies. I make this point not to point out a missing literature, but rather to say that without this grounding the real significance of making do gets lost. Making do is always political.

Making do isn't merely a survival technique, it's tactic in the struggle for power and self-determination. Through making do, individuals transform the material provided by powerful structures to achieve their own ends. It's a way of living out our visions—a way of "dwelling"

(Fiske, 1992). The concept of making do underlies my analysis of what follows in two specific ways.

First, making do reminds us that making is a contextual practice. Both action and creativity emerge from what surrounds us. *Craft:* and *Make:* magazines are embedded in much larger patterns of socialization that create material repertoires that are deeply gendered. The "context" for creativity is quite different. Considering the acts of user innovation celebrated by *Make*, modification and repair take distinct sets of devices and materials as their foundations. This means that the outcomes of those engagements (e.g. projects) also look quite different. Yet, they may share many of the conceptual foundations. Discourses of innovation that harden around *Make:* do so at the expense recognizing innovation emerging in other material contexts – and ultimately those who are innovating there. *Craft:* magazine takes this idea on directly by reframing craft as sharing many of the same scientific and mathematical concepts that are often credited to *Make.*

Secondly, making do motivates my analysis of craft as "subversive" innovation. Crafting is a method of redistributing or reclaiming power. In *Craft:* magazine*,* makers frame their practice as material interventions into larger structures predicated on exploitative labor and environmental destruction. These commitments emerge *from* their engagements, which are windows into how things made and how things could be made better. Visions of making that don't include soft material practices also fail to include the profound critical thinking that can emerge from these activities. The crafters mindset becomes the source of a responsible approach to innovation, accounting for the at times destructive impact of productive activity.

## Craft: Innovation through Subversion

By definition, subversion entails a reversal of a system—structures are inverted and power is redistributed to those who'd previously occupied the lower rungs of hierarchy. One method of subversion is challenging accepted categorizations, refusing to enact prescribed characterizations that purify one thing from another. Central to the mission of *Craft:* magazine is "pushing beyond traditional boundaries, either through technology, irony, irreverence and creative recycling … or innovative materials and processes" (Craft, Volume 1, p. 9). As this mission statement makes clear, *Craft:* magazine's vision of innovation is tied to reimagining what craft is, how it done, and what it does in the world.

**Crossing Boundaries.** On the most basic level, *Craft:* magazine reframes craft though aligning it with widely held understandings of innovation as a mathematical, scientific practice. A recurrent theme of the magazine is discussion of how craft practices contribute to scientific or mathematical understanding. Part of this is an appeal to the enormous cultural value of Science, Technology, Engineering and Mathematics (STEM). STEM fields are widely celebrated as the drivers of innovation. Through aligning craft with STEM, craft becomes a mode of acquiring the knowledge and skills of innovation by different means. Yet, discussions of the scientific and mathematical nature of craft also challenge accepted understandings of craft as distinct from these realms. Craft is traditional. Craft is decorative. These words starkly contrast with cutting edge, productive visions of innovation. Projects in *Craft:* magazine complicate this division, challenging readers to see the things they value in a new set of materials and practices.

Within the pages of *Craft* is a menagerie of crocheted scientific specimens. There is an anatomically correct human brain, a collaboratively produced coral reef. There are projects from a CERN particle physicist who makes molecular jewelry and a molecular geneticists who makes biologically accurate felted fruit. The creators of these projects emphasize craft as complementary to innovation. They argue it draws on their knowledge and powers of observation. It puts abstract concepts and remote specimens in the hands of people who may otherwise not comprehend them.

Textile arts are a natural fit for producing artifacts meant to increase public understanding. Take, for example, the knitted hyperbolic plane featured in the first issue of *Craft:* magazine*.* Hyperbolic planes are basically the opposite of a sphere. Rather than having a constant positive curvature (like a ball) they have a constant negative curvature (like a ruffle.) Mathematician Dr. Daina Taimina explains that hyperbolic planes are common in the rippling edges of natural objects, but she said models were a challenge. Two-dimensional models were difficult to grasp mentally. Three-dimensional models were usually made of paper and so fragile they couldn't be grasped physically. But, crocheted models were "sturdy, pliable." Simply by its material qualities, yarn was an ideal medium for interaction.

However, craft is more than a method of communicating scientific or mathematical concepts. The contributors to *Craft*: magazine also emphasize the ways in which craft *is* scientific and mathematical. Beadwork has mathematics "at the heart," (Craft, Volume 1, p. 33) Sculptures made of canned food require "healthy doses of mathematics, geometry and structural engineering" (Craft, Volume 1, p. 44). A profile on e-textile designer Diana Eng discusses how a knitting technique for counting stitches in your head parallels the formula for the Fibonacci sequence.

Through recognizing craft as both *like* mathematics and *inherently* mathematical, *Craft:* magazine challenges accepted boundaries that position craft making in the realm of purely decorative. Projects like the knitted hyperbolic plane symbolically connect craft to STEM fields, entwining the knowledge that would be required to produce this type of artifact. One can be skilled in both textiles and geometry and, indeed, these skills can inform each other. Narratives to recognize the abstract mathematical concepts embedded in craft attempt to dissolve this boundary all together—showing craft to be simply a different set of materials to experience these shared underlying concepts.

*Craft:* magazine further challenges accepted boundaries of craft through breaking conventions of scale and material. One article profiles a crafter who knits with 20-foot telephone poles and a John Deere tractor (Craft, Volume 1, p. 16). Another looks at embroidery of a screen door. While the artist uses traditional embroidery floss (in industrial neon colors) it is described as "more of a hardware project" (Craft, Volume 1, p. 27). She operates as a significantly larger size, with wire mesh rather than fabric as a surface. Projects like these flout expectations that crafts are often small and delicate. *Craft:* never fully leaves these ideas behind, however. Project descriptions are peppered with words tied to minutia—"precision," "perfectionism," "attention to detail," and "patience" among many others. Although materials and scale change, these mechanics remain. They at once uphold traditional understandings of craft and, as I'll discuss later in this chapter, are source of more radical insights into what making things requires of the people who do it.

**Making at Scale.** The second volume of *Craft:* introduces a new quality the separates *Make:* from *Craft:* magazine. Beyond the soft materials and artistic sensibility introduced in Volume One, craft projects engage in repetition. On a methodological level, craft techniques are often repeating. Think: knit-pearl, knit-pearl. "One aspect of many crafts is duplicating a particular technique hundreds, even thousands, of times to complete a project," Sinclair writes. Yet, crafters also often repeat entire projects. "It is not uncommon for a beader to make 20 copies of the same earring, or a knitter to make dozens of the same stuff owl" (Craft, Volume 2, p. 7). Anyone who has known someone with a crafty knack is familiar with this proliferation. Knitted blankets are wrapped up for every baby shower. Ceramic bowls stack-up in kitchen cupboards, progressively improving. Repeated construction makes crafters generous gift givers (Make, Volume 4). Sinclair observes it also makes them "business minded." After all, bulk production is the basis of industry.

Exemplars of business within *Craft:* are typically akin to the model of the alpha maker proposed by Dougherty. A crafter or maker creates an artifact by hand that then becomes widely desired in the broader public. For example, Volume One describes the "ugly doll" a knitted or sewn, creepy but cute, creature that was first made by Sun Min-Kim in early 2000s. Kim began by stocking 20 ugly dolls in the Los Angeles boutique Giant Robot. Within eighteen months, Kim was selling 1,500 robots, and her "hands were bleeding from sewing them all herself." The year the article in *Craft:* was published, more than 60,000 ugly dolls were being made in China. In 2019, Ugly Dolls became a major animated film. Kim's creations also spawned an entire industry of similar creations called Amigurumi (Japanese for knitted doll). Etsy predicted they might be "the next beany baby, except handmade" (Craft, Volume 1, p. 44).

It's interesting to think about repetition as a resource for the business minded, especially in comparison to *Make.* The projects created in early issues of *Make* are often singular; they are novel executions of an idea. It's difficult to imagine someone needing more than one automatic cat-food dispenser made from an old VCR. So much of the value in that project is in the doing – in the puzzling, problem solving and the learning that comes from that. Once it's accomplished, what more is there to learn? In their reoccurring column "Life Hacks," Danny O'Brien and Merlin Mann define the disposition of the geek as one who is "novelty seeking" and who has an "overpowering fear of tedium" (Craft, Volume 6, p. 17). While coding, good work means removing redundancies not doing the same thing over and over.

Repetition enters into the business minds of *Make:* in the form of iteration – the cycles of improvement that generate a better product. For example, a maker constructing a set of speakers *does* create multiple sets. But they are bigger and bigger systems, testing as he goes (Make, Volume 3, p. 18). Iteration is definitive for the influential model of design proposed by the Stanford Design School (or "d.school"). This 5-step process ends with prototyping and testing, and then begins again. Iterative models like these integrate feedback from building and using a prototype into a new design. However, the output is only ever a better – and singular – prototype. As Fred Turner (2016) argues in his entry for the series Digital Keywords, prototypes are above all communicative objects. They just need to make an imagined idea seem possible.

These different perspectives on repetition mean that makers and crafters become acquainted with different parts of the innovation process. The Smithsonian Lemelson Center for the Study of Invention and Innovation distinguishes between invention and innovation. Invention is defined as creating a unique material, device, or method. Innovation means "scaling up" an invention in a way that creates value. As one of the exhibit designers at the museum explained to me, innovation occurs at the moment an invention becomes valuable to your culture, to someone besides *you*. It must be widely useful and widely available.

Up until this point, the craft concept of repetition has been almost totally inline with the goals of *Make:* magazine. Repetition helps crafters to think it a way that turns their creations into sellable products. Yet, for the rest of this chapter, I'd also like to explore a point of divergence that is also prevalent in the pages of *Craft.* With an overarching focus on personalization and prototyping, makers learn a lot about what it takes to make an invention. But, they learn very little about what it might take to make something over and over. In my experience crafting with my research team on the *Making Core Memory* project (the focus of Chapter 3)—we learned rather quickly that making a component once and making a component 43 times were quite different, not only in terms of time but in terms of strained eyes and blistered fingers. Modern prototyping processes separate creators from understanding the material conditions required to bring their designs to the masses. Craft practice, through its engagement with process, is an intervention into the human consequences of mass production.

**Breaking Cycles of Consumption.** In the Crafter's Manifesto, Ulla-Maaria Mutanen writes that, through craft, "materials become important. Knowledge of what they are made of and where to get them becomes essential" (Make, Volume 4, p. 7). The Crafters Manifesto was a crossover. Published in Volume 4 of *Make:* magazine, it appears in the same issue as the Maker's Bill of Rights (formatted in the same style) and almost two years before the first issue of *Craft.* Mutanen would go on to be a regular contributor to *Craft:* where an attention to materials was a recurrent theme. The materials used in craft projects were often unconventional. They subverted expectations of craft that are often limited to fabric.

The use of unconventional materials in *Craft:* was about more than novelty. Although unconventional materials do ascribe to the most basic definition of innovation – that is to say, newness – they also required innovation in terms of process and technique. Artist Ann Carrignton, who uses buttons and telephone wires in her tapestries, described her work as such:

> "It's hard work working the way I do, as each new sculpture involves material I have not worked with before and often there is no precedent – so I can't consult a guidebook."

For Carrington, and many other makers within *Craft,* working at the edge of precedent comes from practices of reuse. Makers created blankets from old jeans, dresses from expired (unused) condoms and undying gardens from foraged branches and found spray paint (Craft, Volume 2; Volume 3; Volume 10). As the magazine progresses, discussions of materials – and the environmental impact of their sourcing – were in nearly every article by the tenth volume. Crafting becomes a way of breaking a cycle of consumption, which begins with buying and ends in a landfill.

Even when the materials used by crafters are more traditional, crafters remain concerned with the processes of creation. For example, in the multi-page profile of crochet artist Stephanie Syjuco, she reflects on what the magazine dubs "conscientious counterfeiting." Syjuco recreates luxury handbags through using a crochet process that is both incredibly true to the original and makes no attempt to appear "real" (Craft, Volume 2, p. 54). Syjuco uses chunky, inexpensive yarns to intentionally "debase" the original. These qualities call attention to the handmade nature of all luxury handbags. The author of her profile, Garth Johnson, writes:

> "Most of the people who manufacture luxury items in sweatshops cannot afford the objects they produce – instead, underground economies trafficking in ersatz luxury goods flourish in their own shadowy netherworlds."

Johnson's observation brings two things to light. First, the work of people who actually *make* handbags is exploitative and under valued. Though this isn't put into dialogue with larger conversations about the maker movement, it calls to my attention to how "working with your hands" transforms some people into innovative makers and leaves others as laborers. Secondly, this perspective essentially claims counterfeiting as a tactic used by those who manufacture handbags to reclaim value.

Projects of symbolic subversion, like Syjuco's, were at times critical in both their content and in the processes through which they were constructed. This shines most clearly in a profile of artist and MacArthur ("genius") Grant winner Liza Lou. Lou reflects extensively on the processes of labor that produce crafts – both on an individual and community level. On her collaboration with South African Zulu bead workers Lou states "Labor is undervalued everywhere and the laborer too often ends up discarded." She goes on to argue that good craftsmanship makes it more difficult to toss things away. Craftsmanship is especially evident in Lou's work, which is created from mounting millions of tiny seed beads on room size installations. One of the installations takes the form of meticulously beaded death row prison cell. "Beadwork is a slow, quiet practice that counts the hours," she says "not unlike doing time." (Craft, Volume 1, p. 32). Craft becomes a physical consideration of production processes, with the object of those processes acting as a critique.

**Representations of Making**

At a 2013 conference dedicated to discussing the power of digital fabrication in education, Leah Buechley asked "What is making?"[22] Buechley was the leading voice of craft within academic maker culture. She'd recently concluded her tenure as director of MIT's High-Low Tech lab, where she had produced a generation of PhD students and projects that integrated fabric and paper with opensource code and electronics. Buechley's keynote address anchored making in the ancient past, in cave paintings 17,000 years old. Making is "what we do as a species … it's really the essence of humanity," she said. Buechley's definition of making isn't that distinct from that of *Make:* magazine. In his TED talk, *Make:* publisher Dale Dougherty declares "We are all makers. We are born makers."[23] Yet, as she continues, Buechley points to a

[22] Leah Buechley (2018). *Thinking about making*. Presented at the FabLearn: Digital Fabrication in Education, Stanford, CA. Retrieved from https://edstream.stanford.edu/Video/Play/883b61dd951d4d3f90abeec65eead2911d

[23] Dougherty, D. (2011, January). *We are makers*. Presented at the TED, Motorcity. Retrieved from https://www.ted.com/talks/dale_dougherty_we_are_makers

vast disparity between make as an essential human practice and the make that is branded in the publication.

Although her work was clearly embedded within the maker movement, Buechley observed that her "interests weren't always in synch with the corporate brand that is *Make:"* magazine. The word "interest" there did double duty. First, Buechley's academic interests – craft, textiles, ceramics and paper – were largely excluded from the pages of the magazine. Buechley had done a basic analysis of 9 years of *Make:* magazine issues, all 36 covers that had been published at the time of her address. Over half of them had featured electronics-themed covers, almost a third had featured vehicles, and a quarter had featured robots. In the question and answer portion of the talk she adds, "There isn't a single cover that features textiles." Absent were grand Trinidadian costumes for carnival (which she described as "feats of engineering") and intricate Acoma-Pueblo pottery ("non-euclidean geometry anyone?") Her observations paint a picture that is undeniably one of STEM knowledge, imagined through a different set of materials.

The covers of *Make:* were also limited in who they showed to be makers. Of the 40 people featured on the cover, 85% of them were men and boys, 15% were women and girls. None (zero percent) of the people featured were people of color. For that last point, Buechley stops an utters an exasperated expletive "Holy f-ck. *Make,* are you serious?" These figures are almost exactly the same as those of the editorial staff during the same period of time. She summarizes her findings in response to the question she posed in the beginning of her talk: "Who are makers? … White guys and white boys." When she breaks for questions, the conversation is tense.

> "Don't they have publications for all those different kinds of makes [sic]. There are pottery publications and ceramics publications and quilting publications," a commenter without the microphone pipes in.
>
> "The problem with that argument…" Buechley responds, "is that those publications don't receive the funding, or attention or visits to the White House that *Make*: receives. So, it's the power and influence that's the commodity here, that's in short supply and not reaching a diversity of people."

In highlighting the power that comes along with status of "maker," Buechley brings in a secondary layer to the concept of "interest." The images on the cover of *Make*: don't align with Buechley's best interests – as in, they aren't to her benefit or advantage. As (though white and highly educated) woman, people like Buechley weren't usually the recipient of the elite status conferred upon makers. As making moved from a geeky subculture to an engine for innovation, this limited definition distributed power to some activities and some participants and not others.

Buechley's choice to focus on *Make:* magazine is fundamentally about the power of representation. As a highly visible brand, the images in *Make:* magazine shape public understanding of the maker movement as a whole. Representation impacts who is seen as a maker. The absence of craft practices also means absenting the people who do them. In empirical research contexts, for example, women are undercounted as "makers" simply because their activities don't align with how making is operationalized, through electronic activity (Faulkner & Mcclard, 2014). Women internalize these criteria. In 2013, MIT added a "maker portfolio" as a supplemental, optional portion of the undergraduate admission process. In its first two years, over 85% of maker portfolio applicants were men – a 15% higher disparity than MIT applicants as a whole. This suggests that, among other things, that women may not identify themselves or their work as making (Peterson & Abelson, 2015).

Today, *Make:* magazine seems to be taking gender representation to heart. Five of the six[24] issues published in 2018 featured a woman on the cover. This pattern comes in the wake of a controversy in the maker community involving Naomi Wu (who was subsequently featured on the first cover of the year.) Wu, who goes by the handle "Real Sexy Cyborg," was already a well-known maker from the Chinese city of Shenzhen[25]. But, she hit a new level of fame after *Make:* magazine founder Dale Dougherty incorrectly tweeted that she was likely a front for a team of other makers. Implicated in his statement was that someone who looked like Wu – a non-western woman, whose augmented body is part of her persona – couldn't be the sole source of such significant projects. Wu points out the deep level of irony in this assumption, stating "chances are the phone or the computer you are reading this on was made here—maybe even by a girl I grew up with." Wu's statement is a reminder that only a small part of technology production processes fall within the purview of "making."

For all its celebration of the material, making is still largely centered on cognitive contributions. The innovative potential of making depicted in *Make:* magazine is always about ideas. Even when engaging in practices of repair or modification, the real value is when they lead to something new.

Early issues of *Make:* are committed to enabling repair and customization. They further an argument that these engagements produce innovators with a maker mindset. This shows up directly in Cory Doctorow's discussion of amateur radio's ability to inspire young people to become innovators. In a *Make:* article titled "The Last Generation of Engineers," Doctorow

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[24] The issue that didn't feature women didn't include people on the cover at all.

[25] Shenzhen is probably the most significant site of making in the world today. It is often called the "Silicon Valley of hardware." Silvia Lindtner and her co-authors (2015) argue that the instantiations of making in Shenzhen challenge the binary of creative work (design) and rote production (manufacturing) that I discuss throughout Chapter 3.

discusses the way that the copyright restrictions on media technologies are killing innovation.

> "This engineer – he's a skilled and passionate geek. He got to be that way when his grandpa showed him how to build a crystal tuner. But, he'll never sit down with his own granddaughter and teach her how to hack a DTV tuner" (Make, Volume 2).

By Doctorow's account, engineers are the product of early interactions with open technologies. They inspire a lifelong enthusiasm for building and knowing about *things*. Although other makers admit that the outdated technical elements of the crystal radio aren't directly applicable today, they "excel as an exercise in creative and logical thought … that teach the timeless lessons of learning by trail and error" (Make, Volume 4, p. 187). While the radios might not teach the tenets of modern technology design, they do teach young people how to develop an innovative mindset through DIY.

*Make:* magazine's vision of innovation-through-DIY is associated with a set of materials in which amateur radios are a recurrent artifact. Volume 4 of *Make* has a section devoted to various types of kits in which one contributor enthusiastically states "I'll bet that every engineer in the country over the age of 50 grew up building Heath [radio] kits!" The mythology of the engineer-via-childhood experience extends well beyond the pages of *Make*. Technological projects focused on both physical and digital artifacts draw on shared imaginaries of the "technologically precocious child" who is enamored with technology, rebellious, and typically male (Ames & Rosner, 2013).

In his book *The Innovators*, Walter Isaacson (2015) traces the personal histories of computing pioneers—and at least two of these stories begin with young boys tinkering with radio. Both the inventor of the integrated circuit, Jack Kilby, and co-founder of Apple, Steve Wozniak, became interested in electronics after interacting with "ham" (amateur) radios as children. In a meditation on the decline of hobbyist culture, Isaacson reflects "for decades young innovators such as Kilby and Noyce had been introduced to electronics … by creat[ing] circuits that became ham radios." Sounding like a page straight from *Make:* magazine, Isaacson observes that in a world of Macintosh, mass production and microprocessors "do-it-yourself kits withered away."

From the beginning, *Make:* magazine has been committed to a reclaiming of DIY practice is technology creation and American culture more broadly. Their narratives have been inextricably connected to the emergence of the making as a phenomenon. At all times they are co-creating and shaping a movement that is emerging around them. How might this movement be different if it told different stories – about different makers, different practices? Taking *Craft:* magazine as a model, we see an alternative that explores innovation as part of a process, not an outcome of a product. As Jean Railla writes "the most powerful aspect of modern crafting is that it turns the very premise of our results-oriented culture on its head. In crafting, what counts more than what you make is how you make it, or rather that you chose to make it at all" (Craft, Volume 2, p. 12).

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## Chapter 2 - Reproduction: Enacting Maker Ideals

The day at the International Symposium for Academic Makerspaces began with Dougherty's plenary and an address by Marty Culpepper, MIT's "maker czar." The first paper presentation was next. Titled *"Sustaining a Diverse and Inclusive Culture in Student Run MakerSpaces,"* the presentation's position in the early hours of the conference underscored the importance of the topic. Alexis, a mechanical engineering graduate student at Georgia Tech, opened by discussing the three-fold mission of the Georgia Tech "Invention Studio:" to instill creative confidence in students, foster diversity in higher education, and create a welcoming and fun learning environment. Their mission echoed three of the primary goals of academic makerspaces across the country: education, inclusion, and community. The second goal, inclusion, was the focus of the presentation.

Alexis and her team had struggled with gender disparity in their makerspace. In Fall 2014, only 9 out of the 65 student volunteers were women. This was despite the fact that 1 out of every 4 engineering majors on campus were women, an accomplishment that put them above the national average of 1 in every 5 (Noel, Murphy, & Jariwala, 2016). The team at Georgia Tech saw that one of the most significant barriers for new participation at the studio was the perception that it was "only for engineers." This idea is a recurrent problem in many makerspaces.

On the one hand, thinking that makerspaces are "only for engineers" is a pragmatic misconception – based in the idea that the tools and skills one accesses in makerspaces are only useful for the kinds of projects pursued by engineers. Without a goal given to them externally (in the form of a course assignment or a task), beginners and hobbyists enter makerspaces unsure of what they could even do there[26]. On the other hand, “only for engineers” also speaks to the kind of gatekeeping that creates implicit ideas about both *who* is welcome in a space and *what kinds of activities* are legitimate. Since the early 2000s, education researchers have theorized computing fields as a “locked clubhouse”—an exclusive realm in which there are insiders and outsiders (Fisher & Margolis, 2002). Those who come to computing through other interests feel like outsiders due to technology mythologies that depict expertise as arising from a single-minded obsession with computing. When not overtly exclusionary, boundaries can also be enforced through hierarchies that dictate “proper” use of the valuable equipment. Throughout technology history, the idea of “wasting time” has been wielded to discipline the more social-uses of technologies (Marvin, 1988).

To dispel the idea that the space was only for engineers, the invention studio began hosting “STE(A)M” workshops. STEAM refers to a growing movement within education to incorporate Art (A) within Science, Technology, Engineering and Mathematics (STEM). Alexis described these activities as “more crafty” – introducing students to metalworking through creating steel roses or solder through stained glass. Through specifically aiming to unseat the idea that the makerspace was only for engineers, the team at the Invention Studio had a surprising secondary result. The majority of the workshop participants were women; a ratio that Alexis remarked they rarely see. The STEAM workshops at Georgia Tech underscore the deeply connected ways that disciplinary activity in a makerspace is always bound up in larger, already unfolding gender dynamics within disciplines. Especially interesting in this case is that the

[26] I’m grateful to human centered design researcher Kathryn Shroyer, who made this observation while advocating for the implementation of project examples, models and patterns at the CoMotion makerspace.

materials were no less “hard.” Steel and solder are metals. The themes and modes were merely more art-forward; focused on creating a visual product.

Their second strategy involved appealing to women more directly, through hosting a “ladies night.” The Invention Studio wasn’t alone with their gender disparity issue. For example, a market report co-sponsored by *Make:* magazine and Intel (2012) indicates that only 2 in every 10 makers are women. Although values of openness and empowerment motivate much of maker culture, makerspaces are never the less also sites where women sometimes feel that they don’t belong (Davies, 2017).[27]

Two-hundred and sixty women showed up for Georgia Tech’s first ladies night. The fact must have stood out to Christa, the new director of the University of Washington’s CoMotion Makerspace. She was also in the audience. A few weeks after returning to campus, she emailed me and another graduate student about wanting to start a ladies night at CoMotion.

In this chapter, I consider the inclusive promise of making within the CoMotion makerspace’s larger goal of innovation. I describe institutional understandings of making as a method of encouraging self-empowered learning and original thought. The makerspace was designed with many types of tools and founded by mentors with various types of expertise—all connected by the belief that creating physical things with your hands is a source of knowledge. While scholars define the knowledge built through mind-and-hand as “craft,” the space emphasized “making” as a gender-neutral form of production. As making remained at the forefront of CoMotion’s narratives, administrators and mentors couldn’t help align the

[27] A culture of masculinity, common to many technology communities, has inspired the founding of “feminist” hackerspaces which support women makers. Yet, these spaces also struggle to address the intersecting oppressions women face (Fox, Ulgado, & Rosner, 2015; Rosner & Fox, 2016).

innovative goals of the space with high-tech and digital fabrication tools. Craft was associated with women's activities in the space and with textiles, and both were often seen as outside of the larger project of innovation. These qualities were ultimately reinforcing. In this chapter I conclude that inclusive innovation will require broadening understandings of making, in which expertise in hardware and soft-textiles are both valued as contributing methods of Do-It-Yourself creation.

**Observations, Opportunities**

"Hello ladies," the email from Christa began, "The former director suggested some of you as collaborators and champions of women in makerspaces. As you know, the CoMotion MakerSpace is comprised of mostly men and I would like to change this balance a little bit." Christa had gotten my information from the former director, Dave, who'd been my sponsor when I began doing a weekly observation of the space in Fall 2015.

When I began observation at CoMotion, the makerspace had opened just a quarter earlier and was in its earliest stage of operation. The people employed there were the founding mentors and were hired specifically to help build the space. The founding mentors embodied aspects of Dave's initial vision, each having deep knowledge over a specific genre of expertise. This was especially true of two of my key participants: Jacob, an expert machinist, and Sophie, a master sewer – both who will be featured prominently in this chapter. Even after Dave left and Christa took over his role as director, Jacob and Sophie's ideas and perspectives shaped the trajectory of the space in the next two years.

During my first ten-weeks of pilot research at CoMotion, Dave and the mentors often said that the goal of the makerspace was "radical accessibility." That mostly meant providing access to tools, equipment, training and space. The makerspace filled a gap created by the closed-door system of other labs on campus. These labs were only available to members of the associated major, making technology design tools inaccessible to undeclared underclassmen or anyone outside the engineering fields. As a student using the makerspace to run a small business put it, “the other labs on campus are selfish.”

By my observation, the makerspace had made significant achievements in terms of access. Like the Invention Studio at Georgia Tech, CoMotion was working to dispel the idea that the space was “only for engineers.” My first time creating anything in the space, I was surprised to find that there were no rules that prioritized projects relevant to school work. I had more freedom with a six thousand dollar laser cutter than I did with the Xerox machine installed in the graduate student office suite. When I began using tools in the space, it took months for me to shake of the fear I was about to get in trouble for making something personal – a feeling that is familiar to anyone who has “stolen time” while on the clock to pay the electric bill or write an email to your godmother. Activities like these are what critical theorist Michel de Certeau calls “le perruque” (the wig); personal work, concealed as labor (de Certeau, 1988). At the makerspace, I didn’t need to wear a wig – because the personal is educational.

Participants were also able to come to the space, with no prior training or experience, and after a brief 15-minute safety orientation, could get to work the same day. Makerspaces – like many labs and studios – must constantly tradeoff between access and sophistication(Resnick et al., 2005). It should be easy for beginners to start participating in the space. But this has to be balanced with serving the spaces most competent users, who need and want high-tech (often dangerous) equipment. In a community meeting shortly after the space was founded, this played out concretely when a member suggested building a woodshop. Dave, the director responded:

> "The way we conceived of the space was a lighter digital fabrication lab that has a low bar for people to get in. We've been thinking about a woodshop, but it's a different class of noise and dust, and needs to be enclosed."

A woodshop would require heavy-duty ventilation systems that would physically separate it from the rest of the space. It would have a completely different threshold for access. After the meeting, I did a recap with Jacob, one of the founding mentors in the space who was intimately familiar with industrial equipment through his metal work. He pointed out a woodshop would necessitate greater training and management, speculating that it would need "two people supervising at all times to make sure people don't kill themselves, and at least three one-hour orientation sessions." This meant an increase in mentor labor and member training, in additional to a complete infrastructural overhaul of the space[28]. As the discussion of the woodshop illustrates, increasing mechanical power can attract and retain the most ambitious users, but makes the space less accessible to beginners.

Ideally, creative spaces are both easy to get into and have lots of room for growth. This ideal – called "high ceilings and low floors" – is especially important to makerspaces and other sites where creators learn from their peers (Resnick et al., 2005). Drawing on constructivist models of learning, makers learn informally from each other rather than using traditional models of instruction for transferring knowledge. Novices learn from more experienced makers, as they create with and alongside each other. Overtime, novices become experts, "multiplying in expertise" as one maker put it. For this model to work, the makerspace needs to make sure that champions don't outgrow the space, and take with them the knowledge they could share. By my evaluation, they were succeeding at balancing this aspect of access.

[28] In Spring 2017, a woodshop was built in the makerspace – occupying a significant portion of the makerspace floor plan and sectioned off behind floor to ceiling plywood walls.

Yet, if accessibility goals of the space meant increasing the diversity of participants at CoMotion – both in terms of gender and in terms of discipline – there was room for growth. According to my rough headcount over my pilot observation period, men out-numbered women 5-to-1. It seemed this hadn't gone unnoticed by Christa, when she took over her role as director the following fall.

The students I talked to during my pilot were also predominantly from STEM majors, meaning that the space was achieving a valuable goal of *supplementing* their access to the prototyping tools provided by their majors. Engineers reported that the high-tech equipment at CoMotion greatly increased the speed of prototyping. They previously had to contend with crowded major-specific labs or send-out specs for manufacturing their more complicated jobs. Their activities directly supported the overarching goals of innovation and generating intellectual property for the university department in which the makerspace was embedded.

However, if the makerspace was just a supplementary source of tools, it was going to be difficult to build the knowledgeable community that the makerspace needed to inspire and teach a new cohort of innovators. The space needed "critical mass" – a robust population, at varying skill levels, with broad expertise and interests. Transitory makers who only visited when their equipment was broken or overloaded couldn't be counted on to contribute. At makerspace community meeting, someone asked Dave what success looked like at the makerspace. "Success is having an active community making interesting products and projects that come out of it," he responded. The complexity of this statement makes it clear that an active community isn't the goal in itself. Rather, a community is how more good things will get made.

Before the makerspace was founded, many of the same tools existed somewhere on campus. The environmental engineers had a lab with their own 3D printers. The drama department had sewing machines that the costume club could use after hours. But, making in either space required membership – and, importantly, happened separately. If someone outside the group wanted to use these tools, “you basically have to know someone,” Jacob told me. This path to access has two main problems. First, it can only ever reinforce existing networks of knowledge – at best bringing in someone adjacent to the field, but rarely completely outside it. Second, through siloing people within distinct areas of expertise, it hampers cross-disciplinary collaboration and cross-disciplinary learning. Through addressing a “gap in access” the makerspace was trying to undo both of these inclinations.

The loftiest goal of the makerspace was to activate *new* innovators and new forms of innovation. Increasing gender diversity became a focus especially. Administrators were going out of their way to increase the number of women in the space. And they were coming up short. Throughout my two years of observation at the makerspace, I saw no evidence of overt sexism, and many instances where gender was put at the forefront of inclusion initiatives – including the “ladies night” that is the focus of this chapter. Why, then, was gender equity still a problem at the MakerSpace? And, ultimately, what could this case tell us about the limits of access as a means of addressing gender equity? What barriers continue to exist for women in STEM – even when the doors are open?

**CoMotion: Innovation Headquarters**

The makerspace is part of a larger department at the University of Washington called CoMotion, formerly known as the Center for Commercialization (or, C4C). The Center for Commercialization, and now CoMotion, focus on managing intellectual property (“IP”) for products and discoveries made through research at the university. Historically, the department was created in the 1980s as part of the Bayh-Dole act, which changed the management of intellectual property rights of federally funded research. Before Bayh-Dole, the patents for federally funded research belonged to the government (Stevens, 2004). As Dave, the founding director of the makerspace tells it, the federal government was woefully inefficient at taking products to market, resulting in a backlog of inventions. Caught up in the bureaucracy of the government, the inventions weren't any use to anyone – so the Bayh-Dole act handed the management back over to universities where they could be more effectively managed. Today, the department is an enormous source of revenue for the university.

Even under a new name, CoMotion had commercialization at its core. One of CoMotion's central roles is "technology transfer." Tech transfer, as the industry calls it, is a process through which the products of university research are developed and made available for further, commercial development in the for-profit sector (Bremer, 1998). On the drop-down menu explaining 'What We Do' at CoMotion, the makerspace is just one part of an organization that also specializes in funding, start-up incubation and IP advising.

As part of CoMotion, the makerspace has explicitly commercial interests. The prototyping that occurs at the makerspace is the first step in a chain of design, development and production—which the student leads referred to as "pipelining." Jacob summarized it succinctly as "taking people's ideas and making money." Pipelining is a term used in many university development settings. A helpful info-graphic from the University of Minnesota shows companies in a Start-up Pipeline, in which the final, narrow opening is marked "commercialization" (*University of Minnesota Start-up Pipeline*, 2015). Along the way, innovations follow a 5-step flow, beginning with seeking ideas, developing intellectual property positions, and ending with a license to start-up.

Start-ups aren't a far off idea for CoMotion makers with entrepreneurial goals. Directly above the makerspace, university researchers and students operate burgeoning technology businesses on the "start-up floor." Start-up employees filter in-and-out of the makerspace, using the machines for prototyping elements of hardware or devices. Their proximity opens the potential for knowledge exchange, like the halls of Bell Labs where cross-team conversation famously made the scientists more inventive (Gertner, 2012). But, their presence is also an aspirational reminder. "Going upstairs" represents the final step in the pipelining process – the moment when your ideas became a viable commercial endeavor.

When the Center for Commercialization rebranded to "CoMotion" in January 2015, they produced a video announcement. It features sweeping shots of the university grounds, whiteboards scrawled in chemical models and scientists in lab coats peering into microscopes. They're the familiar, historical images of science and technology—of pioneers of discovery. Yet, the video also features more contemporary images. The camera stops on a poster reading "Start-ups Are Here to Save the World" and then cuts to a shot of two young men playing Ping-Pong in an office space. Ping-Pong tables at the office are a short hand, even clichéd, image used to reference the modern workspace of technology giants in Silicon Valley. A song sounding like Florence and the Machine's optimist anthem "Dog Days are Over" breaks for the first time to the voice of Renuka Ramanathan, a PhD student in Bioengineering. While at the University of Washington, Ramanathan founded Empreva, a discrete drug delivery technology designed to protect women from HIV and pregnancy. "Innovation," she says, "is really the process of understanding an issue, being able to distill it down to its key components and then addressing those components with a very effective, but also practical technology."[29]

CoMotion's rebrand in 2015 signaled a larger rhetorical shift made by the university from the discrete activity of commercialization—which involves patents, licensing, and intellectual property—to the more abstract concept of innovation. By definition, commercialization is an act of management in which the goal is making a profit. It's about revenue, yes. But it's also an endpoint. It's the last turn of the screw, the moment at which the long road of development generates a profit.

Innovation, on the other hand, is a holistic process. According to CoMotion, innovation begins with building "innovation mindsets" and ways of thinking. For the university, emphasizing innovation represented a change in "philosophical viewpoints." No longer solely focus on intellectual property; they emphasized "innovators, teams and organizations" (Levy, 2017). This meant investing in every step of the pipeline from incubation to external partnerships.

However, CoMotion's rebrand in 2015 doesn't just reflect a change in spirit but also a significant change in the university's revenue strategy. In 2014, the university was facing a "revenue cliff" resulting from the expiration of the Hall portfolio (Levy, 2017). Named for the UW faculty member who pioneered a new method of yeast production, the Hall patents provided the world with the basis of the Hepatitis B vaccine and provided the university with $350 million dollars in royalties over the course of 30-years (UW News Staff, 2014). The significantly

[29] The original video and associated content are no longer accessible on the CoMotion website. A similar video, featuring the conversation with Ramanathan, can be viewed: https://www.youtube.com/watch?v=olKjrUTx2KE

diminished commercial revenue stream forced a complete rethinking of the department's outmoded business model (Levy, 2017).

Rather than simply focusing on intellectual property licenses, the university needed to become an "entrepreneurial ecosystem" (Romano, 2014). Encouraging the innovation mindset was a part of this. Ideas needed to come from somewhere. But, more concretely, the entrepreneurial ecosystem positioned CoMotion as a contributing part of a larger arrangement reaching beyond the confines of campus; a system of cooperation between universities, founders and businesses. This meant changing their approach to licensing agreements, which took 10-times longer than comparable institutions and often financially favored the university. Founders were unmotivated to develop their products, the UW Committee on Technology and Entrepreneurship argued. Their report went on to state:

> "The goals of technology commercialization are broader than revenues from IP licenses and should primarily be the diffusion of knowledge and innovation developed at the university and the contribution to economic development" (Romano, 2014).

The committee concluded that the university's singular focus on commercialization was stifling the pipeline that makes commercial revenue possible. If they were going to stay-afloat financially, that needed to change.

Innovation, as a concept, now drives everything at CoMotion. Until 2019, the top figure in the organization was Vikram Jandhyala, title: Vice Provost of Innovation.[30] Jandhyala was appointed in 2015, as the university was shifting its strategy.[31] During his tenure, the University of Washington has consistently ranked in the top-5 of the worlds most innovative universities alongside renounced private institutions, Harvard, Stanford and MIT (David M. Ewalt, 2018;

[30] Jandhyala tragically passed away while this dissertation was being written. His advocacy for inclusive innovation has left a lasting impact on the University of Washington.
[31] Even his title represents the shift in language. He replaced Linden Rhoads, Vice President of Commercialization.

Thiveaud, 2015). These rankings position the university as a major player in cutting edge industries, as intellectual and immaterial labor plays an increasing role in the U.S. economy

Beyond scientific discoveries and inventions, universities also produce scientists and inventors. Universities have been valued for their capacity to transform individuals into specialized workers at least since the land-grant system began. More recently, cities like New York have invested in technology-focused satellite campuses of prestigious universities. The *New York Times* largely credits education initiatives for the reemergence of New York as one of the country's central technology hubs (Lohr, 2018). Becoming a technology hub began with a "long-term campaigns to upgrade the technical skills of the city's workforce." In Seattle, industries see the UW as a major source of the talent and ideas that underpin a local economy fueled by technology and engineering enterprises: Amazon, Microsoft, and Boeing (Romano, 2016).

**The CoMotion Makerspace**

The CoMotion Makerspace garners both funding and space on the university campus through its potential contribution to the University of Washington's revenue and reputation as an innovation hotbed. In an info-graphic explaining the CoMotion innovation process, the makerspace sits squarely in a quadrant called "Creating." Within this area are other creative spaces (research labs and workshops) and creative activities (projects and design). From this perspective, the CoMotion makerspaces represents the preliminary step in innovation – the step before the first steps of commercialization, "step 0" in the language of Silicon Valley.

For example, early on in my observations of the MakerSpace, I met William, a boyish and eager college freshman. On the screen of his laptop was 3D modeling software, where the shape of a human hand was outlined in green on a black background. It looked like how movies imagine the future of computing, like maybe he was building the terminator. But, William was designing a glove that could translate sign language and speak it aloud[32]. The makerspace had the equipment William needed to prototype the physical aspects of the glove, the 3D printed joints and the circuitry. He was working with the entrepreneurial law clinic to get a patent. Even though William had been working in the makerspace, CoMotion didn't automatically have rights to what he built. In the spirit of the innovation ecosystem, the makers retain them. William's story illustrates the ideal functioning of CoMotion's Innovation Quadrant, where innovators move from "Creating" and into "Building" for development and IP.

The makerspace most explicitly contributes to innovation "Creating" through enabling rapid prototyping. Machines like the LPFK allow makers to mill custom circuit boards – cutting a pattern through a sheet of copper laid over a fiberglass insulator. Before the makerspace, they would have done a rough prototype by hand and then sent out the specifics to be made in China. Within a ten-week academic quarter, they would have time to make three revisions, maximum. Each version took two weeks to arrive. Now, makers can create multiple versions of a product in quick succession, rather than getting it exactly right (or, hopefully right) and then sending it out for fabrication. While working on the LPFK, a maker described it as "shoot first, ask questions later." Prototyping in this way not only increases the speed of innovation, but also transforms the innovation process to allow for small tests-and-revision cycles that technology communities call iteration.

More abstractly, the makerspace also contributes to one of CoMotion's highest ideals:

[32] After winning a prestigious college invention prize, this project was met with a needed, critical discussion about the nature of sign-language gloves (Erard, 2017). The deaf community expressed that technologies like these are reductive (overlooking important elements of facial expression and emotional gesture) and abelist (meant to improve accessibility for the deaf but, because they are worn by signers, burden them).

"inclusive innovation." CoMotion defines inclusive innovation as reaching across disciplines and space. It comes from a mindset that values "diversity of thought." Inclusive innovation was championed by Jandhyala for its ability to weave compassion into technology innovation, creating a more ethical and impactful design practice that emerges from networks of people working together to solve large-scale problems(Jandhyala, 2018). As a creative space open to all students on campus, the makerspace offers inclusive innovation through its potential for multi-disciplinary interaction and collaboration. Here, makers meet others who share their interest in innovation but have differing sets of skills.

Yet, even more significantly, the makerspace also has the potential to bring greater diversity to who participates in innovation. Students, who may not consider themselves inventors or innovators, come with an instrumental need (like access to a specific tool) but overtime learn new skills and develop new goals. The link between greater gender equity in STEM and increased innovate thought is made clear in the 2015 report from the American Association of University Women: "Why does women's representation in engineering and computing fields matter? The answer can be summed up in one word: Innovation. When women are not well represented in these fields, everyone misses out on the novel solutions that diverse participation brings" (Corbett & Hill, 2015, p. 10).

Together, the makerspace appeals to the value of innovation as a source of *innovative ideas* and as a source of *innovators*. Over two years, the CoMotion makerspace attempted to broaden participation through socially supporting budding innovators and incorporating creative practices at the margins of innovation. As the previous chapter showed, scientific practices based in circuitry and code are central to the visions of "maker" built by *Make:* magazine. These images bind the value of making to a narrow set of practices, historically rooted in STEM fields.

In this chapter, I argue that making has the capacity to broaden participation in innovation—but only when it is valued on its own terms, and allowed to stand as a alternative to narrow understandings of innovation that are merely the monetized version of STEM.

**Crafting & Making, or "A Martha Stewart in a Mechanical Engineering World"**

At the meeting to organize ladies night, Christa and I are joined by Alexandra. As a PhD student in the department of Human Centered Design & Engineering, Alexandra is studying the potential of hands-on learning in mechanical engineering education. She'd been observing the process for the better part of a decade. After graduating college at MIT, she led a program that taught young people engineering through tackling problems in oceanography. Her team collaboratively built underwater robots. In some ways, Alexandra is just how I'd imagined engineers. She is technically competent, confident and forthright with her opinions. But, in other ways, she is totally different.

Alexandra is an avid sewer, knitter and ceramicist. She plays the French horn in an activist marching band that assembles for local protests. Over most of the time I worked with her, she was in the process of combining these interests by sewing a giant pink fur coat to wear when she performs. Shortly before coming to UW, Alexandra was "hacker-in-residence" for the minicomputer manufacturer Spark Fun where she designed an activity-plan to create e-textile flowers. "I'm a Martha Stewart in a mechanical engineering world," she told me. Her research as a PhD student would be bringing ideas like these together and was being funded by a prestigious grant from the National Science Foundation.

At the meeting, Christa is enthusiastic and frenetic as she lays out the challenge for us. According to her data, only one third of the people registered to use the makerspace are women.

Perhaps more concerning is that only half of the women registered with the space have actually used it. This means that even after clearing all the hurtles for access – locating the space (in a concrete tower on lower campus), visiting for the first time, and taking the safety orientation – half of the women aren't returning. Access isn't the problem, I think to myself. It's social or it's material.  Women either don't feel welcomed in the makerspace or they don't think their work has a place here.

To address both of these things, we decide to assemble a weekly event called "Crafting & Making." The makerspace already hosted weekly workshops. The most recent event calendar has "Intro to Rotary Laser Cutting" and "Intro to Rhino (CAD)" on the schedule.  But, Crafting & Making would expand the thematic focus to center craft-based forms of making such as sewing, beading, and paper circuitry. It would be like a meet-up. Sometimes we would have tutorials and curriculum, sometimes we would just gather together to work on our own projects. The key, for Christa, was that it was social – a standing engagement, where women knew that other makers would be there to share their skills. It could encourage women to come for the first time, and then give them a reason to keep coming.

**Makers Night**

When I arrive at my first meeting of Crafting & Making at the start of the next quarter, I am enthusiastically welcomed to "Makers Night." The meet-up had been renamed. In the weeks proceeding, Christa had sought input on the workshop from members in the space to assess if there was buy in. Ella, one of the mentors, told Christa that "crafting" made it sound too much like a "women's thing." Before the workshops had even begun, I ran smack-dab into a conundrum that would come up over and over again in my two years of observing the makerspace. It wasn't that *women* were seen as less integral to the makerspace. It was that *the* *ways of making associated with women* were already positioned as less valuable, less legitimate, in the innovative activities that went on there.

Ella wasn't someone who had internalized misogyny to the point of not wanting other women in the space. It was just the opposite. Each week, Ella was running a session for women in her prototyping class, teaching them the basics of laser cutting. On one particular Tuesday, I did a rough headcount of the space; there were ten men and eight women. Five of those women had come to the space to learn from Ella. Ella was a graduate student in the Human-Computer Interaction and Design program (HCI+D). She was a brilliant maker, someone who had the creative mind of an artist and the technical mastery of fabricator. She didn't want to do making-for-women; she wanted to make.

Within the narratives that emerge from *Make:* magazine, "making-for-girls" is often captured in a single word. Making-for-girls *is* "craft." As Chapter 1 revealed, *Make:* and *Craft:* magazines assemble separate material repertoires – distinguished between "hard" (electronic) and "soft" (fabric) materials. These material qualities are the primary editorial criteria for the two publications, yet the contributors and featured makers tend to fall along gendered lines. This conception of craft follows a historical precedent in which craft is used to describe a set of gendered material practices. Work with textiles has long been coded as feminine. As Roziska Parker (1984) argues in *The Subversive Stitch*, craft is separated from art through qualities also associated with women. Craft is made domestically (rather than the publicly), for love (rather than money), and with thread (rather than paint)[33].

However, craft is also defined – both in public praise and in scholarship – through physicality and process. Books such as Matthew Crawford's *Shop Class as Soul Craft* (2009),

[33] Rather than neutral categorizations, Parker argues these categorizations are "inherently unequal" and benefit masculine forms of creation.

celebrate craft as a method of reconnecting to meaningful, material work in an increasingly digital world. Crawford uses craft as a concept to highlight the knowledge and integrity that is inherent in “manual work” – or work done with ones hands. Though craft scholars have negotiated the relationship between industrial tools and craftwork (Adamson, 2013; Pye, 1995), predominant understandings of craft emphasize the relationship between hand and mind. In his seminal work *The Craftsman,* Richard Sennett (2008) argues for craft as a type of “material consciousness” in which knowledge is built through bodily practice. Similarly, Alexander Langlands (2018) uses the concept of “cræft” to highlight wisdom acquired through practice.

Taken together, craft is both a set of material practices – defined through physicality and process – and a subset of *gendered* material practices – defined by a specific set of materials, mainly textiles. At the CoMotion makerspace the material, hands-on qualities of craft are embodied in the Do-It-Yourself spirit that impels activity learning in the space. However, certain forms of craft are recognized as innovative – while others aren’t. These boundaries are often drawn along the gendered lines that have delineated craft in other aspects of creative culture.

**Learning Through Doing(-It-Yourself)**

On a Tuesday evening at the makerspace, everyone is quiet and hard at work. On a long worktable, a young man peers through his goggles and into a magnifying glass. Behind him are stacks of plastic nail drawers and a bank of voltage meters that have nobs like vintage radios. In front of him is a green computer chip. In one hand is a pair of needle nose pliers and in the other a blue tool that looks like a screwdriver. A methodical click is coming from his station, as the tool makes contact with the chip and the white board beneath it. He punches the chip and clicks the tool, like a pen, reloading and punching again.

Two sets of red and black wires are winding across the table. Another set is plugged in at the end, where a pair of makers – a young man and a young woman – is watching a YouTube instructional video of an Arduino with a yellow multi-meter laid out beside them. To the right, one of the mentors in the space is hacksawing a piece of metal clamped into a vice. To the left is a rack of 3D printers. All four printers are humming along. A slender young man watches—his faced almost pressed against the plexi-glass, monitoring imperceptible progress.

Closer to the entrance, there is a student using the laser-cutter to engrave logos on the wooden USB drives that graphic designers and photographers use to deliver digital materials to their clients. The student begun as a photographer himself, and had only recently learned to use the laser-cutter.

> "I think every skill in the world is simpler than it seems" he says "People look at these tools and they think 'oh that's an engineer thing,' but you just have to go after it and learn it."

"Just going after it" represents a venerated mode of engagement at the makerspace, where self-directed learning is encouraged, necessary, and incredibly fruitful. Makers tinker with machines and learn as they work their way through a project. "My learning process is a combination of screwing around, trail and error, and watching tutorial videos," a young woman named April once told me. She and her friend Ava were sewing a set of identical Victorian-era costumes. "But, sometimes, you need another person for help." April added. The day before we chatted, she called her dad – who taught her to sew – because she couldn't remember how to make a sleeve. You can ask for help in the makerspace too.

**DIY, meet SOS**

There are several sources of assistance at the makerspace, and all of them are people. First, there are other makers—peers, usually working on their own projects. Rather than requiring mastery from the instructor, I saw this kind of peer-to-peer teaching relationship occur between anyone who knew slightly more than the person asking. You didn't need to be an expert; you only needed enough knowledge to help. When I admitted not knowing much about sewing to April and Ava, April responded generously "I'm not the greatest sewer, but I can teach. I'm passible."

The makerspace also has two institutionalized sources of assistance: student leads and mentors. Like most of the other makers in the space, they're undergraduate and graduate students, and thus technically peers. But, student leads are employed hourly by the makerspace, and the mentors are formal volunteers. Mentors trade their time for additional privileges at the makerspace, like being able to use machines outside the "open" hours. When the founding director Dave hired the first student leads, they'd been selected for their expertise. Each of them had mastery of a particular domain – sewing, machining, or 3D printing. They possessed a wealth of information to help makers overcome challenges in their projects. Perhaps more importantly, they could also help the founding director, Dave, select the needed tools and write the safety protocols. Sophie, one of the founding mentors, sarcastically called it "outsourcing." But, since Christa began her role as director, this emphasis on expertise has changed.

The CoMotion website describes the makerspace as a "social hub for innovation." Where Dave had emphasized innovation – talking to me at length about product development – Christa was emphasizing the social. From her perspective, the most important thing a student lead could have was a welcoming attitude. A job call she put out advertised the position as seeking candidates who are "makers/tinkers interested in building a community in our space!  You should be welcoming, a quick learner, and curious!" Christa wanted people who wanted to build a community, not just build devices.

Throughout the time I observed her as director, the social environment of the makerspace was of central importance to Christa. Early on, she tells me it doesn't feel like a place where people can gather and "you can't expect innovation to come out of a space like this." She speaks about it in a way that frames her perspective as a departure from how things had been done before her – saying at one point that some more tenured staff needs to "unlearn" their approach to helping students. In all honesty I knew what she was talking about. It was difficult to know who to ask for help in the space. And, even when you did, the emphasis on learning-through-doing could give way to a dismissiveness, with troubled makers being told to figure it out for themselves. Under Christa's direction, student leads began wearing colored armbands to make them more identifiable. She hired a friendly new cohort of student leads. And, there was Makers Night.

For Christa – and the administrators more generally – the key to unlocking the innovative potential of a makerspace was fostering a social community. Crafting & Making was initially conceptualized as a workshop that acted as both a social and material intervention, integrating a more varied range of activities at the space and making participation "FUN" (in the all-caps emphasis of Christa). Under the new name "Makers Night," the workshop themes still introduced new activities to the space such as laser-cut jewelry making and sewn circuitry. Yet, to the unknowing maker, the name simply communicated an evening event. By the fourth meeting, Makers Night was being marketed as a source of assistance: "an opportunity to ask experienced makers for help." The craft element had disappeared.

**Masters, Crafters, Hackers**

Back at the sewing machines, April and Ava talked to me chattily. Their hands kept running as they simultaneously answered my questions and checked in with one another about their progress.

> "How far do you stitch the seam?" Ava asked
> "I just went until I could stitch it anymore."

April's response is like an allegory for the kind of engagement that I observed as inherent to the maker ethos. One needn't fully master a task before beginning; learn the musical scales before learning a song. Rather, makers are told to learn through their making. They go-on as best they can, until they hit a limit in their abilities. Then they seek out help.

Learning as you go, students can accomplish their immediate goals pretty quickly. For example, I talked with two students working on a medical prototype. Ashley and Corinne are both juniors, both bioengineering majors and both hope to be doctors. I don't realize it at first, but they're twins. Ashley and Corinne are trying to model the joint for a prosthetic finger.

> "We like the makerspace because, like six hours ago, we didn't know how to do this. We had to start from scratch. We had the basics. But we needed someone to help us get unstuck. Now, we could make anything."

Stories like Ashley and Corinne's are a maker ideal, especially from an innovation perspective. Regardless of their skills, they were quickly able to make an idea a material reality. All it took was a little help and a few short hours.

This improvisational creation seems like the antithesis of visions of craft that equate it with "craftsmanship"—the careful and learned mastery of a single domain. Theorizing technology makers as craftspeople connects them to lineages of practiced workers who engage deeply, sometimes over lifetimes (Coleman, 2013). Yet, there is also an alternate vision of craft that lives in the term "crafty"—used to describe objects in design cultures that seem tackedtogether, homemade, or lack polish [34] [35]. Making, in the innovation context, is more crafty than craftsmanship. The iteration of rapid prototyping and the learn-as-you go ethos both position skill as an outcome of making, rather than a prerequisite. Prototypes are imperfect products of a self-directed design process that begins with engaging with tools.

In wider American culture, craft has contributed to a vision of the "maker" which is mostly a reclaiming a reclaiming of material knowledge. Studios like New York City's "Craftsman Ave." offer courses in material skills ranging from spoon carving to motorcycle design theory. Craftsman Ave. is one of many craft studios in the United States using a broad conception of making in which the maker is anyone who makes physical things. For example, San Francisco's "Case for Making" offers watercolor classes and Baltimore's "Maker Practice" offers classes in string art, silk screened tea towels and faux-stained glass. Craft here is material, often traditional, and creative. As discussed in the opening chapter, making in universities *is* framed as an intervention into the growing number engineers who lack even basic material knowledge – with a startling number of freshman MIT students having never drilled a hole. Both of these understandings of craft animate an approach to technology building is both material craft and learn-as-you-go craftiness. Yet, making in the space often becomes a function of interacting with a specific set of tools.

[34] See: RuPaul's Drag Race, Season 11, Episode 11 in which a garment created by Yvie Oddly made of repurposed denim is described as "too crafty" and not high fashion (Rogers, 2019).
[35] The "crafty" of maker cultures is considerably different than the "crafty" of hacker cultures. In a chapter titled *The Craft and Craftiness of Hacking,* Coleman (2013) discusses craftiness as a kind of clever slyness. She uses the term to describe a ceaseless irony that pervades hacker culture. This disposition was mostly absent from the participants in my makerspace field site, which I would describe as overarchingly earnest.

## The Power of Tools

In this DIY world, learning is envisioned as motivated by necessity or curiosity. Makers like Corinne and Ashley have an instrumental goal in mind: engaging with an unfamiliar software program or machine as part of a larger design process. But, administrators, student leads and makers at CoMotion also emphasized that the opposite is possible. Again and again people expressed to me that tools could be an impetus. Makers see an exciting new gadget and ask themselves "what could I do with this?" Several times, makers told me they'd taken on a particular project because of the tools they could use to create it – not motivated by what they'd produce, but rather as something to learn on.

This was especially true of digital fabrication machines – 3D printers and laser cutters – that had been imbued with a cultural cache before participants even stepped into the makerspace. For example, a graduate student working on a Masters of Fine Arts[36] in sculpture reported that she was learning to use the 3D printer to "stay relevant." [Literature: 3D Printing in the Media] She admitted that she thought the plastic filament used for 3D printing felt undesirable from a tactile perspective. But, she shrugged, "maybe that's just a generational thing." At 28, she didn't want to get left behind in the new wave of three-dimension form creation. So, she came to the makerspace to develop a "rudimentary" understanding of the tools.

Both these modes of activation are a window into why access is spoken of as *the* key contribution of the CoMotion makerspace. In the first scenario, the makerspace helps young people with a wealth of ideas access expensive and regulated tools that may have been off-limits due to the closed-door policies of campus labs. Through merely opening the door, these

[36] Within her department, students working in ceramics, glass and metalwork had recently assembled as a concentration called the 3D4M, spoken as "3D Forum." As opposed to 2D media, like painting and photography, these artists focused on materials and form. But, it wasn't lost on me that the rebranding to emphasize "3D" seemed strategic.

ambitious makers are off-to-work, innovating and creating. In the second scenario, access is a means of inspiration. Through merely seeing the tools, and knowing the tools can be used, makers will begin to learn them.

Yet, tools can communicate something else to makers. They can also be intimidating. The machines are large, industrial, and looming; especially so, makers thought, for artists and non-engineers. Though seemingly oppositional outcomes, activation and intimidation share the same underlying philosophy on the power of tools. The tools in the makerspace are almost magical in their ability to determine participants. Their inert material encourages or dissuades would-be makers. At their best, they inspire one to learn.

In the eyes of the founding director, makers, and mentors it was *tools* that define the makerspace. Dave stated this directly when he told me "the overall goal, the reason for creating the space, is to provide a space to give access to the tools people need to innovate." The makerspace was a container. The presence of tools was perhaps more important than any other aspect of the space. One evening I had a conversation with Leo, a mentor at CoMotion who also helped organize Makers Night. Before moving to Washington he'd helped establish a makerspace where he was living in New England. While telling me about his history with making, we discussed Leo's decision to call his space a "fab lab" [37] rather than a makerspace.

[37] Fab lab is term from Neil Gershenfeld, a professor at MIT who taught the incredibly popular course "How to Make Anything." Gershenfeld is a foundational figure in the maker movement. His perspective on making has emphasized the power of digital fabrication tools since the early 2000s. At the time, *Make:* magazine project tutorials didn't use digital fabrication tools really at all. Today, he seems prescient. Digital fabrication tools are basically inseparable for contemporary understandings of makerspaces, and are often pointed to as the impetus for the maker movement. My reading of the early issues of *Make:* magazine has found that isn't really the case. However, this discourse is important for considering the way contemporary making has become defined through a particular set of tools – as "fab lab" has become a synonym for "makerspace."

"Does the name matter?" I asked him. He replied no, "in so far as it has no bearing on the tools that you can put in it." As a shortened form of "fabrication laboratory," the term fab lab seems like it might dictate a space's identity based on a particular set of tools. But, to Leo, the artifacts defined the space above all.

Midway through her tenure, Christa added the statement "more than just tools!" to the makerspace website, emphasizing the value of the maker community in addition to the objects. Initiatives like Makers Night used the social – assistance and camaraderie – to overcome the troubles of the material. Christa hoped that through being included at the workshops, these makers would come to see themselves as belonging in the makerspace as a whole. The craft practices we mobilized were seen as a pathway to broader participation. Attendees would begin with what they knew. Then, they'd learn new skills and new machines – on their own, or with the help of peers and mentors.

Interacting with tools of all kinds was meant to be an impetus for personal growth. Through Doing-It-Yourself, makers would develop not only hard skills but also the resilient and independent mindset that produces innovation. This ultimate goal parallels the media narratives that emerge from *Make:* magazine. In the pages of *Make:,* the maker mindset is an orientation in which creation begins with hands-on experimentation. Making is framed as upending corporate Research & Design processes which separate the physical activity of building from the information gathering and ideation that occurs on paper. This "build first" mentality means that skill acquisition happens in tandem with construction—makers figure things out while making an idea into a material reality. The outcome of this process is typically flawed at best, and a complete failure at worst. Yet these mistakes are a small price to pay for innovation. More careful and more measured processes – like those in corporate Research & Design – are constrained by precedent and what is “possible.” Making is meant to teach students how to be comfortable enough with failure that they can truly innovate. When CoMotion encourages students to Do-It-Yourself, they not only encourage self-directed learning of concepts but they enable the struggles that produce resilient risk takers.

**Series B**

As the space became more established after it’s first year of operation, it expanded from 4,000 to 6,000 square feet. With this 50% increase in space, makerspace administrators had an opportunity to pursue a more fully realized version of the makerspace. In a funding proposal requesting over one hundred thousand dollars from the Student Technology Fee budget, $55,497 was dedicated to a new laser cutter. The current laser cutter at the makerspace was described by the application as “the most heavily used single piece of equipment in the space” – which was seemed to be the case during my observations. The practices of makers participating in the space were helping to chart what it would become. Other major line items were explained as expanding prototyping capabilities: various tools for a proposed woodshop and equipment for manufacturing printed circuit boards (PCBs).

The remaining budget was dedicated to purchasing more than a hundred sensors of different types, many of them “soft” for wearable devices. Wearables were a recurrent project in my initial observations at the makerspace. The category of wearables covered biometric devices (like the FitBit) as well as devises meant to improve mobility and accessibility, like prosthetics. Projects of this nature had been so popular that at the first community meeting Dave explored them as a potential “theme” of the makerspace. He addressed the group, inquiring about where members saw the space headed. Would it be a place that focused on creating a “big social impact” through addressing issues of usability and disability, he asked speculatively.

Imbedded in wearable projects was huge opportunity for sewing and textiles work—lightweight, flexible methods of construction. Yet, the bridge was rarely so clear. For example, in one particularly memorable conversation, an electrical engineering student described designing a glove that could help people who had difficulty gripping things. Peter was holding a hand-full of black plastic pieces, rounded at either end. The pieces looked vaguely like the digits of skeleton's hand and they hinged together with a set of smaller parts using metal jump rings. He'd seen a 3D printed exoskeleton online and wondered, "what could I do with this?"

When I inquired about how Peter designed the exoskeleton glove, he explained the merits of laser cutting over 3D printing. He'd decided to laser cut the pieces because many of them were similar in shape and cutting was faster than printing. "Building the glove is just the first part, this is the foundation." Then he would add a push sensor. At this point he paused for a second and reconsidered my question. "Did you mean: why not just use a *regular glove*." Neither of us had considered that and we both laughed. Our conversation had traced his decision making between the only tools he saw as options.

In projects like these, working with fabric might be easier and more elegant. But, a refined final product isn't necessarily the goal. Peter wasn't trying to design a prosthetic that would ultimately be patented. He just needed something to learn on. In moving away from the language of commercialization, CoMotion had invested in producing innovative thinking rather than just intellectual property. Peter's product taught him hard skills like digital fabrication. It also taught him fundamentals of design. He'd iterated on an idea, modified what existed, and had come up with a way to make it better. The outcome might not have been innovation, but the process certainly was.

Through centering the *process* of innovation, making makes perfect sense for CoMotion. There are many material practices—ranging from woodwork to printing circuit boards—that teach students to think like innovators. From this perspective, Do-It-Yourself is transformative. Engaging with your hands, with tools, with physical things transforms students into curious, creative and competent individuals. Yet, some tools were seen as more transformative than others.

Although textile work was part of the space since it's opening, it lacked a direct line into the strategic goals of the space. Jacob, one of the founding student leads, saw little connection at all. "Making doesn't include textile projects," he said, sitting in front of an industrial serger. "But, sewing machines can be difficult to find." They were in the space as a resource—they enabled a related, though distinct, creative practice. The founding director touched on a similar perspective, but saw more in their potential contribution. "The sewing machines are primarily used by costume club," he explained "and they add to the space because they have that knowledge to share." He went on to describe a project upstairs on the Start-Up Floor, where someone was making a wireless power suit. Textile projects were part of making because they could be integrated with more overtly technological things.

In 2013, the interest in wearables gave way to the next hot trend in technology. A dozen Virtual Reality headsets were installed in the space, with seemingly little input from Christa or the mentors. CoMotion HQ had pivoted to focusing on emerging VR technology (Levy, 2016). While incredibly high-tech and innovative, it was unclear to me how VR fit into the makerspace. By its definition, Virtual Reality lacks most of the physical qualities that define making. *Make:* magazine and the HEMI conference had both positioned making as a material intervention. Even the more bounded "digital fabrication" is defined as a practice that combines manipulating both bits (the digital) and atoms (the physical) (Gershenfeld, 2006). The arrival of the VR headsets signals a kind of regress of terms, in which making collapses into innovation. Here, innovation – and ultimately making – acted as synonyms for "new technology."

The distance between making and innovation is short when routed through high-tech tools. Through digital fabrication, makers learn to use cutting edge technologies—objects the broader public clearly codes as "innovations." At CoMotion, students learn modeling in Computer-Aided-Design software to build artifacts for 3D printing. They test designs through plugging wires into lo-fi breadboards and then used state-of-the-art LPFK machines to mill custom made circuit boards. Even when their creations weren't new inventions, their thinking was new and modern. Makers had the skills to use "innovations" (high-tech tools) in their technology design projects. Engineers and technology designers were innovating, and thus making was innovating too.

Yet, there were all these other *things* – all these other activities, all these other people at the makerspace. They were making too. One afternoon I spoke with a student while she made part of a costume on a sewing machine. "There's lots of DIY things you can do with these," she said as she gestured to the machine. "But, the makerspace isn't focused on that. I don't know if it's the gendered aspect, but they are underused in the projects." She paused and considered why that might be, "Everyone wants to use the 'cool' technology." The CoMotion makerspace existed in a much larger world that was always already distributing value to practices and materials – long before students stepped foot in the space. In order to realize the potential of making, CoMotion needed to include the broadest range of creative capacity. Did it – could it – do that?

**Digital Fabrication on Fabric**

A digital embroidery machine is a "CNC machine that works like any other CNC machine." At least, that's how Sophie explains it. Sophie, CoMotion's resident sewing expert, is leading a workshop, introducing a group of makers to the new machine. All CNC—computer numerical control—machines share a basic premise. They alter a material based on programmed coordinated: an x (width), y (height) and z (depth). On the CNC embroidery machine, the needle moves up and down just like a regular sewing machine. But the area where you place the fabric moves around automatically according the design specifications created in a computer connected to the machine. Everyone crowds around as she demonstrates how a vector image will be stitched, using a fill like function in the program. One of the observers asks about different kinds of stitches, and Sophie demonstrates how they'd be programmed using different colors on the screen. Everyone crowds around as she begins with the most basic of sewing machine lessons, how to thread a bobbin.

In the few weeks following Sophie's workshop, the machine sat in its box. Tucked inside were a few pieces of denim fabric with circuits sewed into them: samples of what could be done. One of the samples the manufacturer had been especially excited about. It was a "D-pad" or a "directional pad," like you'd see in an old Nintendo controller. Four directional arrows surrounded a square microchip, embroidered out of rust colored conductive thread. When I asked Sophie why it was still in the box, she shrugged. "Nobody wanted to make circuits, unprompted."

It wasn't that the machine was useless. She'd just wanted to use it for other, non-conductive purposes. Maybe make a set of embroidered patches. Sophie was part of the University Costume Club, along with many of the other women in the space. Members often used the makerspace sewing machines to create elaborate cosplay costumes—that sometimes involved electronic components and sometimes didn't. The video game controller wasn't all that relevant, but the machine could be used as part of her larger practice of stitching and creating. But, with dwindling interest, it was packed up for returning to the manufacturer. It had been on loan for Research & Development about conductive thread.

A year later, the first meeting of Makers Night (née Crafting & Making) is starting with the most well attended workshop we'd ever hosted. A visiting scholar, named Mia, is teaching a workshop on "Exploring Circuits Through Art." When I arrive, the makerspace worktables are covered in stars cut out of multicolored felt. At the center of one glows an LED light, the wiring sewn into the fabric. There are pens and colored construction paper, markers, and a ziplock baggy full of colored embroidery floss. Another table holds paint pens filled with conductive ink, paintbrushes and paint pallets, scissors, binder clips and round cell batteries. The workshop feels sort of momentous, like something is really concretizing.

"There are many ways you can make something," Mia explains in her introduction, "you can make something by hand, you can make it with a machine, or you can make it with a programmable machine." The power point slide behind her shows a needle and thread, a sewing machine, and a digital embroidery machine respectively. At this, Christa chimes in "Yes, we have a digital embroidery machine!" which she produces from the storage racks, like a ghost.

After Mia's introduction and a warm-up activity, we move on to independent explorations using the materials that were spread out across the table. Rose, a student in the art department, is sitting next to me. This is her first time participating in the makerspace after going to the orientation last year. Rose stands up, collects a few pieces of felt, and decides she wants to embroider her circuit. Christa goes to find a mentor who can help her.

Christa and Rose stand next to the machine, as a cast of makers filters in and out. Leo and another makerspace mentor forthrightly state they have no idea how to use it. Though they're both skilled in digital fabrication, Sophie was the go-to person for fabric. She graduated last year—and even then, it'd taken *her* several hours to learn how to use the digital embroidery machine. Eventually, it's determined that none of the five or so mentors, leads and employees present in space could get us started. Rose asks about using a standard sewing machine, and after finding little help, decides to stitch her star by hand.

**Connecting Hard to Soft**

The digital embroidery machine is an especially evocative example of how value is distributed in the CoMotion makerspace. Just like laser cutters, 3D printers and CNC routers, the digital embroidery machine could be programmed to do precision work. More than any other craft tool in the space, the digital embroidery machine has a direct line to building an understanding of the way software interacts with physical tools and computer-aided design. It uses the same concepts, the same mechanisms. It just used a different material. The 3D printers and CNC routers had teams of experts working within the makerspace. The digital embroidery machine only had a single champion.

The directives from the digital embroidery machine's manufacturers had limited the value of the tool to stitching circuits, and the makerspace textile community hadn't connected with that. As a result, even the most fabric-savvy members of the space hadn't developed a skillset for using the machine. Building community knowledge and enthusiasm for a tool matters in moments like Rose's—moments of activation—in which there is a desire to achieve a goal (build a circuit) through different materials or different processes. These are incredible opportunities for innovation, constrained by a kind of path dependency that limits action to the way things are most commonly done.

Imbedded in the emphasis on conductive thread is the idea that craft is only every innovative in association. Because the machine used fabric, the focus on the machine had been on creating products (circuits) that were easily recognizable as technological. It was about *making something,* not making as a process or practice that teaches us as we go. This understanding of innovation collapses the term into a synonym for "high-tech" or "digital" and forgoes understandings of innovation that are grounded in creative activity and ways of thinking.

When defined through new technology, innovation becomes a product not a process. New technology is the *outcome* of idea generation, prototyping, and testing. It's the outcome of creating and failing and creating again. In moving away from the language of commercialization, the University of Washington had sought to distance itself from a limited framework that only recognized products (e.g. patents and IP). Building the CoMotion makerspace was a manifestation of the belief that it was worth investing in the hands-on, creative activities that are the fertile soil for new ideas. It was an investment in the *process* of innovation. Yet that process included some practices and not others.

In projects concerning electronic textiles, Leah Buechley and Michael Eisenberg (2009) have observed that the most challenging aspect of design is the place where fabric meets hardware[38]. Building the *Making Core Memory* quilt – the focus of the next chapter – I encountered this breakdown continually. Conductive thread easily integrated into the fabric through sewing. It ran the length of the quilt, folding and bending along with the cloth. But, ultimately, the thread had to connect to an Arduino microcontroller made of metal. The input

[38] One of the solutions proposed by Buechley and Eisenberg are "LED sequins" – which are used in Electronic Tank Top project Buechley designed for *Craft: Magazine.*

holes were designed for wire. The delicate thread pulled out too easily. When soldered, the connections became so rigid they broke down completely. We had to develop new – indeed innovative – strategies for connecting these two materials.

Bringing together hard and soft requires developing methods of connection that challenge the recurrent purification of categories like “crafter” and “fabricator.” This is true on a physical level and a metaphorical level. Mia’s Art and Circuitry workshop described above is a failure of integrating the knowledge possessed by the textile community about soft-materials into larger culture of workshops and mentorship. As Sophie had pointed out to me, these areas of expertise – and those who practiced them – remained mostly separate.

With initiatives like Crafting & Making, the makerspace was struggling to come to terms with where expertise comes from. Makerspaces are immersed in long-term socialization processes that have gendered different forms of expertise. Makers bring a lifetime of knowledge with them into the space. In my brief unstructured interviews I was constantly struck by how often people talked to me about their parents – the people who taught them to sew, solder, and fix. Their stories began long before the stepped foot in the makerspace, with moments of engagement as children.

Intimidation is a natural barrier for beginners of all kinds. But, the emphasis of digital fabrication machines meant the makerspace was failing to include a specific cross section of potential makers who weren’t necessarily starting from zero. People with outside expertise – the “artists” – didn’t see their skills as relevant to the machines that dominated the floor plan. Because collecting data of non-participants wasn’t part of the observational nature of this project, I have little information on would-be makers who didn’t feel capable or didn’t feel welcome to learn the tools in the makerspace. Yet, we do know that significant number of students came to the space once and never returned. They had achieved access to tools – tools that were both available instrumentally and as a source of inspiration. But, they didn't engage them. A disproportionate percentage of these people were women.

There is only so much in the promise of access. Access will never change our cultural visions of innovation. It can't redistribute value, or undo our ideas about what is legitimately technological. Makers Night could welcome new individuals to the space – but it couldn't change the way their skills were perceived beyond the workshop. If we limit our interventions to open-door policies and social inclusion, there is the looming possibility that makerspaces will produce only a single kind of innovator. Reclaiming the inclusive potential of making means reclaiming a diversity of material practices in the technological field.

**The Uncertain Place of Craft**

In closing, I want to reflect on the perception expressed by Ella that crafting "is a girls thing." The idea that there is making – a gender neutral form of production, lauded for its potential to inspire a new generation of innovators and self-sufficient handypersons – and then "making-for-girls" follows patterns across computing and an American culture in general in which there is basketball and then women's basketball. Ellen DeGeneres put it humorously when she lambasted the product designers at the pen brand Bic who introduced the *Bic, for Her.* "Can you believe this? We've been using man-pens this whole time!" Within technology design, this phenomenon is what computer scientist Margaret Burnett refers to as "Shrink It and Pink It," or the tendency for product designers to make things smaller and cuter in an effort to attract (or "include") female users by producing a gender specific product.

Technology fields, especially, are rife with discourses that empower women through sidelining many of the traits that are culturally and socially ingrained in feminine gender performance. In recent years, we've seen a proliferation of apps and articles attempting to "de-gender" women's language (Stop up-speak! Delete sorry!). Yet, as feminist technologist Judy Wacjman (1991) points out, there is no similar process for men whose communication style becomes the default. Through this combination of products and persistent messaging, it's no wonder that practices associated with women are seen as peripheral alternatives to the essential core of technology creation.

Ella's perspective highlights something that women grappled with across the sites that I observed. For example, at a mending workshop I attended, fabric repair was often characterized as a lost skill – a narrative that is common throughout the maker movement. The setting was completely removed from the innovation ethos of the CoMotion makerspace; it was an art space that had once been an old church. We sat in a circle on the creaky, warm-wood floors as a choir practiced below. Yet, several participants discussed the complicated relationship between sewing skills and their gender. They'd once shirked sewing lessons from their mothers; they hadn't wanted to do what was expected of them, as women.

Exemplifying this viewpoint, the founding editor of the feminist magazine *Bust* writes in her book "Stitch n' Bitch" that she spent most of her life viewing people who knitted, sewed, cooked and cleaned as "frittering their life away" (Stoller, 2003). But, as Stoller grew older, she rethought her position; coming to the conclusion that the only reason feminists looked down on knitting was because it was done by women. This position was, in fact, anti-feminist she argued: "since they seemed to think that only those things that men did, or had done, were worthwhile" (p. 7). If feminist themselves were still debating the position craft within women's empowerment, it's understandable why it also occupies a contested space within the contemporary maker movement.

Yet, my experience both within the makerspace and within techno-culture more broadly, tells me that craft is just one of the many practices that are devalued through their association with the women who perform it. After presenting this work at a conference for Internet researchers, a woman approached me afterward saying that even as an interaction designer she felt this work was still positioned as less than the “truly technical” work of “back-end” engineering. Interaction design (or “front-end” engineering) creates the look and feel of platforms – the systems of color and visual hierarchy that comprise information architectures. The back-end is the high-paying world of code. Her perception is supported by recent academic research in Silicon Valley’s coding boot camps, where gender and practice fall along a well-defined axis of value: women and front-end engineering on one side, and men and back-end engineering on the other (Miltner, 2018). Value is given to those who are “close to the machine” – and these days, at least, that tends to be men (Ullman, 1997).

Gender divisions in technology industries are further complicated by the undeniably artistic, “softer” nature of certain design roles that appear more similar to craft than mathematics – but are the never the less deeply technical. It’s difficult to know if it’s a bias against who does the work or just a lingering perception that anything adjacent to art is frivolous and non-essential. Throughout this project, gender and practice became inseparable in the way they organized work and organized workers within innovation cultures. In the next chapter, I’ll explore a project that uses making to subvert these structures—positioning craft, and the work of women, as significant methods of technology making.

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## Chapter 3 - Intervention: Making Through Craft in Innovation History

You can't be what you can't see[39]. For communication scholars concerned with issues of media representation, this is a familiar dictum. Stories and figures give shape to our dreams and, at their best, help us reimagine our place in the social world. Media representation has been a primary focus of recent initiatives attempting to address the persistent gender imbalance in science and technology fields. A 2016 White House report highlights the power of "diverse role models—both past and present" to inspire the next generation of innovators (Handlesman, Smith, & Ford, 2016).

Representation has been a key issue for communication scholars working from a variety of perspectives. From critical theorists to media effects empiricists, media studies scholars have sought to understand how the representation of social groups reinforces social positions and maintains inequality (Lull, 2000). At the core of this issue is both *a lack* of representation and troubles with *the way* people are represented. Across American film, TV and digital content, the number of speaking roles for women and people of color don't reflect the American population (Smith, Choueiti, & Pieper, 2016). And, when their stories do appear, roles are often one-dimensional—omitting the wide variety experience within these categories (Kellner, 2003).

Representations of women in technology fields are especially scarce. For example, women portray just 7% of movie characters employed in computing—despite being about 20% percent of the real life computer scientists and computer engineers (Handlesman et al., 2016). In non-fictional accounts, men readily feature as central figures in histories of engineering developments, but women rarely appear positioned as central innovators (Wajcman, 1991).

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[39] Sally Ride, the first American woman in space, was especially fond of this saying. See: Sally Ride (2012, September 1). Harvard Business Review (A. Beard, Interviewer). Retrieved from https://hbr.org/2012/09/sally-ride

When historical accounts do implicate women in engineering procedures, women typically assume clerical roles that are framed as unimportant. Such media engagement reinforces gendered associations between men and technology professions and accordingly effects perceptions of who is technological. Stereotypes like these are a key factor in discouraging women from participation in science and technology (Corbett & Hill, 2015). Indeed, the foundational research of Linda Gottfredson reveals that children begin to define their career aspirations based on gendered "occupational images"[40] as early as age six (Gottfredson, 1981).

In this chapter, I present an intervention into the representations that dominate *Make:* Magazine and maker communities; representations that frame craftwork and repetition as separate from the world of high technology production. This intervention takes the form of a creative counter-narrative. It enlivens a forgotten moment of technology history in which the handwork of women was essential to engineering. Between 2016-2018, my collaborators and I created a workshop called *Making Core Memory*. The workshop integrates communication and design scholarship in a "critical fabulation" of design—a method that opens up technology narratives in an imaginative process of re-making (Rosner, 2018). I argue that addressing issues of representation within innovation culture requires more than just depicting women as engineers and technologists. We must tell stories that represent the myriad of practices that constitute innovation at every level. Critical fabulations are an opportunity for communication scholars to engage in new types of inquiry—beyond recorded histories and tales of genius, invention and original insight.

[40] In this case, occupational image isn't just media images but akin to a generalization or stereotype. Occupations coded as masculine and feminine held with a high level of consistency across respondents.

**Engineering Histories and Representation of Gendered Labor**

To challenge entrenched beliefs about the contributions of women to technology work, advocates have begun to highlight women in science and technology history. For example, the 2016 hashtag #blackwomendidthat reminded the world of figures such as Shirley Jackson, inventor of the touchtone telephone and the fiber-optic cable, and Patricia Bath who developed the probe for laser cataract treatment. Stories like Jackson's and Bath's focus on what Sandra Harding terms "women worthies"—the unsung figures who overcame structural obstacles in pursuit of scientific accomplishment (Harding, 1991). Their narratives rewrite women into scientific histories as inventors and pioneers of scientific discovery.

However, such recognition only goes so far. Even as women worthies signify an important cultural turn toward recognizing absences, they reflect only a narrow portion of women's contributions to science[41]. Women, and especially working class women of color, have always done the low status, material labor just below the surface of discovery. Women measured the brightness of stars at the Harvard Observatory (Sobel, 2016), calculated the flight paths for the Apollo space program (Shetterly, 2016), and produced the first computer programs for ENIAC (Light, 1999). However, managers' accounts of this work often framed it as secondary or menial. For example, Carolyn Marvin (1988) demonstrates how the supervisors of female telephone switchboard operators undermined their considerable electrical knowledge by framing them as chatty and distracted. Managerial accounts position women as non-essential participants in technological development, diminishing perceptions of their scientific know-how today.

[41] We take technology to be a particular sub-culture within the scientific field. For a more in-depth discussion of this relationship see "From Science to Technology" (p. 13-15) in Wajcman, *Feminism Confronts Technology.*

Given the gendered history of formal engineering and design, narratives that center disembodied intellectual contributions are doomed to reproduce a vision of the technological field in which women are absent or, at best, singular and rare. Stories of "women worthies" illuminate the remarkable rather than the ordinary (Harding, 1991). And, the ordinary is an aspect of science that is brimming with the stories of women. By recognizing less visible and dramatic roles we begin to see that women's contributions to science are enormous and ever-present, rather than novel. However, the processes, trajectories, and techniques of technological production are hard to render in writing and easy to overlook.

As Susan Leigh Star and Anslem Strauss (1999) observe, it is difficult to make manual work visible. Scholars create narratives through connecting actions to personal biographies. Yet, the nature of industrial production requires labor to be broken down into discrete, learnable parts. Many individuals can perform a single task and any task is only a portion of a much larger accomplishment. Unlike the stories of inventors, the experiences of task workers are fractured into small parts that seem insignificant even to the people who hold them. Routine manufacturing work appears ordinary—neither valued nor unique—making it possible to overlook the accounts in the historical record (or, most commonly, not document them in the first place).

Rather than seeing ideas and insights as inherently more important than the work of articulation and assembly, feminist technology studies scholars attune us to the contingent nature of the given order. In her canonical book *Simians, Cyborgs and Women*, Donna Haraway (1991) calls us to recognize – and claim – that our investigative frames are always partial[42]. It is a mistake to take any one perspective as the universal standard for evaluating "what counts as

[42] Partial as in incomplete (a part of a whole) and partial as in biased (influenced by one's own position).

knowledge" (p. 188). Feminist scholarship requires embracing a multiplicity of knowing (Wagner, 1994). This is true of both the knowledge produced in our own research activities and the knowledge held by the subjects of our investigation.

The feminist technology studies perspective calls for a rewriting of cultural histories, pushing beyond simple binary conceptions of the relationship between cognition and manual work to see the myriad types of scientific knowledge that constitute the field at every level. But how do we do that? How can we tell stories about ordinary women who do the kinds of technical work often categorized as menial and routine?

**Methodologies of Critical Fabulation**

Developed by Daniela Rosner (2018), critical fabulation for design is a method of storytelling that engages the practice of design. It is an analytic technique that occurs alongside acts of building, creating and repair. Projects of critical fabulation are both inquiries and interventions. As inquiries, they implore scholars to identify the shared values and singular histories that define disciplinary parameters. As interventions, they create meaningful alternatives drawing from absented lineages and speculative futures.

Projects of critical fabulation attune scholars to the way technology design practices always occur within disciplinary imaginaries of what is promising, worthy, and good. Rosner writes "As investigators of design, we rarely examine how what's called design came to be so" (p. 8). The *Making Core Memory* project takes up this point of critique – turning careful attention to the contributions of "non-designers" in a moment of technology history. It then integrates communication and design scholarship to entwine their absented histories with the experiences of workshop participants.

The software code for the Apollo moon missions was stored in woven memory, handmade by a team of women in a Raytheon facility outside of Boston (Mindell, 2008). This technology—called "core rope memory"—was constructed using a process extraordinarily similar to weaving. They called it the "LOL method" for the Little Old Ladies who did the work (*Moon machines*, 2008). The Apollo project is one of the most significant engineering accomplishments in modern history. There are countless biographies and scholarly books detailing the accomplishments of astronauts and engineers (Eyles, 2018; Hall, 2000). Yet, there don't seem to be any first-person accounts of the women whose careful handwork transformed software into hardware. Because we neglected to collect their stories in the past, we fail to know them in the present. The absence of their accounts re-inscribes our contemporary understanding of what innovation looks like and, in turn, closes the possibility of doing differently.

In light of this emptiness, we created a workshop – called *Making Core Memory* – that invites participants to engage in collaborative acts of core memory weaving[43]. Through the weaving, participants develop sympathetic understandings of technology making experiences. They incorporate new lineages of practice into contemporary understandings of how technology comes into being.

## Watches, Weavers and Textile Work

The history of computing is a history of textiles. In 1837, Charles Babbage used the punch card technology of the Jacquard Loom to conceptualize the analytic engine(B. Toole, 1987). It was a machine that could automate mathematic calculations and was the earliest inkling

[43] Many of the insights in this chapter have previously appeared in two collaboratively authored articles (Rosner, Shorey, Craft, & Remick, 2018; Shorey & Rosner, 2019). I'm deeply indebted to the team of scholars and makers who have been part of creating and thinking through *Making Core Memory.* I use the pronoun "we" throughout this chapter to recognize their contributions.

of a modern computer. Babbage's collaborator, Ada Countess of Lovelace, described the analytic engine as "weaving algebra" (Lovelace, 1992). One hundred and thirty years later, Fairchild Semiconductor put Navajo women to work on integrated circuit manufacture in Shiprock, New Mexico (Nakamura, 2014). In their marketing materials, the company used their perception of Native American women as skilled craft workers to explain the successful production in the plant. Lineages of material labor (represented by rug weaving) were used to harden the notion that dexterity and emotional investment came naturally to indigenous people (Nakamura, 2014, p. 928).

Between the punch card and the integrated circuit is an interlude in information storage technology called "core memory." Throughout the first two decades of the cold war, core memory stored information using tiny magnetized ferrite cores. Typically, ferrite cores were assembled into squares called arrays or planes. Each core stored one bit of information, with the magnetic polarity indicating either a 1 or 0 of binary code. For the Apollo moon missions, the Massachusetts Institute of Technology (MIT) Instrumentation Laboratory developed a unique form of core memory called "core rope memory" (Hall, 1972). Core rope memory stored information using a physical distinction. The Apollo missions used both types of core memory, but core rope memory is an especially evocative object. Core rope memory transformed software into hardware. When digital information is made material, it helps us to see the hands that bring technology into being.

Core rope memory is a technology built in the shell of the American textile industry. Beginning in the 1950s, electronics companies moved into the textile mill buildings that had stood vacant for years as symbols of a struggling New England economy (Fenton, 1956b). Reports of the time celebrated the potential of high-technology industries to revitalize communities that had once been built to support the workers of fabric production and now faced unemployment as high as 37 percent (Fenton, 1956a). Over the next ten years, these dreams were realized. The region became known as "the Golden Semi-circle," named for the flourishing technology businesses located along highway Route 128 (Lieberman, 1968).

The success of the Golden Semi-circle was produced through an incredibly prosperous blend of government contracts, academic laboratories, and private companies. This region exemplified the "military-university-industrial" complex that drove early computer innovation, and laid the foundation for the shape of the technology sector we know today (Saxenian, 1994). A 1961 *New York Times* article reports an intermingling of ideas in "campus-type" environments (Fenton, 1961) where this model itself was viewed as the region's greatest invention (Lieberman, 1968).

At the center of the Golden-Semi Circle was Waltham, Massachusetts, home of the electronics company Raytheon. By 1961, Raytheon employed 36,000 people in the 35-mile radius around Boston (Fenton, 1961). Employees at Raytheon worked on a variety of projects—ranging from everyday consumer electronics, like microwaves, to the guided missiles that had earned the company $56 million dollars in government contracts (Fenton, 1956b; "Raytheon wins 5 contracts," 1960). The missile guidance systems, in particular, provided the rationale for Raytheon to receive a subcontract from General Electric to manufacture a similar system for an extraordinary project. They built a computer for human space flight.

In 1961, computing still relied on the punch card technology proposed by Babbage and Lovelace over 100 years before. These room-sized machines were heavy and large, making them poorly suited for a mission where minimizing size and weight was essential. Traveling to the moon would require a light and compact form of information storage that could survive the threat of power loss (Mindell & Hamilton, 2002). Core memory met this challenge by storing information on foldable beaded ropes that could fit into the cone of a rocket.

The software programs for the Apollo Guidance Computer were permanently stored within core rope memory (*Computer for Apollo*, 1965). Once wired, the ropes were nearly impossible to change (Fildes, 2009). Margaret Hamilton and her team at the MIT Instrumentation Laboratory had to write the programs perfectly—at a time when software engineering was so new it was barely recognized as a field (McMillan, 2015). As the "rope mother," Hamilton directed the creation and verification of all of Apollo's onboard software programs[44]. The program listings created at the Instrumentation Laboratory were translated into binary code, punched into tape (Hall, 2000; Mindell, 2008) or cards (Fildes, 2009) and shipped to the Raytheon factory in Waltham (Ceruzzi, 2016). There, the tapes helped position the "weaving machines" (Mindell, 2008) women used to transform software into hardware.

Core rope memory was made by hand. In every core rope there were three kinds of wires, each threaded by "operators" at a Raytheon factory in Waltham. Apollo engineers called this process the "LOL method" for the little old ladies who did the work (*Moon machines*[45], 2008). Sometimes alone and sometimes in pairs, operators passed a needle back and forth through a matrix of ferrite cores. The sense line was especially important. It passed through or around the cores in a pattern, based on the 1s and 0s of binary code. The pattern was determined using a machine that automatically selected the cores in sequence (*Computer for Apollo*, 1965). The operator threaded the open core, pressed a button, and threaded the next—creating a pattern that comprised the software program.

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[44] Anyone, regardless of gender, could be considered a "rope mother" (Garman, 2001; Hancock, 2014).

[45] As stated by Richard Battin, Technical Director, MIT Instrumentation Laboratory

In popular accounts, the women who wove core memory are often reported to be former textile workers (Fildes, 2009). The core memory production process has such similarity to needlework and weaving. It would be poignant to think that their expertise could have been applied so directly—simply switching the threads for wires. But, this fact remains difficult to confirm. In oral history interviews, engineers from the Apollo projects recount that the women who made core memory had previously been employed by the Waltham Watch Company (Blondin, Bates, & Hall, 2001). Waltham Watch had laid of its entire workforce in the early 1950s, creating an available labor pool with experience in precision manufacturing.

Rather than being the direct product of textile workers, it seems more likely that core memory is the product of a larger histories of manufacturing in New England—in which textiles, and women especially, played a significant part in the routines of industrial labor. A 1920 newspaper article reported that the typical watchmaker was a young girl ("Woman's Place in Work," 1920).

> "Women's small and agile hands are especially adapted to the work of certain industries. Women make and assemble the delicate parts of adding machines, office appliances, electric lamps…"

Weaving, watchmaking, and core memory manufacturing share the qualities that have defined women's work throughout industrial history. Managers feminized factory labor as the delicate and repetitive, suggesting women's nimble fingers and patience naturally fit the conditions of high-tech manufacturing and casting women as the ideal factory laborers (Monteiro, 2017).

Forty years after the Apollo missions, MIT Instrumentation Laboratory deputy director Eldon Hall reflected on the women who manufactured components for the Apollo Guidance Computer. Weaving core ropes required extraordinary patience, he said. But, working at

Waltham Watch's tool division had required something similar. There had been "tender loving care in that work too." The precision manufacturing on both these lines required an attentive eye and a steady hand. Hall went on to say, "Those little old ladies were essential" (Blondin et al., 2001).

Hall's recollection paints an uncommon picture of innovation work. For him, computing was a natural field for women who had long been precision workers. Women powered innovation and innovation was powered by care. As harbingers of patience and love, the gendered figure of the weaver re-inscribed certain stereotypes while challenging others. Through re-presencing the process of core memory weaving, these contradictions co-exist as they haunt our experience of the past.

## The Making Core Memory Workshop

*Making Core Memory* started in a tangled knot between the past and the present. Creating the workshop series was not just an act of translation, taking an already existing body of scholarship and making it interesting to public audiences. There was no definitive historical source to draw from: no text to adapt into a screenplay. Rather, this work involved an unwritten history – and parallel acts of searching, excavating, building, guessing – and all throughout inviting the public into that process.

We sought to design a workshop that could communicate the story of the core memory weavers by engaging people in material encounters with the artifacts, production process, and history of core memory technology. These encounters took two primary forms: 1) the weaving of core memory "patches" and 2) interaction with a Core Memory Quilt.

At the *Making Core Memory* workshop, each participant receives a kit containing a 5-inch chipboard loom, yarn, beads, a plastic needle, a felt square, and two strips of copper tape. Yarn and beads stand in for the wire and ferrite cores used in actual core memory technology. Through the workshop, we invite the participants to partake in a weaving process akin to that of the core memory weavers. The scale of the chipboard loom is equal to only a few millimeters of actual core memory planes. Once the weaving is finished, participants use the felt and copper tape to create a simple electronic switch. The switch is attached to conductive purse snaps that are installed at the corners of the looms and correspond to squares on the Core Memory Quilt[46].

Connecting a finished patch to the quilt squares completes an electric circuit, causing two things to happen. First, the Core Memory Quilt played an audio recording about the history of the Apollo Guidance Computer project. The brief clips share the perspective of the AGC engineers and Raytheon managers, reflecting on core memory production. The audio is sourced from documentary projects, the Apollo Guidance Computer history project (Mindell & Hamilton, 2002), and newspaper articles. Secondly, connecting a patch also triggers the Core Memory Quilt to tweet a 120-character version of the clip from @lolweavers account. The 120 characters reflect the storage capacity of actual core memory planes[47] that are also installed on the quilt.

The Core Memory Quilt integrates electronic-textile (e-textile) components, such as conductive thread, with traditional quilting materials to further entwine fabric metaphors with

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[46] This essay focuses on the patch kits. For an in-depth discussion of the functionality, design, and findings from the Core Memory Quilt, see: Rosner, D. K., Shorey, S., Craft, B., & Remick, H. (2018). *Making core memory: Design inquiry into gendered legacies of engineering and craftwork.* ACM Conference on Human Factors in Computing Systems (CHI ’18).
[47] The core memory planes are from the Digital Equipment Corporations PDP-8, the “first full scale, general purpose computer selling for under $10,000”; “Small Computer Handbook” (Digital Equipment Corporation, 1966).

core memory technology. The quilt was sewed and co-designed by our collaborator, Helen Remick. In her past work, Remick has used outdated technologies ranging from slide film to CDs to create intricate textiles. Her expertise in using unusual materials and the foundational skills of quilting were key to designing solutions for circuitry insulation and functionality. Brock Craft, who assembled the software for the Arduino microcontroller that enabled the tweets and audio, assisted Remick. Craft is a technologist with an interest in obsolete technology and also helped to interpret the patents that informed the patch kit design.

To date, the *Making Core Memory* workshop has been held five times with over fifty participants. The participants have been from a variety of intellectual communities: technology historians, design educators, makers and librarians. The following reflections are based on our experiential accounts of the workshop, as organizers, and informed by field notes and audio recordings of each session.

**Tedious, Time Consuming and Subject to Error**

Defining the meaning of work is an action imbued with power. Managers and other over-seers are often the people who set these definitions, rather than the people performing them(Star & Strauss, 1999). In the case of the Apollo Guidance Computer, the voices of engineers tend to define what we know about the AGC project. In oral history interviews, the reflections of MIT engineers acknowledge the importance and expertise of the core memory weaver's work. Yet this perspective is complicated by the accounts of Raytheon managers, which are more publicly visible.

In 1965 the MIT Science Reporter visited the Instrumentation Laboratory to document the "miniaturized computer" that the Lab was designing for the Apollo missions (*Computer for Apollo*, 1965). The twenty-nine minute film walks through each level of the navigation system in language that's understandable to an educated, but not expert, audience. After explaining what the AGC does and how it stores information, they visit the Raytheon factory in Waltham. Hosting the tour is Jack Poundstone, the Raytheon Apollo engineering manager. Poundstone speaks with the reporter, as rows of women work industriously and wordlessly behind them.

Poundstone describes the work of "a pair of girls" who are passing a needle back and forth through a matrix of ferrite cores. With the push of a button, the matrix changes to open a new aperture for the next pass of the needle. "She doesn't have to think about which core it goes through next?" the reporter asks "No, the machine does that for her" Poundstone responds(*Computer for Apollo*, 1965). A focus on the mechanized nature of the work is a perspective shared by Lee Woodworth, the Raytheon Apollo line engineer who oversaw training and implementation of manufacturing for core rope memory. In an original interview conducted for this project, Woodworth explained the manufacturing process as mostly "actuating"—or pushing a button. "The operator could have been anyone, because the machine was automated," he said.

While some of the Instrumentation Laboratory engineers described the work as skilled, Poundstone and Woodworth had worked on the Raytheon factory floor. Without the stories and experiences told in the words of the weavers, the Raytheon managers were the closest accounts to the actual work. Histories are entwined with the person remembering them. Because of Woodworth's role at Raytheon, it makes sense that he saw the work as routine. He wrote the procedures. Core memory weaving had to be a process that could be concretized, taught, and performed interchangeably.

Automation is as much about efficiency as it as about pedagogy[48]. Recalling that the first "computers" were people who performed simple portions of larger equations, it becomes clear that the foundations of automation are processes that can be broken down into easily instructed units (Chun, 2011). In the early 1800s, de Prony's logarithmic tables were specifically inspired by the division of labor in pin factories—another textile connection!—described by Adam Smith in *A Treastise on the Wealth of Nations* (Grattan-Guinness, 2003). In the twentieth century, women largely performed this clerical work. For example, the government's Willow Run Laboratory employed female students at a Michigan highschool. "The first girl in each row was given the first step, and then passed it to the second girl and on down the line. The last girl would bring up the sheet" ("Human computers from Pioneer Highschool," n.d.).

Yet, the tasks of the weavers weren't equations. They were the kind of material gestures that appear simple when the person doing them is skilled. In a follow-up interview, Woodworth explained to me there were challenges on the manufacturing line. The completed core ropes were folded-up and slid inside a metal casing. If the wires hadn't been taut through out the weaving process, the ropes wouldn't fit inside the case. Reflecting on how Raytheon overcame this problem, Woodworth said it they focused on the operator's technique. Woodworth's account is in line with the final project report from Raytheon that cites workmanship – "higher skilled production personnel" – as key to the reliability of the hardware.

Forty years after the Apollo missions, MIT Instrumentation Laboratory deputy director Ed Blondin reflected on the women who manufactured components for the Apollo Guidance Computer. He recollected that they had "tried to build the Apollo components at Waltham with

[48] I am grateful to a conversation with Lorraine Daston at The University of Washington's Simpson Center for the Humanities where she challenged a question I posed about efficiency with this observation.

supervisors, industrial engineers, foremen—people that allegedly had experience. Everything they made was scrap. There was a technique about how you positioned it, and when your hand shook. The female operators were good at it, those that stood around telling them what to do were terrible at it" (Blondin et al., 2001). Blondin's statement is satisfying from a narrative perspective because it recognizes the weavers as skilled craftswomen. Yet, our goal with *Making Core Memory* workshop wasn't to purify a history of industrial labor that was at all times both routine and skilled – but rather complicate understandings of technology making that see these experiences as mutually exclusive.

## Towards a New Knowing

In the shadow of these definitions, the *Making Core Memory* workshop engages people in embodied experience. As participants open their packet, we walk them through step-by-step instructions that resemble the work of the operators. Almost immediately there are hurdles. Beads roll onto the floor and the yarn is knotted around the needle. It is difficult to keep the yarn taut, suspending the beads in place. One participant said it's "like surgery to keep the tightness." Another looked at the slack in her completed lines, describing her work as "clumsy."
Despite the lo-fi nature of the materials and relatively generous size of the 5-inch loom, participants find themselves surprised by how time consuming the process is. "Why am I so slow?" one asked, even while she was on pace with the other participants. The work was difficult. "This is hard." Another said "I'm a really detail oriented person, but this is hard. Why can't I get this right?"

These experiences occur between moments of silence in the workshop, heads bent over the looms and needles in hand. "We're really concentrating" one participant explained. As we reached the time limit for our workshop session, a few were still working to finish their patches. "I'm really invested in this," another said. The *Making Core Memory* workshops preserve the contradictions in our gathered histories, that technology labor can be at once both monotonous and skilled, repetitive and satisfying,

Probably the most widely circulated fact about the Apollo Guidance Computer is how little memory it had. The colossal feat of traveling to the moon was accomplished with less storage than is available on the average MP3 player (*Moon machines*, 2008). Yet, when core memory is framed in this way it is purely about its technical capacity, not what it required of the people who made it. After completing their woven patch, a participant—who used "they/them" pronouns—looked at an actual core memory plane artifact we introduced earlier in the workshop. Holding the plane in their hands, they responded with disbelief that it could only contain the information for a single tweet. Thinking back to the effort their patch had required they said, "This is a lot, for not very much." The moment of connection, to the "a lot" of core memory weaving, is key.

Core memory work is the product of a lot of time, a lot of attention and intense focus. The core memory planes are 120 characters of information; they are also 40 hours of women's labor (Pugh, 1984). Participants build these understandings through connecting artifact to practice, and practice to history. A workshop participant, who developed the broadcast technology for the Apollo missions, rattled off an accounting of our work on the chipboard looms. "We're just doing sixteen cores here. There were…" he paused to do the math "sixty-four by two hundred and fifty six … over sixteen thousand cores in Apollo." Now, the number is more than just storage. It's sixteen thousand tiny actions by an unknown number of women.

**Crafting Our Historical Understanding**

As I've laid out so far in this chapter, critical fabulations provide a method for interactive storytelling. Through the workshop, participants access the simplicity that underlies abstract computational concepts. They encounter the diversity of the past beyond historical texts. They build understanding through their own feelings. These are all outcomes of knowledge diffusion. Public audiences engage with stories of the past and their experiences are part of the narrative process. However, critical fabulations are more that a form for creatively communicating scholarly knowledge. They are also a method of producing new knowledge.

Designing the patch kits for the *Making Core Memory* meant replicating a manufacturing process that wasn't concretely described in a How-To guide. Rather, our understanding of how core memory was made was based on speculation, recreation and knowledge triangulated from other fields. We weren't seeking to design a direct simulation of historical activity. Rather, we were designing a material form that could open the past to interpretation and embodied experience. Digital humanities scholar Jentry Sayers (2016) has called similar pursuits "prototyping the past." Prototypes are often gestures. Rather than definitive models they communicate an idea, making something seem possible (Turner, 2016). Prototypes are usually forward facing. Yet, the spirit of the prototype can also be applied to investigations of the past, creating imperfect incarnations of outdated technologies that have no functional future.

Our desire to work closely with the artifacts tangled the histories of core memory technologies—crossing institutional origins and functional mechanisms. The core memory ropes, where we focused our historical inquiry, were a minor variation of more widely produced core memory planes. Although the archives of the Smithsonian Air and Space Museum held the Apollo core memory ropes, we couldn't create something new from those precious artifacts.

Instead, we found plenty of core memory planes on eBay. The Apollo missions used similar core memory planes for erasable memory storage. These 5-inch squares were flat and intricately woven. Their visual language easily referenced the textile metaphors that underlay their manufacture. We decided to use the planes. The two technologies shared so much that they illuminated a shared lineage of labor.

We began with the material, trying to reverse engineer the process. Helen, the master quilter, inferred the sequence of actions from what she knew about weaving.

> "The weaving is so fine on the memory boards that the pattern is not obvious. When we enlarged an image, I could see more or less what the pattern was. I created a frame of foam board and experimented with recreating the weave. There was only one method by which the ferrite beads could end up with three or more wires through them, alternating orientation at 45 degrees left or 45 degrees right."

The beads would have to be loaded on to the horizontal string (the weft). Then, the vertical string (the warp) would be threaded orthogonally, separating each bead at a unique interstice. Once all the beads for the matrix were threaded the diagonal string would be woven in. This seemed right. The patents and technical papers we found supported our methods, but they were an odd source of understanding (Patent No. 3,529,341, 1970; Patent No. 3,460,245, 1969). Each of these documents described machines that were designed to automate core memory making. We had to read for the actions of the weavers, through the machines that were built to emulate them. The documents described frames and jigs meant to hold the ferrite cores in place. One, titled "Method of Wiring Core Memory Arrays," used puffs of air to separate them (Patent No. 3,460,245, 1969). The operators then threaded the cores with an orthogonal wire, not unlike the process we were designing.

In these documents are the absent but lingering presence of women's hands and eyes—disappearing, sometimes literally, into air. As Kat Jungknickle (2018) observes in her research on Victorian cycling wear, patents are rich sources of both social and technical data. Patents document women's innovative voices in times when their public contributions were limited. Yet, Jungnickle reflects that patents also raise questions about "who gets credited in the past and remembered in the present" (p. 5). Though the embodied actions of core memory weavers were being integrated into automated systems, they weren't legitimized as intellectual contributors to patent design.

And, there is so much that patents can't capture. In an interview with the Smithsonian's Computer Oral History project, Milt Rosenberg reflects on this specifically within the context of core memory production. Rosenberg was employed at International Telemeter while they were producing an early computer known as Mnemotron that ran on core memory planes. Rosenberg explains that patents are supposed to be "a teacher." But, "there are very few things you can every make from reading a patent. It's what's unsaid that really is the heart of how to assemble or manufacture something. The things that are unsaid, the techniques, are important." By my interpretation, Rosenberg isn't necessarily talking about individual technique (as in skill). Rather, he is talking about the larger methods through which things are made. Yet, this work on core memory urges us to see the way that the knowledge and skill of operators are always implicated in the achievements of process.

The machine patents describe manual techniques for core memory production as "very tedious, time consuming, and subject to error" but tell us little else about the people who made them (Patent No. 3,460,245, 1969). Throughout the *Making Core Memory* workshops, participants have asked us questions we don't know the answers to: How many people did this work? What was the scale of the operation? How were they recruited? There is so little documentation and so few recollections that we can only guess about the lives of the weavers or how they made sense of their work.

Yet, the workshop offers participants an opportunity to build their own understandings and imaginings through their experience. "What was" is an open question that may never be fully known. Yet, even partial understandings open new possibilities for what could be.

## Conclusion

As a field, communication offers a robust toolkit for critiquing the stories that shape the social world. Communication has various and longstanding traditions that analyze media narratives—richly describing latent biases, quantifying demographic absences, and theorizing about the mechanisms that perpetuate these recurrent patterns of inequality. Recently, critical media studies scholarship has extended well beyond the walls of academic institutions. Projects like the University of Southern California's "Inclusionists" bring failures of media representation to the forefront of public consciousness and have been mobilized in calls for institutional change (Smith et al., 2016).

Critical fabulations of design offer a creative toolkit for reshaping the social world through constructing new stories. In *Designing Publics,* Christopher Le Dantec (2016) summarizes design as a field that "considers a situation, imagines a better solution and acts to improve that situation." Design is defined by the belief that change is not only possible – but also possible through something we create. It is a hopeful exercise motivated by action. In many ways, I see media critique in the first clause of Le Dantec's summary. Critique is a consideration. It points our attention to what is absent, or disappearing, or silenced from inside a frame. Design scholarship implores us towards improvement. And in between, in the imagining, we find projects of critical fabulation. *Making Core Memory* is an imaginative inquiry, enlivening a past that might always be unknown.

The year that the Apollo 11 landed on the moon, Margaret Hamilton was a thirty-three year old software engineer with a bachelor's degree in Mathematics. She was one of the only female engineers on the Apollo project. In an oral history interview, Hamilton recalls that in her previous position as a programmer many of the people working alongside her were women (Hamilton, 2001). The same wasn't true as an engineer. During her work on Apollo, Hamilton helped to establish software engineering as a discipline. Her contributions earned her the 2016 Presidential Medal of Freedom (Obama, 2016) and made her a Lego minifigure (Berger, 2017).

Hamilton's cognitive work, her code and creations, are familiar parts of innovation stories. Once recovered, we know the contribution of these things. The mundane, material work of making computer parts is more difficult to render. As Laine Nooney writes, "The only people we have made historically visible are those we have organized ourselves to see"(Nooney, 2013). Women appear absent (or, in Hamilton's case, singular) in much of Apollo's history because of limited definitions of what labor counts as innovation, and what kinds of knowing are legible in technological history.

*Making Core Memory* frames interdisciplinary weaving collaborations as imaginative tools to encounter invisibility and representation. Engaging with core memory artifacts does more than remind us of a seemingly anachronistic moment when the pinnacle of modern engineering relied upon a woven rope of beads and wires. It rekindles a story of innovation that is deeply material, deeply gendered and deeply felt. Through remaking the technological past, we turn a light to the women—working by hand—that are always just out of view. How might their stories inform the way we proceed?

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## Conclusion: A Creative Spark

On a May afternoon in 2015, I walk from my graduate student office—in a gothic-style brick building on the edge of the campus quad—down a steep staircase and into a parking lot. On the descent, the buildings around me become concrete, brutalist dorms. The busy boulevard, the mall, and the mountains are all visible beyond the outer boundary of campus. Only one university hall is down here and it looks more like a business park than a place of learning. The austere building, named for a local corporation, was constructed at the end of the 1980s specifically to "foster and commercialize research of benefit for Washington state companies." Today, it holds the department of mechanical engineering, a nano-fabrication facility and the CoMotion makerspace.

The makerspace is full of energy. It's sunny outside and there are only a few more weeks left before summer break. Activity tends to peak at the end of every quarter (as people finish up final projects) and increase throughout the year (as people get acquainted with the space). In September, things will be quiet again and the cycle will start over. But today, there is lots going on. A group of makers is circled around a plasma TV screen that has just been installed on a wall near the entrance. Farther back, two makers are craned over a circuit board. With the click of the door, one of them turns around. Her T-shirt reads: The Future is Female. I haven't been in the space more than a few seconds before I hear "Hi Sam!" from three of the student leads. I set my tote bag full of chipboard on the seat of a chair at their table.

Sophie, the space's resident textile expert, opens her phone to show me a project that she's been working on for nearly two months. For her senior capstone, she'd sewn a quilt. It's beautiful and complex—made of blue, red and green rectangles in a pattern that's seemingly random. Each rectangle is actually a piece of encoded information. Each color is a nucleotide.

Sophie was conceived using an egg donor, and the quilt is a sequence of her mitochondrial DNA, passed down from mother to daughter.

Across from Sophie, Betty and Rebecca are working together on a sewing machine. They'd both been part of Crafting & Making and I'd gotten to know them pretty well. Betty is a talented graphic designer who created the marketing for the workshops at the makerspace. Earlier this week she silkscreened a few pieces of cotton fabric, and Rebecca is teaching her how to sew them into tote bags. Rebecca isn't using a pattern. "Once you start sewing, you start recognizing the basic relationship and geometry of things." She says. "Then it becomes easy."

I'm at the makerspace today not for research, but because I need to use the laser cutter. I hadn't planned on doing any observation, but there are half-a-dozen names on the laser cutter sign-in sheet before me and I'll need to wait at least hour. I don't even have my field notebook. Ella, another student lead, offers me a few pages from her journal. I walk around to the pegboard full of hand tools, grab an x-acto knife, and carefully cut a few of the soft pulpy pages from the spine. I know the people here, I know what to do here – I feel like I belong.

I've been using the laser cutter to make the looms for *Making Core Memory* since we had our first workshop in March. Making something in the space has given me a window into rituals, and flows and unspoken rules. It's given me something *to do*. Plus, the laser cutter is the perfect tool for making these pieces. They're simple but need to be produced in batches. With digital fabrication, all I have to do is pull up an Adobe InDesign file on adjacent computer, adjust a few settings, and it's off to work. The laser – evident only as a white spark, and the charred line it creates – will cut 12 identical squares from the chipboard, each with 16 perfectly spaced holes and 4 angled slits for the magnetic attachments.

I had started here as an observer and outsider. To my surprise, I became a maker.

**Making Makers**

How does one become a maker? The narratives from *Make:* media follow two potential pathways. Sometimes, making is an inclination that seems to have been with people since birth. *Make:* magazine traces the stories of many makers to childhoods filled with mechanical curiosity. The DIY spirit is something inherent. Yet, the DIY spirit can also arise from acts of making. In his book *Made by Hand,* founding editor of *Make:* Mark Frauenfelder narrates his own journey as a maker as beginning with household projects. Through acts of improvement and meaningful creation, he discovered the sense of satisfaction that emerges from having control over your physical environment. Initial experiences can be catalyst for the DIY spirit. This belief motivates much of the strategy at the CoMotion makerspace. Administrators envision a place in which access (to tools, to creative space) will catalyze a new generation of makers on campus. Both sites believe that making would not only help people learn basic skills, but help them unlearn entrenched ideas about their own abilities[49]. Perhaps the greatest thing that a maker can learn is that "they can learn to do anything" (Dougherty, n.d.).

As I laid out across chapters one and two, the maker identity – depicted in *Make:* magazine and built through work in the CoMotion makerspace – is underpinned by two driving principles: the Do-It Yourself spirit and radical accessibility. The Do-It-Yourself spirit impels makers towards hands-on-engagement, learning and innovating as they go. These activities occur within larger maker communities (i.e. print publications and physical makerspaces) where makers are encouraged to make their recipes, methods, and source files accessible to others.

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[49] See: Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

While the individual implication of Doing-It-*Yourself* seems at odds with the collective value of sharing, embedded here is a completion rather than a contradiction. Both *Make:* media and the CoMotion makerspace further a vision of making in which the passion of individuals is supported by access to tools and information held within a network of people.

**The Do-It-Yourself Spirit**. In the formative issues of *Make:* magazin*e*, Do-It-Yourself (DIY) represents a mode of engagement in which makers tinker with, modify and repair the material world. These activities are motivated by an inner enthusiasm for getting inside objects. Makers take things apart, put things together, and want to know how things work. The "makers mindset" transforms material objects into platforms for innovation—as hands-on engagement attunes makers to opportunities for improvement or inspires entirely new, disruptive ideas. DIY is the thread that connects *Make:* to its sister publication *Craft,* where objects are embedded in the cultural world. Here, the Do-It-Yourself spirit positions makers as active participants in the processes that produce and sustain material things. Creative practice becomes a reflective practice, where personal engagements with materials become a means of touching and transforming a larger context.

For the DIY spirit to make any sense within the context of education, it needs to be an orientation that can be developed, encouraged and even taught. Within educational discourses, "DIY" becomes subsumed in the language of "making" while continuing to motivate the independence, resilience and material connection that become defining features of the maker mindset. At the International Symposium of Academic Makerspaces, making is framed as a method of reconnecting engineers and designers to the knowledge that comes from practical engagements with physical things. This perspective is almost indistinguishable from Frauenfelder's reflections on the power of making. At the symposium, MIT's Dean of

Engineering explained the contribution of making to his department. Making was helping to produce a cohort of students who would innovate within companies because material, hands-on engagement gave them a different perspective. Makers knew what it meant to “make something in the real world” and to “make something new.”

Yet, making *better* innovators – from existing engineers – is of comparatively small impact when seen alongside the potential of DIY to *create new* innovators from people who’d previously occupied the margins of technology fields. The CoMotion makerspace, for example, is certainly working as a space for supporting engineering students. The tools there enable rapid prototyping and digital fabrication, facilitating idea exploration and invention from students in STEM majors. However, within in the official discourses emerging from the CoMotion office, the makerspace is employed as part of activation initiative intended to engage the whole campus. The space is open to any student, for almost any purpose. Once they enter the space, the Do-It-Yourself spirit is meant to impel student to learn through making, developing skills as they go. The DIY vision of education is both hands-on (material) and hands-off (self-motivated). DIY is a means of capturing an entire student population as potential makers—and ultimately innovators. All they have to do is “just go for it.”

**Radical Access.** Early on in my observation of the CoMotion makerspace, one of the student leads described the space’s goal as “radical accessibility.” The space existed to make the tools of innovation widely available to the student body. The closed-door policies of other labs on campus – limiting their spaces to students of a particular major – had created a “gap” in coverage. Not every major had studio space, materials and machines for making physical things. Not every student could have experiences that awakened a maker mindset. By providing access to tools, the makerspace hoped to address the most basic barriers to innovation. These hopes reflect liberal feminist perspectives that focus on equal access (e.g. admission) as the key to ending gender imbalance in STEM fields (Rosser, 2005).

As the makerspace evolved, the space's director emphasized access to a community. The makerspace had always been defined as "a collaborative hub for innovation" – but the visibility of space's technical capacity tended to eclipse the social element. The director aimed to cultivate a sense of fun and playfulness in space. Yet, it was also about creating a community that could provide encouragement and support for beginners. While makers are expected to tinker, and figure things out for themselves, the space is run on a model of learning that is entirely transmitted from maker to maker. A welcoming attitude became an important hiring criterion for makerspace mentors. We began hosting a meet-up called "Maker's Night" to attract new makers, especially those with a background in craft. Both the mentors and Maker's Night were meant to institutionalize the support needed for learning new tools and skills. Implicit in these initiatives is a belief in the power of others, even when you're Doing-It-Yourself.

These two types of access – access to tools and access to information – directly parallel the narratives of access that emerge from *Make:* magazine. The fourth volume of *Make:* features the Makers Bill of Rights, an enduring symbol of the maker movement today. The Makers Bill of Rights is rallying call for makers to fight for access to their technologies: both physically and in terms of knowledge. Makers-friendly technologies can be unscrewed, for repair and tinkering. Information for enabling these practices should be widely available. *Make:* magazine itself is part of this larger project. It openly provides tutorials and instructions for projects as tools for teaching and models for doing.

In *The Maker Movement Manifesto,* Mark Hatch writes that the sharing of knowledge is what "gives makerspaces their magic" (Hatch, 2014). Much of this magic comes not just from linear forms of instruction – in which a beginner learns from master – but from the blending of expertise. Connecting "hard" (electronic) and "soft" (textile) expertise remains the largest opportunity for change at the CoMotion makerspace. The space was founded with an, at times, unclear sense of how textiles contributed to a larger project of making. Although CoMotion emphasized the potential of the makerspace to nurture innovative thinking, in practice innovation became about high-tech tools and high-tech outcomes. These divisions are reinforced by the narratives that have concretized around the vision of making proposed by *Make:* magazine, which is largely defined by electronics and new ideas. Realizing the "radical" potential of makerspace means centering the process of innovation, and it's various points for contribution and intervention.

## Knowing From The Inside[50]

Although each chapter of this project examines a distinct field site and uses a distinct methodology, these projects are deeply informed by one another. Taking the principles of the Do-It-Yourself spirit and radical accessibility, I want to conclude by exploring some of the possibilities and limitations of this project through my own journey as a researcher and creator at the CoMotion Makerspace. My field research there (chapter two) is situated between a textual analysis that identifies the core narratives of *Make:* media (chapter one) and an intervention into those narratives using a method of feminist design (chapter three). In many ways, this organization reflects my perspective on the activities of makers within the space. As an act of cultural production, making at CoMotion is a constant negotiation between institutional visions

[50] Inspired by Tim Ingold (2013) who wrote "the only way one can really know things – this is, from the very inside of one's being – is through a process of self-discovery. To know things you have to grow into them, and let them grow into you, so that they become part of who you are."

of innovation and the creative goals of makers. The significance of innovation—and STEM disciplines more specifically—is an inescapable current within the university, the city of Seattle, and the country as a whole. Nearly everyone in the space, including myself, internalized its importance. Yet, there was an ongoing fight for what innovation would look like: how it would occur and who would be a part of it.

Working on the *Making Core Memory* project taught me just what Do-It-Yourself and access to tools could do. In January 2015, when the project began, we were working on every part of the workshop simultaneously. The quilt, the patch kits, the historical research—all of it was still in pieces. My collaborators were unflinchingly inclusive. But, as the least materially savvy of our team, I was dealing with some insecurity. I couldn't shake the feeling that I was constantly derailing their conversations as they paused to carefully explain to me the basic principles of electronics.

I wanted badly to contribute. So, I volunteered to prototype the patch kit. The kits needed to be simple and accessible. They needed to be understandable to people who didn't know much about computers. My beginner's mindset could be an asset here, I thought. The challenge was to design a basic loom. We imagined the workshop participants weaving squares that would be installed on the quilt. They just needed something to guide their work and hold it all in place. I made three prototypes from thumbtacks and foam board "frames" I'd cut by hand using an x-acto knife. We'd need another set for the next round of prototypes and then dozens of them, every time we ran a workshop.

Admittedly, cutting the frames had been the most difficult and least fun part of the prototyping. First off, my frames were a mess. Helen, who was leading the quilt construction, had also cut a set frames and it was easy to tell which ones were hers. She was a wiz with a blade and a straightedge. She knew the importance of precision. Quilting had taught her that errors are cumulative. A little off leads to a little *more* off, and 12 squares of different sizes. That's basically what I had in front of me. On top of that, interacting with the x-acto knife was stressful. My dad is a craftsman by trade and, from a very young age, he'd instilled in me both the DIY spirit and a deep fear of shop tools. He'd made sure that I knew the x-acto knife kept in a box on his drafting table would "cut right through to the bone." I couldn't imagine making the frames by hand over and over until we came up with a design, much less for everyone who would someday be part of the workshop.

"I could make these on the makerspace laser cutter!" I offered. An interesting claim because, no, in fact, I couldn't. I didn't know how to use the laser cutter. And, as I would find out later that week, foam board is banned for the makerspace machines. However, in that moment, I knew *just enough* to make a leap. I knew what the tool could do, I knew what I'd need to learn, and I knew someone that could help me.

A month earlier, Leo had started to teach me how to use the laser cutter. He was one of the graduate students researching the space and he helped organize Crafting & Making. Nobody had come to the workshop that week. Leo, Alexandra, and I were all sitting around the table with nothing to do, planning a programming schedule for the next few months. Maybe we would organize workshop around the laser cutter? In our conversation it became clear that I knew nothing – I knew zero – about laser cutting. Given the opportunity, I was still reluctant to learn. I was supposed to be *observing.* I had my notebook; I had a way to explain why I was the only person in the space who wasn't making something. Leo must have seen through me, because he responded with a warm kind of persistence. "I'll teach you, we have the hour."

We didn't get very far in the tutorial before our workshop ended and the space shut down for the day. We'd started to design a test file on my computer, and didn't even get to cutting it out. But, this tiny bit of knowledge was an entryway. It was enough to make me volunteer at the lab a few weeks later. A tool that had once overwhelmed me with imagined complexity used a set of skills I already had. "Digital fabrication" was just drawing red lines in an InDesign file and picking settings from a drop-down.

Makerspace administrators had hoped the space could include people like me, giving them a pathway to innovation. I am a woman. I am a student in the social sciences who entered the space with limited technical knowledge. Through my time there, I learned a new set of tools for my scholarly inquiries. My academic work was invigorated with a sense of creativity. The knowledge I built also gave me access to a new degree of cultural capital—as my work became relevant to computing and engineering fields with booming enrollments and endowment dollars. The critiques I make throughout this project are always accompanied by my own knowing that *making was transformative for me.* I intimately experienced the ideal outcome from the university's perspective. I know what is possible. I feel it personally.

Using my experience as a window, I also see the limits of DIY and access. I am not every woman. Although lacking in gender and disciplinary privilege, the considerable education I brought with me into the space facilitated my success. I was almost instantly connected to a network of skilled peers (fellow graduate students)—a resource that is available to other students, but is not always clear how to access.

Building a truly inclusive future for makerspaces will require specific attention to the barriers that exist for black, indigenous and women of color. Future work on this topic must use analytic frameworks that account for the way that multiple aspects of maker's identities—such as gender *and* race—overlap to create multiple forms of oppression (Cooper, 2016). As African American and women's rights activist Dorothy Height reminds, a woman of color "has the same kinds of problems as other women, but she can't take the same things for granted."[51] Any solutions that arise from my analysis here may help address problems shared by women – such as those created by historically gendered divisions of labor – but fail to address problems unique to the experiences of women of color. Initiatives that seek to serve "women" (as a category) often distribute the most significant benefit to white women, reinforcing racial disparities in technology communities (Ong, Wright, Espinosa, & Orfield, 2011).

In *The Master's Tools Will Never Dismantle the Master's House,* Audre Lorde (2018) argues for the redemptive power that women can build through connection and a commitment to our varying identities. She writes that difference "is a fund of necessary polarities between which our creativity can spark." Lorde reminds us that difference is creative. Difference is fertile ground for innovation.

After presenting a piece of this research at an academic conference, a person in the audience asked me an honest question: After all I'd seen, did I still believe in the power of making to build an inclusive future for innovation? The answer I gave was mostly semantic. "Making" is already the broadest of terms, I reflected. If we abandon it what else could we call a creative practice liberated from any one kind of expertise? In reality, my belief in making is felt more deeply than that. From a cultural production perspective, culture is not merely the outcome of creative processes. It isn't just in *what* people create. Rather, as Lisa Henderson (2013) reminds, "culture is *wherever* people create." This perspective attunes me to the power of practice to make – and ultimately remake – the cultures in which we make things.

[51] Quote exhibited at the Smithsonian National Museum of African American History and Culture.

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