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HCI's Making Agendas

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Abstract

In this survey, we examine how making emerged as an interdisciplinary arena of scholarship, research and design that connects entrepreneurs, designers, researchers, critical theorists, historians, anthropologists, computer scientists and engineers. HCI is one among many other fields and domains that has declared having a stake in making. And yet, a lot of what and who defines making is happening outside the familiar research laboratory or design studio. We take this article as an opportunity to reflect on HCI's relationship to making and how this relationship has changed over the last years. Making, we argue, presents HCI with the opportunity to question and revisit underlying principles and long-held aspirations and values of the field. Exactly because HCI and making share some fundamental ideals such as user empowerment and the democratization of participation and technology production, making confronts us with both the potential and the unintended consequences of our own work.

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1

Introduction

2012 might well be called the year of the maker. It was in that year that former US president Barack Obama visited a techshop in Ohio and famously declared that a future of "made in America" was being prototyped at Maker Faires, in makerspaces, and at hackathons. 2012 was also the year in which Pebble smartwatch raised one of the largest Kickstarter campaigns in history, with more than US $10 Million of funding, provided by 68,929 consumers who invested in a future of interconnected devices that the small hardware company promised. To implement this promise, the co-founders would spend the following year seeking partners in the manufacturing region in and around the city of Shenzhen in Guangdong, China, to scale into mass production. Pebble had successfully demonstrated that a move from hobbyist tinkering to mass-produced end-consumer electronics was insofar feasible as it showcased how the combination of crowdfunding and electronics manufacturing in China would enable a whole new generation of technology entrepreneurs to experiment with hardware: platforms like Kickstarter would provide seed capital for hardware start-ups to implement technological visions that might appear too risky for a Venture Capitalist and Shenzhen would be the place where one implemented in practice the move from idea into production.

Excitement was in the air also in scholarly and academic networks. Making appeared to provide - at last - the concrete tools and methods to implement a long-held promise of the tech industry and tech research communities like Human-Computer Interaction (HCI) and Participatory Design (PD): the democratization of technology production [Lindtner and Lin, 2017]. From HCI designers and researchers who saw in making a continuation of their commitment to empower users to governments across regions, large tech corporations like Intel, and venture capitalists to activists, artists, designers, and tech enthusiasts, a range of diverse actors saw something of themselves in one of the key vision of makings: to democratize technology production [Lindtner et al., 2016].

The particular excitement that surrounded making is in many ways reminiscent of earlier techno-optimistic narratives that had risen in the heydays of the Internet and entrepreneurship in software. Social media and digital publishing platforms, in particular, were celebrated as sites of empowerment of many by giving people to the tools and platforms to creatively express themselves, to socially organize, and make money in new ways [Benkler, 2006, Lessig, 2008, Shirky, 2009, Jenkins, 2006a]. Just like content creation and distribution tools—word processors, web and phone cams, Photoshop, iMovie, YouTube—back in the mid to late 2000s enabled anyone with a computer to produce and distribute cultural content, now a variety of hardware tools and maker platforms, paired with the power of digital networks, would allow anyone to make a phone, a computer, a smart watch - so the story went. And just like influential writers would help proliferate a story about a new era of media, software and information, so would an old and new cast of thinkers help spread ideas about making and hardware by means of writing - this includes but is not limited to Neil Gershenfeld's early book on *Fab* [2005], Chris Anderson's book on *Makers: The Third Industrial Revolution* [2005], the writings of Dale Dougherty including blog posts and books (founder of Make Media) as well as "how-to" periodicals from the founders of Arduino and the writers at *Make*. In other words, making and its story of individual empowerment by way of democratizing tech production appeared as if it had transplanted earlier visions of open source software and user participation into hardware. But was

making really just about a transition from software into hardware, from making digital things to making physical things, from coding on machines to making machines?

One of the key differences, we argue, was that the optimistic narratives of making were almost immediately accompanied by sharp criticism. Whose empowerment was this?, many asked. Maker and hackerspaces seemed to advance the interests of masculine and technological elites rather than constituting a space for "everybody" as the promotional campaigns of Make Media and writers like Chris Anderson wanted us to believe [e.g. Anderson, 2012]. It was as if the kind of techno-optimism that had persisted even after and despite the 2000 burst of the dot com bubble [Neff, 2012] had suddenly run out of steam. People began differentiating between hacking as a countercultural practice and making as a commercial endeavor [Maxigas, 2012, Sivek, 2011]. The commercialization of open source 3D printing projects like Makerbot in 2013 made stories of mass empowerment that had fueled so much of the 2012 and earlier rhetoric appear stale at best and co-opted by market capitalism at worst [Söderberg and Delfanti, 2015]. People began critiquing making's underlying premise of producing more and more stuff by turning attention to sites of repair, maintenance, and re-use [Houston et al., 2016, Jack and Jackson, 2016, Jackson, 2014, Jackson and Kang, 2014], but even there making's potential was circumscribed by economic and political forces opposed to reuse and repair [Avle and Lindtner, 2016, Irani, 2015, Lindtner, 2015b, Roedl et al., 2015]. Others challenged making's affinity with "hard" projects (soldering, CNC machines, hardware) and critiqued how, in contrast, craft and many other forms of making were rendered as less technological innovative and hence valued less [Fox et al., 2015, Rosner and Fox, 2016]. In other words, making simultaneously fueled earlier techno-optimistic promises *and* was the site to voice criticism of the political and capitalist gains that such promises granted. Many of these debates did not occur in maker-related networks alone, but were also carried out in the writings and talks of fields like HCI.

In this survey, we outline this process, examining how making emerged as an interdisciplinary arena of scholarship, research and

design that connects entrepreneurs, designers, researchers, critical theorists, historians, anthropologists, computer scientists and engineers. HCI is one among many other fields and domains that has declared having a stake in making. And yet, a lot of what and who defines making is happening outside the familiar research laboratory or design studio [Lindtner, 2014]. We take this article as an opportunity to reflect on HCI's relationship to making and how this relationship has changed over the last years. Making, we argue, presents HCI with the opportunity to question and revisit underlying principles and long-held aspirations and values of the field. Exactly because HCI and making share some fundamental ideals such as user empowerment and the democratization of participation and technology production, making confronts us with both the potential and the unintended consequences of our own work.

If we openly acknowledged and debated such overlapping interests and values, we might raise important questions that often remain silent in the publications and talks at conferences like CHI, e.g., questions about the relationship between HCI design/production and economics, the politics of participation, our relationship to industry and corporate management: What does HCI's strong focus on tool making and problem solving preclude us from seeing? What are the consequences of our commitments to democratize design? How is designing and making of technologies imbricated in the advancement of capitalist interests? What is HCI's position as making oscillates between the promise of building alternative futures on the one hand [Ehn et al., 2014] and the capitalist and economic interests this very promise allowed to pursue? Is HCI furthering a naive promise of a better future for the select few or working alongside those rarely included into conversations on technology production and innovation? In which ways does HCI confront or fail to confront its own affinities and alignments with the ideals and capitalist tendencies of making? How does HCI construe the relationship between making as an ideal and making as an economic project that has brought funding to universities, schools, entrepreneurs? How has HCI construed the tensions and overlaps between making, hacking, DIY, open hardware, craft, repair, and entrepreneurship?

That said, even though we maintain a critical stance throughout this work, we want to stress that in the end we share the optimistic and even utopian goals of maker practitioners and researchers. We believe that making does have the potential to emancipate, democratize, educate, and empower. As three of us wrote in Lindtner et al. [2016], we hope to learn from voices critical of making not to tear anyone down, but rather to help makers pursue their utopian aspirations in a pragmatic, hard-headed, and dogged way.

The survey is structured as follows. In Chapter 2, we summarize the two dominant frames of making research in HCI: the idea that making democratizes computing, innovation, and fabrication; and the idea that the development of new tools and infrastructures is one of the key roles for HCI researchers. Another key role is to develop solid and actionable empirical understandings of makers, both mainstream and those on the edges. Accordingly, in Chapter 3, we examine the maker methods and identity; how/where makers hope to intervene; how this fashionable notion of making relates to much older as well as tangential traditions, including handwork, craft, and repair; and finally how making empowers people to identify as makers and express themselves through making. Then, in Chapter 4, we step back and out of making to look at making's relationship to critique. This includes critiques of making, and it also includes making's critiques of society, including both critical making and also feminist un-hacking.

Throughout this survey, we consider ways that making is used as part of an intervention–into STEM learning, social justice, innovation and entrepreneurship, nation-building, and even reflexively back onto making itself. We share stories of hope, and technical achievements, of sociotechnical breakthroughs, and of coming up short. If we may, our intervention in writing this survey is to bring readers into maker research and practice, to cultivate their appreciation for making's many potentials while shining a critical light on cases of over-optimism and even delusion, and to empower you, our reader, to participate in this project of making making.

2

Democracy and Tools: HCI's Overarching Maker Agendas

As a field of research, HCI and adjacent fields such as Computer-Supported Cooperative Work (CSCW) and Science and Technology Studies (STS), often position research on making in relation to two interrelated overarching agendas:

1. the desire to democratize hardware use and innovation by increasing access to making, in part by . . .

2. . . . developing better tools with which to do it, including artefacts, tools, and systems crucial to DIY making.

The projects are interrelated because the use and creation of these tools is spurred by an interest in democratizing both the tools themselves as well as what they enable functionally. For example, maker tools have been incorporated in educational settings where efforts are channeled towards addressing gender biases in making (e.g. Buechley et al. [2008]) and the anthropocentric view of the hacker ethos [e.g., Devendorf et al., 2016]. Other work also includes enhancing particular features of existing fabrication tools and systems [e.g. Hudson, 2014, Mueller et al., 2014] and the democratization of fabrication tools [e.g., Gershenfeld, 2005]. Much of the early interest in this area started with

an intellectual excitement around the potential impacts of increasing access to fabrication afforded by new tools, such as arduino, 3D printers, laser cutters, CNC routers, and other tools commonly found in makerspace, hackerspace, Fab Labs, and similar spaces.

What we mean here by maker technologies include but are not limited to hardware platforms, digital fabrication tools and systems, modelling software, and craft tools. For example, one of the most ubiquitous hardware prototyping platforms is the Arduino. First introduced as the Arduino in 2005, the Arduino hardware has now expanded to 17 versions, each fulfilling a specialized function or serving as an upgraded version of the prior. Adafruit Industries, an enterprise specialized to both develop and sell hobbyist kits and electronics, estimated in 2013 that 700,000 official boards belong to users. ("Arduino FAQ – With David Cuartielles". Malmö University. April 5, 2013).

2.1 Making and the democratization of computing and innovation

The promise that making as a technological innovation will empower and emancipate is prevalent in maker discourse. In this section, we link it to similar (Western) narratives, which have told about earlier technologies, and we seek to unpack at a finer level of granularity exactly how it is that making will do this democratizing work.

2.1.1 The prehistory of making as democratizing

Tracing how tools have historically come to be seen as democratizing tech production directs us to prior forms of anti-establishment, communitarian technological efforts, which encouraged experimentation with digital tools. Stewart Brand, his publication *Whole Earth Catalog* – an American counterculture magazine advocating hacker ethic and tools since the late 1960s – and hackers and tinkerers in the Whole Earth Network serves as a useful reference. First offering methods and tools on how self-empowerment can be realized through the use and innovation of digital technologies, Brand's publications offered hackers the discursive and material means for mobilizing the personal computer as

a means for revolutionizing cultural production in post-war America. Evaluating the success of this "revolution" is out of the scope of this survey, but it is useful to note how computer hacking came to preoccupy earlier notions of what led to DIY making. While contemporary making also evolved outside of the ethics advocated for by Californian computer hackers of the 1960s/1970s, Stewart Brand's catalog still resonates for many who are active in making, particularly in its notion of "makers" as the "new hackers" [Morozov, 2014].

Theoreticians and practitioners of maker culture have also narrated the prehistory of their field using computer hacking as a prior example of recent developments in open source hardware movements and experimentation with other sciences such as do it yourself biology [Kera, 2012, Roosth, 2017]. Akin to previous pursuits by the tinkerers and amateurs of Whole Earth Network, the Homebrew Computer Club (HCC), an amateur group started in Menlo Park, California in 1975, featuring members such as Apple Founders Steve Jobs and Steve Wozniak, serves as a crucial historical moment for understanding how hacking and making unfold in the U.S. Adjacent to breakthroughs in computer programming and electrical engineering, the HCC helped promote notions of home and personal computing [Roosth, 2017]. The concept of personal computing, as it was forged by amateur groups like the HCC and Whole Earth Network, was a direct response to the enormous (both physically and functionally) computing machines built during World War II and the following decades. Its proponents sought to make computing an accessible, user-friendly, and even a domesticated technology [Coleman, 2012, Levy, 2010, Roosth, 2017].

According to Mota [2011], all of these developments echo the Arts and Crafts movement of the late 19^{th} century. In that movement, supported by their political values, skills, and tools, European artisans pushed for alternative lifestyles and livelihoods that rejected economic reforms and industrial ways that questioned the role of crafts in modern living. The Arts and Crafts movement of the late 19th and 20th centuries was, in some ways, a response to the deskilling of labor under the pressures of industrialization in Western Europe [Dormer, 1997]. Anti-modernists who wanted to find a way to preserve tradition sought for a

"world in which there was enjoyment in labor through the regeneration of handicraft" [Greenhalgh, 2002, 38]. Recalling the tenets of the Arts and Crafts movement, advocates of crafts called upon the integration of the decorative art, the vernacular, and labor politics, pushing for a "utopian society based on creative meaningful work undertaken by all members" through revaluing the crafts (Greenhalgh [1997] cited in and [Buechley and Perner-Wilson, 2013, 22–23]). Hunsinger and Schrock [2016] presents a collection of tools and technologies that contribute to various "revolutions" tied to the increased popularity of personal manufacturing practices. Mota links the increase of references to such a revolution to "a renaissance of the Do-It-Yourself (DIY) movement with a hi-tech facet." This modern movement, Mota argues, is enhanced by "the most powerful many-to-many network the world has ever known" [Hunsinger and Schrock, 2016].

In short, some HCI research on making is tapping into a technological narrative that dates back over a century in the West. In it, new technologies are claimed to disrupt a hegemonic force and empower everyday people: first the undesirable qualities of industrialization (in the Arts and Crafts movement), then of post-War consumerism (in the *Whole Earth Catalog*), next of corporate/government mainframes (in the Homebrew Computer Club), and now of mass-produced IT manufacturing (with the maker movement). "Empowering" individuals in this narrative refers to ways that control over the means of production, as well as the ideologies and values perpetuated through it, is undercut, either by redistributing the means of production to broader segments of society and/or by directly challenging the ideologies and purposes underlying it.

This technological narrative is visible in an influential book by Neil Gershenfeld [2005], *FAB: The Coming Revolution on Your Desktop—From Personal Computer to Personal Fabrication*. This book presents a variety of cases to support an argument that people from all backgrounds can, through access to personal fabrication technologies, be taught how to make almost anything–and that this constitutes a revolution that will empower future generations to become more independent. The maker stories related throughout the book focus on the tools

FabLab participants from around the world have made for themselves in a variety of contexts, from sheep tracking networks in Norway to an interactive table setting installed at the Museum of Modern Art. These stories demonstrate how participation in FabLabs, and taking advantage of the maker tools they provide, can in some cases help to deliver on the promises of the maker movement in the context of personalized fabrication technologies. Collectively, the stories showcase a cross section of what can be possible, while also concretizing the aspirations driving the maker movement.

Research has shown that makers characterize themselves in a similar light, suggesting that the underlying ideologies and aspirations of Gershenfeld's work have spread with and alongside 3D printers and FabLabs. In an interview study, Grimme et al. [2014] asked North American makers about how they saw their practice as intervening in the world. Their responses were typically framed around the concept of empowerment, with their participants offering three different modes of empowerment. As the authors summarize, the three modes are as follows (the bullets constitute a block quote):

1. *Empowering oneself*, artifacts and activities that allow the maker to provide them self with a product or experience that they want or need, feel a sense of pride or accomplishment through their actions, or achieve self-reliance or self-sufficiency.

2. *Empowering others*, artifacts and activities that allow makers to teach and inspire others, to raise awareness of or affect changes toward social issues, or to create new choices for artifacts or experiences.

3. *Empowering communities*, artifacts and activities that allow makers to contribute to the making community by sharing tools, resources, networking, and collaboration (p. 4)

In short, the argument can be boiled down as follows: new technologies lead to new tools that lead to new practices that change society, in part by getting even more people to engage the new technologies, thus feeding the cycle.

2.1.2 Making and Democracy in HCI

DIY making researchers in HCI offered similar arguments. The democratizing argument is explicitly laid out in Tanenbaum et al. [2013] article, "Democratizing technology: pleasure, utility and expressiveness in DIY and maker practice." Arguing that DIY making is often seen as a mere hobby, they propose "shifting the focus" to DIY making as a "democratized technological practice." This practice brings together the virtues of playfulness, utility, and expressiveness–a powerful motivation to participate. And the practice results in demand for new types of tools and literacies, which HCI is well positioned to develop and support. Thus, the democratizing potential of making is championed, and HCI researchers are given a clear role in contributing to that potential.

Buechley et al. [2008] similarly argue for making's potential to democratize by being applicable to people's real life situations and thereby more meaningful. They describe the creation and implementation of the Lilypad–an Arduino kit focused on e-textiles that takes advantage of novel materials, such as conductive fibers and fabrics–to enable people of all ages to engage with wearable computing in new ways. Through this work, the authors call for others to take advantage of such novel materials in order to contribute to "democratizing the range of human expression and creativity." They tie these arguments to their devotion to "making educational experiences intrinsically motivating and relevant to youth culture." Similarly prioritizing meaning over technology, Devendorf et al. [2016] focus on ways to facilitate making from everyday materials with a distinctively artistic take. Inviting 14 participants to use their system, the authors showed how making can "support aesthetic experiences and critical reflections on the relationship" between humans and machines. They also expanded upon hybrid (physical-digital) fabrication design space to show how artistic values might help navigate these tensions that might help get at the different kinds of fabricators and types of fabricating.

Another way to activate making's democratizing potentials is to make use of its social dimensions. Hudson et al. [2016] discovered that casual makers encountered barriers throughout 3D printing and fabrication workflows, but often negotiate such barriers with the assistance

of print operators and other fabrication tools. They urge designers to develop better tools and workflows for casual makers, in part by focusing on ways that people can accomplish things in social situations that they cannot do alone. In this version of the democratization argument, making can function as a sociotechnical infrastructure that can democratize by increasing the accessibility of technologies to more people.

HCI researchers have also carried forward Gershenfeld's focus on formal educational settings for the young as a locus of making-enabled empowerment. For example, researchers have argued that introducing making into education can stimulate an early interest in science and technology. Richard et al. [2015] used a hackathon as a college recruiting event to stimulate student interest in computing, with implications for the design of hackathons as IT program recruiting events. Beyond stimulating interest in computing in general, making has also been used as a pedagogical strategy to improve creative designing in children. In an experimental study, Fitton et al. [2015] found that completing a maker task prior to doing a design task increased the complexity of construction in the design task, compared with students who did the design task first and then the making task. Another study explored DIY assistive technology in children: Hook et al. [2014] hoped that making could democratize assistive technology innovation leading to low cost, rapid development of new devices for the children, though they found a range of challenges, including barriers to participation.

Researchers have also argued that making empowers traditionally marginalized populations. For example, feminist hackerspaces use making to "work out their place in society" and to "contest widely accepted understandings of hacking, technology, and collaboration" [Fox et al., 2015]. (For more on feminism and making, see section 4.2.1.) A key result of these hackerspaces is thus reflexive: to bring forward and rework active definitions of making, in this case to call into question tacit but gendered assumptions about which acts count as making, thereby silencing and/or blocking access to the movement.

An even more ambitious argument has been made about making and the Global South, where high-tech industries seek to move beyond manufacturing for Western multinationals and instead create their own

products for the global markets [Cervantes and Nardi, 2010]. In other words, the "democracy" in this case refers to equality of access to selling products on global markets, currently dominated by what one might metaphorically characterize as an oligarchy of Western multinationals. To develop such products, innovation is needed, and emerging infrastructures and social networks of fabrication become an important part of that story [Lindtner, 2015b].

Collectively, this research shows that making can contribute towards democratic outcomes in several ways. Making can empower individuals to make, repair, and actually *own* their own devices. Making also empowers by heightening people's sense of self-efficacy, helping them to be more comfortable around technology and feeling like they can do it themselves. And because making is accompanied by an exciting and evolving meta-discourse, participants become empowered to reflexively help define what "making" means moving forward. Finally, making offers diverse ways for individuals, collectives, and even nations to gain improved access to markets, increasing their economic value.

2.2 Developing tools, developing makers

A key idea behind making in general and the democratization of making in particular is the availability of new tools. These new maker tools–3D printers, CNC routers, and laser cutters being the most celebrated–do a lot of work: they make possible new computational practices, help define what/who a maker is, define (or make recognizable) what a "makerspace" is/looks like, and are key to the empowerment that drives the democratization project in the first place. And, because HCI has a storied history of developing content creation tools, it is not surprising that a key focus of maker research in HCI is about the development of tools to support makers.

Tool development was prioritized in a 2013 CHI workshop seeking to build momentum for maker research in HCI. In it, Mellis et al. [2013] outline five themes to be explored by HCI researchers at the intersection of digital fabrication, tools, design, and community: "design tools and interfaces, online collaboration around physical objects,

prototyping in the interaction design process, hands-on learning, and unique, personalized artifacts." Specific research foci that they proposed included the creation and prototyping of personalized interfaces, the support of network-connected maker communities, as well as the creation of one-off designs.

2.2.1 HCI makes tools

As one of its key contributions to making, HCI research has improved the tools available to makers. We summarized earlier how, for example, Leah Buechley built on the Arduino to create LilyPad Arduino, opening up the platform not only to a new domain of fabrication–e-textiles–but also to enroll many more female users into the maker project. Others have addressed other limitations of maker tools. For example, a key challenge of 3D printing is that the time and resources required to do 3D printing discourages physically larger scale prototypes, while also providing a higher resolution than is often needed.

Mueller and colleagues sought to address this challenge in two different ways. In [Mueller et al., 2013], the authors present their LaserOrigami system, designed to be faster and more efficient than traditional 3D printing techniques. The authors categorize LaserOrigami as a type of "interactive fabrication," which is when whatever is being fabricated alternates between user and system control. In this case, that alternation takes place during the bending, folding, and stretching process that the LaserOrigami system facilitates, "allowing users to make changes even within a version." Taking a different approach to the same problem, Mueller et al. [2014] developed a method for improving the efficiency of 3D printing for prototyping purposes that includes replacing large, regularly shaped areas with Lego bricks and similar building blocks to cut down on print time. Areas that need to be in higher resolution, or are the focus of the prototyping project, can be 3D printed, and areas of the prototype with less of a need to be in high resolution can be replaced with building blocks. In both cases, the authors support the broader goal of end-user 3D fabrication by contributing both a new tool and a new process.

Another limitation of mainstream maker fabrication tools is that they are limited to making hard things, most typically hard plastic and wood objects, often created with computer-aided precision. Recognizing a need for tools needed to fabricated soft and imprecise materials, Hudson [2014] developed a 3D printer to work with soft materials such as fabrics and yarns, using a 3D printed teddy bear as his paradigm example. This 3D printer functions in much the same way as felting, wherein yarn or roving is matted together so that the fibers entangle with the use of a barbed needle. While this type of felting (or similar fiber arts in the form of knitting or crochet) could be done by hand, Hudson argues that this soft fiber printer can create these objects more quickly. The inclusion of this new type of material, Hudson argues, provides researchers and makers alike with a new capability to explore in the context of personal fabrication and 3D printing.

In a similar spirit, [Efrat et al., 2016] saw an opportunity to use computational methods to produce the geometry of embroidery patterns. They introduced Hybrid Bricolage, a new parametric design paradigm pattern catalog and computer-aided smocking (CAS) design software that enables craftspeople to use parametric design tools to make specific kinds of embroidery patterns. The authors hypothesized that "the arrangement of parametric design space in modular representation" can assist craftspeople new to parametric design and would allow them to work with a limited set of computer-generated metapatterns. They conducted a user workshop with 8 fashion designers and discovered that while amateur crafters were relatively easily able to incorporate technology into their workflow, they expected the technology to help them at design time, rather than fabrication time, as the authors of the study had expected.

2.2.2 From tools to ecologies

Part of the success of making as an idea and even a "movement" is that it is not all about a single tool, but rather a whole *category* of tools: tools that are relatively inexpensive and easy to use that allow lay users to do computer-assisted fabrication themselves. Perhaps the most visible and successful leveraging of this category is the FabLab, which is a

globally replicated makerspace setup featuring a more or less standardized collection of tools and protocols intended to support learning and knowledge sharing. Today, there are more than 700 Fab Labs worldwide. Its standardized collection of tools features 3D printers, CNC mills, electronics benches, laser cutters and similar computer-assisted tools, often situated alongside traditional shop tools, such as table saws, workbenches, saws, planes, etc. The official list as of this writing can be found in the FabLab Inventory [2017]. The Fab Lab in some senses reifies the idea of making in the form of a template physical space featuring certain kinds of tools. In addition to supporting end-users, the Fab Lab also supports ongoing discursive production (e.g., what is making? How can I become a "maker"?) and also guides what kinds of tools can be targeted towards makers. For example, the tools contributed by HCI researchers that we have just described make perfect sense as additions to Fab Labs, in terms of both their capabilities and their assumptions about who is using them and for what kinds of purposes. Section 3.1 introduces some other examples of making infrastructures.

Taking this line of reasoning to its logical next step, some have started to view maker ecologies as infrastructures. For example, Kera and Graham [2010] consider the consequences of the increasing mass availability of data. They ask how design can support communities that are "built around sharing and integrating data from various sources," observing that such sensors, data, and heterogeneous human participants operate across diverse scales. Much of the popular discourse on making focuses on individuals–the individual with a great idea who wants to turn it into a startup, or the under-employed worker who wants to improve his or her skills, or the high school student whose interest in computing is awakened. The focus on infrastructure incorporates all of that but also imagines whole communities as actors, and data collectives as materials to think with and act upon. Optimistically, it tries to understand the potentials for such infrastructures to support the emergence of better communities–Kera and Graham use sustainable communities as one example.

A more pessimistic take is to consider how infrastructures already in place shape communities in less benign ways. For example, Nguyen

[2016] argues that the specific practices of hacking in Vietnam are situated in the intersection of sociotechnical as well as sociocultural infrastructures. Sociotechnical infrastructures include the proprietary lockdown of the iPhone, while sociocultural ones include Vietnam's location at the margins of global modernity. In such a context, hacking blends traditional Vietnamese practices of making-do combined with participation in global technocultures of hacking as a "strategy of breaking into global techno-culture." In other words, hacking in Vietnam is either "breaking in" to technologies that people in Vietnam use but have no control over (such as products in the Apple ecosystem), or as a form of "making do," that is, finding merely acceptable solutions within situations of too-limited resources. The sociocultural technical infrastructure of hacking in Vietnam suggests that making helps shape not only individuals or communities, but even whole nations.

2.2.3 Tools make makers

Even as tools have helped shape and even define making, HCI researchers also remind us of what anthropologists have shown for decades: humans don't merely use tools, but tools extend our capabilities and thus change us. Devendorf et al. [2016] questioned how particular maker-oriented tools and specifically, the 3D printer and its workflow reinforce the role of the "human" and particularly, the maker as "visionary and commander of passive machines and materials". In this paper, they offer an alternative system for 3D printing, called Redeform, which embraces material "recalcitrance and unpredictability" to adopt a less anthropocentric view towards working with maker-oriented tools and systems. Doing so allows makers, and in broader sense, users to reconceive new modes of designerly work whereby unexpected and surprising instead of non-random, controlled ways of making can be conceived as an alternative workflow or experimentation with materials.

Offering findings that support the underpinnings of the Devendorf study, Bardzell et al. [2014] studied maker attitudes towards tools and found the relationship between humans and tools to be more fluid than expected. A series of interviews conducted within a broader ethnography of a maker space showed that what the makers called "tools" did

not always fit into traditional understandings of tools. To account for this usage, the authors connect two discourses of interest to research on making: tools and adhocism. They show that what the makers call "tools" fluidly shifts among materials to be shaped and worked on, tools that do the shaping and working, and signifiers of selfhood to represent the individual and collective identities of a given maker and his or her maker space. An implication is that HCI researchers developing tools for makers can think more ambitiously about how tools link materials, tasks, identities, and communications–affirming the motivations of Leah Buechley's work on the LilyPad Arduino, as summarized earlier.

2.2.4 Summary

We have seen how HCI researchers who are makers themselves are not only interested in understanding how makers use these tools in naturalistic contexts and settings but are also interested in improving their own instruments as well. Researchers such as Hudson [2014], Mueller et al. [2013, 2014], Efrat et al. [2016] are primarily interested in how to support maker creativity and productivity through improved tools and workflows. They identify a problem with currently available tools–that current methods of fabrication only supports the production of hard things, that it takes too long, that it doesn't always operate at the best level of resolution etc.–and develop new tools and processes to address the problem.

This line of reasoning is extended to tool ecologies. With Fab Labs, we saw how the opportunity to *design* an ecology created a replicable model that reflects the values of the maker movement (as seen by MIT) and constructs a globally networked community of makers. We also saw that once a given technology achieves a critical mass (e.g., environmental sensors) that an infrastructure emerges and one or more potential communities who collaborate to act on them. But Nguyen [2016] reminds us that infrastructures are not only sociotechnical, but also culture, so that projects of modernity, global participation, and nation-building also become tied up in making.

Additional research has proposed to build further on these contributions by looking more broadly at the problem space. Buechley et al.,

and Devendorf et al. show us how prior modes of making, whether anthropo- or male-centric can be disrupted with the introduction of new tools that sought to be inclusive. Bardzell et al. emphasize that maker tools are often an ad hoc assemblage of available materials, immediate tasks at-hand, and signifiers of selfhood. Not surprisingly, making reaffirms, with its own particulars and consequences, the general idea that tools, identities, and values are tied up with one another. Making is, in the West, ideologically founded on a century-old, oft-repeated promise that new technological advances will disrupt the status quo by creating new opportunities for an ever-widening set of participants. But research suggests that it is also deeply influenced by another ideology, one of entrepreneurship, innovation, and participation in capitalism. With making, the two ideologies are presented as compatible, that is, to be able to participate better in capitalism is seen as democratizing, all of which made possible through the emergence of new tools and technologies.

Researchers have called attention to and even critiqued this narrative. Yet rather than just debunk it, we hope also to show why it is seductive–not only to an industry that stands to benefit economically from it, but even to critical scholars such as ourselves who seek to grasp glimmers of hope–glimmers that making undoubtedly offers. In a way, one might argue that even the more "critical" takes on making are themselves in alignment with its narrative: the critiques reflexively disrupt the status quo of making itself in service of creating even more democratic opportunities for even more participants to be a part of making.

3

Cultivating Making and Maker Identities

Early HCI work on making can be roughly split into two areas of interest, with the first focused on utilizing HCI methods and tools to help cultivate a maker ethos by offering new tools, systems and interfaces, and the second comprising qualitative studies of grassroots producers, hobbyists, amateurs, tinkerers, and crafters and their construction of expertise, their organizational and entrepreneurial work, and the material and social processes of their production. A subset of this work has been motivated by a broader commitment to better understanding and further enabling diverse technology design and production practices outside more familiar professional environments such as the university lab, the design studio, or industry research lab. This includes research in settings and regions that are excluded from dominant (e.g. Western and/or male-dominated) lineages of design and computing.

This section elucidates how HCI research shares with advocates of making an underlying commitment to open up technology design and to democratize production. Some of this work is interventionist by providing educational platforms or tools and systems that support users to become makers. Others draw from empirical, ethnographic and auto ethnographic methods to theorize relations between activism,

the potential of democratization of production, and intervention into established social and economic structures.

We also emphasize that this body of HCI research coincided with a much broader legitimation process of making. The research and development that has gone into making–from the development of tools and infrastructures to empirical studies of practice to the global spread of the Fab Lab as an institution–required considerable investments. These investments in turn required a project of legitimation for multiple actors and institutions. For industry, arguments were mounted to the effect that making would lead to new areas of growth, new pathways to recruit capable employees, and new models of innovation. For instance, several players in the tech industry (e.g. Intel, Qualcomm, Microsoft, Google) as well as a series of venture capitalists and incubator programs (e.g. Highway1, Hax, Bolt, Y-Combinator) saw making as providing the ideal methods, tools, and spaces (e.g. open source hardware platforms like the Arduino, maker and hacker spaces as the social organizations that facilitated informal and collective learning) for training the next generation of tech producers, who'd not only tinker with software and data, but also with hardware and by extension lead a new area of technological development and expansion of the tech industry: the Internet of Things (IoT). The usage of IoT granted large corporates to rebrand their earlier visions that had fueled investments by the tech industry such as the smart home, smart devices, and wearable technology by tying together newer visions of big data with older visions of ubiquitous computing [Weiser, 1999].

For this to work, the industry required not only creative knowledge workers, but also people trained in hardware prototyping, manufacturing, and digital fabrication – and making was seen as the ideal training ground and pathway to cultivate this new workforce. Intel, for instance, initiated a series of educational programs in the United States and China that would train a new generation of "developers" in exactly such skills. This included amongst other efforts a TV show entitled "America's Greatest Makers" (https://newsroom.intel.com/press-kits/americas-greatest-makers/) and the Beijing-based platform called "Maker Collider (http://www.makercollider.com/)," each promising

financial rewards for teams who competed against one in another building innovative solutions and products on top of Intel's open source hardware platforms Galileo and Curie. The key idea was to create an inventory of IoT prototypes built on Intel chip technology that could function as models or patterns for future products. For the defense industry, there was similarly an interest in recruiting as well as crowdsourcing basic research into emerging technologies, such as robotics. Governments saw opportunities for job growth, the resurrection of failing manufacturing-based economies, and for eroding the digital divide. Universities were attracted to opportunities to pursue constructivist learning while stimulating interest in science and technology fields. Part of the success of making was its ability to appeal to different constituencies for different reasons, even if doing so resulted in some strange bedfellows.

3.1 Cultivating a maker/DIY ethos to upgrade HCI design

Although making tends to be associated with a deep engagement with materials beyond the digital including hardware, electronics, wood, paper, fabric, plastic, and so on, software coding and digital networks have played a central role in the proliferation and adoption of making. This includes e-commerce websites focused specifically on making and digital fabrication including for instance Sparkfun, Adafruit, and Seeed Studio, Chinese e-commerce websites Taobao and Alibaba, as well as a myriad of information and project sharing platforms including but not limited to: LilyPond, an online community for sharing e-textile projects developed by Lovell and Buechley [2011]; MIT's Scratch, a platform enabling children learning to program to remix and appropriate programming projects built by other children; Instructables, a large-scale tutorial-based website much like Scratch but for a wider variety of DIY projects catering adults; Stack Overflow, a programmer-specific website for sharing answers to programming problems, ranging from complex to commonly encountered; and many other communities with less of a technological focus such as Ravelry, Deviant Art, and fanfiction writing groups.

Drawing from methods applied to user studies such as surveys, interviews, and online observations, HCI researchers have approached these and similar platforms as unique environments to study maker practices. Kuznetsov and Paulos [2010], for instance, drawing from a survey of over 2600 individuals active across a variety of different online platforms, urge HCI researchers to take inspiration from values they found expressed on these sites including open sharing, learning, and creativity. HCI would be well served if it incorporated such values, the authors propose. This would help adapt HCI technology design and production practice to a modus of integrating physical and digital domains, designing systems that allow the transfer of knowledge across domains, and supporting an iterative studio culture. In other words, the underlying idea here is that HCI's own culture of research and design would be positively transformed if adopted technology production and sharing practices central to making.

In a similar vein, Wakkary et al. [2015] propose that a DIY making approach applied to HCI design could enable the cultivation of interaction designers as so-called "hybrid designers." A hybrid designer, as the authors propose, is a professionally trained interaction designer who takes on a mediating role between expert communities, hobbyists and amateurs. The hybrid designer would be focused less on producing completed artifacts or systems but more on translation and education, further enabling DIY making practices and a – what the authors call – "paradigmatic shift of empowering a new class of producers." The authors ground their arguments in an autoethnographic engagement with online DIY tutorial sharing and learning practices, which they propose as an ideal site for the cultivation of a hybrid design subjectivity. Interaction designers empowered by a DIY mentality, here, are rendered as ideally positioned to open up technology and design education to a broader audience. Similarly, other HCI researchers have highlighted DIY making as a unique method to scale-up and speed-up prototyping (e.g. Gaver et al. [2013], Hartmann et al. [2008]). Taken together, there has been an expanding body of work in HCI research that frames DIY making as ideal in helping designers, engineers and researchers to adapt to shifts in the industry and processes (and speed up of) tech-

nology production. DIY making, in other words, is here understood as an important arena to prototype alternative ways of doing HCI design and research.

This line of research has family resemblances with another adjacent body of HCI work that coincided with the field's interest in making and was focused specifically on questions of materiality, e.g. [Blanchette, 2011, Dourish and Mazmanian, 2012, Robles and Wiberg, 2010, 2011, Rosner et al., 2012, Wiberg et al., 2013, Bergström et al., 2010, Vallgårda and Redström, 2007]. This work draws attention to the material configurations that enable and constrain the digital, which includes not only physical stuff and infrastructures, but also "historical particularities, cultural specifics and political consequences of information work" [Dourish and Mazmanian, 2012, p. 4]. Others were focused on how an engagement with makers of non-digital things could rework dominant frames of design. Rosner and Ryokai [2009], for instance, developed a system for knitters called Spyn — an information-sharing system that associates digitally recorded messages such as geographic locations to positions on knit fabric — to understand how people appropriate digital technology in craftwork. This, they argued, could in turn open up HCI design; approaching technology through craft, the authors argue, knitters didn't just highlight technological expertise, but also the care work done between people, places, and technology. A study of knitters and crafters, here, is offered for HCI to challenge false binaries between the "material and immaterial constituents of the social world" and enable a move from the study of objects to a study of "future-directed, transformative potential of materials" (p. 203).

More broadly, making has been stipulated as carrying potential to reinvigorate STEM education, visible in political speeches by former president Barack Obama as well as a range of philanthropic projects focused on maker education (e.g. Ford Foundation, MacArthur), all of which have been investing in the idea that making can revamp top-down educational settings by engaging students in hands-on learning and adapting a DIY and often also entrepreneurial attitude [Lindtner, 2015a, Irani, 2015, Avle et al., 2017]. In alignment with these ideals, HCI researchers and designers have applied making to education in design

and STEM fields and disciplines [Mellis and Buechley, 2012, Kolko et al., 2012]. Others have explored how making and DIY can offer a new educational paradigm, whereby learning is construed as unfolding more naturally when emerging from within self-driven projects and interests specific to smaller communities or societal groups [Buechley, 2010, DiSalvo et al., 2008, Mellis and Buechley, 2012]. Much of this work follows the theories of John Dewey, Seymour Papert and Paulo Freire, who have written on constructive technological use, culturally-aware education, experiential learning, and interest-driven curricula [Blikstein, 2013]. By surfacing similarities between computer programming language Logo and maker tools like the Lilypad, Blikstein [2013] shows how these theorists have found continuous uptake in what is often celebrated as radically new or rupture of earlier educational models.

Bowler and Champagne [2016] propose that earlier capacities for learning that have been theorized to emerge from digital technologies from online gaming to social media and tools like scratch in a form of "production-oriented, interest driven, and peer supported, connected learning" now "finds its full expression in the maker movement and its attendant maker spaces." "Exciting things are happening in makerspaces," Bowler asserts in a 2015 blog post and continues as follows:

> "including learning to think critically about oneself as a maker and about the social responsibilities that come with making. In the world of Human-Computer Interaction, this is called critical technical practice, or critical making. From this perspective, making is about more than creating objects, learning STEM principles, or how to code; it is also about understanding the process, thinking critically about oneself and the role that one's values and assumptions can have on the objects one makes, and the effect that one's creations might have on others."

In a similar vein, Peppler [2016] are concerned with how making can facilitate learning processes for children. They study, for instance, what motivates children to participate in the building of digital artifacts and machines such as robots and to engage with amateur hardware platforms such as the Arduino. Peppler et al. find that software

and hardware focused activities enhance tech awareness and experience, inviting students to collaborate and share ideas across different boundaries, but the specifics of how these activities are designed matter tremendously in either encouraging or discouraging participation. Access to technology alone, the authors show, does not in and of itself guarantee increased information sharing and knowledge acquisition.

Collectively, these works position making to pursue long-held HCI values and approaches from critical technical practice to engaged learning and individual empowerment to a much broader audience by applying it to education via making. In his recent book *Disruptive Fixation. School Reform and the Pitfalls of Techno-Idealism*, Christo Sims, drawing from a 7-year long ethnographic engagement with exactly such an educational experiment that applied values of hands-on learning, DIY, peer production and making to reform classroom and educational settings, shows convincingly how such projects can reproduce, despite their rhetoric of empowerment and social change, "many of the problems that it had been designed to remedy" [Sims, 2017]. Humanistic work in HCI, similar to Sims, has increasingly raised awareness of the pitfalls of techno-optimism and the complexities of gender, race, and class inequalities it often masks or even exacerbates (e.g. Ames [2016], Ames and Morgan [2015], Ames [2016], Bardzell [2010], Bardzell and Bardzell [2015], Dourish [2010], Lindtner et al. [2016], Rode [2011]), this survey shows how a language of optimism and opportunity still (almost stubbornly) still pervades yet again recent work on making and learning.

A recent literature review of empirical studies about the implementation of maker practices in learning environments by Papavlasopoulou et al. [2017] describes how a large majority of the work related to bringing maker culture and maker practices to learning environments is done in the context of teaching programming languages and other STEM interests. The authors report that almost none of the papers they found in this context discussed negative effects of incorporating making into the learning objective. One potential reason for this, the authors argue, is that many of these studies focus on extracurricular activities, rather than core classroom interactions. Some of the positive effects mentioned

in the research these authors cite include: attitudes and perceptions toward STEM subjects, self-efficacy, impressions about the processes of making, and engagement, as well as a few studies that more directly linked making activities to test scores. In other words, while there have been myriad of efforts of applying maker tools and maker ideals to learning and education, an underlying assumption of its positive implications shapes research directions and studies, with far fewer studies focused on questions of unintended consequences and potential negative implications such as further proliferation of existing inequalities [Sims, 2017].

3.2 Intervening in or co-opted by capitalism?

In a 2013 article, Tanenbaum and colleagues propose that making offers new forms of literacy that go well beyond technological know-how, but that would enable more and more people to find ways into what the authors call a form of "friendly resistance" to contemporary forms of market capitalism. This was possible, the authors reason, because in today's age, knowledge was contained in machines, which are typically black-boxed, mostly for the benefits of those who own the machines, i.e. large corporations. Making, they argue, by merging craft and industrial methods, can empower people to intervene in processes of industrial production and capitalism. This would be possible, because people were now "making a living off of their creations," which associates new values with technology practice. In the paper, the authors speak openly about their "unflinching optimism," which they articulate as being central to their own belonging to the maker movement. Such optimism, they reason, does not contradict "critically engaging with the role of making and broader consumer culture."

Similar to what we have examined in the sections on education above, when viewed as a continuation of the arts and crafts or DIY movements, maker practices are often characterized as having "a gentle revolutionary dimension" [Gauntlett, 2011, p. 56]. Betsy Greer refers to this as "craftivism," in which choosing to create something rather than buy it involves an inherent political choice, or a form of resis-

tance [Greer, 2008]. Mota investigates contemporary maker practice that draws from professional industrial methods "a trend that promises to revolutionize the means of design, production and distribution of material goods and give rise to a new class of creators and producers," which she paralleled with the Arts and Crafts movement a century ago [Greer, 2011]. Her work speculates on the future of the DIY and hacker movements, with specific attention to intellectual property, sustainability, and safety and environmental quality regulations. DIY making, across these efforts, is theorized as carrying the means to transform and question prevailing economic systems (e.g., Hunsinger and Schrock [2016], Lipson and Kurman [2010], Tanenbaum et al. [2013]).

An adjacent body of work warns how the very story of intervening in and hacking the status-quo has itself been economized and turned into a profitable market place [Irani, 2015, Lindtner, 2015a, Lindtner and Avle, 2017, Sivek, 2011, Söderberg and Delfanti, 2015, Söderberg, 2013, 2016]. The introductory article of a special issue on the topic edited by Söderberg and Delfanti states this as follows: "hacker practice and innovation are adapted and repurposed by corporate and state institutions on a regular basis, thus made to serve other ends than the (emancipatory) ones claimed at the outset." The goal of the authors' critique here is "not [to] deny there is a potential in hacking, only that this promise must be weighed against the likelihood of a future recuperation of the same practices." Similarly, Lindtner et al. [2014] propose that entrepreneurial efforts and economic interventions in and through making should be taken seriously by HCI as they confront the field with how its own values, methods, and tools play a central role in economic and social experimentation.

Some scholars have resorted to dealing with this dilemma by delineating a historical trajectory from grassroots and countercultural ideals of hacking to a commodified and co-opted version thereof visible. Maxigas [2012], for instance, separates the ideological genealogies of hacklabs and hackerspaces, which he argues have been unintentionally equated in both current academic and public discourse, thereby undermining the ability of researchers to understand the ideological development of either community on a deep level. Where hackerspaces

might not define themselves as political (even though they usually are), hacklabs are intentionally and overtly political. Maxigas suggests that conflating these two genealogies minimizes the effects of the critical, activist efforts of hacklabs, historically.

Others have shown the limitations of a linear reading of hacking's lineages and genealogical by stepping outside the Western context. Lindtner, drawing from long-term ethnographic research, for instance shows how making in China has emerged as a site to challenge Western authority claims over technology design and innovation; makers in China have established business and economic models that are motivated by a desire to challenge common binaries of "made in China" and "created in the West." The goal, here, is less to form a full-on counter to capitalism, but more to experiment with ways in which economic markets are being done, e.g. by prototyping business models that are rooted in partnership and co-ownership rather than in the more common precarious labor models and racially discriminatory practices Silicon Valley has become known for [Lindtner et al., 2016, Lindtner, 2017]. In Taiwan, two lineages of making and hacking are divided by which Chinese term is used: *chuangke* is used to refer to an entrepreneurial/innovation-centered understanding of making, promoted by government policies seeking to stimulate economic growth, while *zizaozhe* is used to connote a more cultural, artistic, and DIY notion of making, tied to specifically Taiwanese traditions of making [Bardzell et al., 2017].

But also, here, such visions of regional alternatives have found uptake by governmental and political interest [Lindtner et al., 2016, Avle and Lindtner, 2016, Lindtner and Avle, 2017]. In 2015, the Chinese government alongside a series of Western agencies and educational entities from MIT and NYU to the British Council have begun endorse the story of China, and more specifically Shenzhen in the South of China, as a rising innovation hub, portrayed as a hopeful alternative to innovation structures in the West [Lindtner, 2017]. Similarly, Jackson and Kang [2014] dampen the emancipatory promise of making by pointing to issues of environmental sustainability. Powell [2012], Greenhalgh [1997], Lindtner et al. [2015], and Bardzell et al. [2017] show how maker and

hardware hacking practices have become sites to further a neoliberal model of citizenship and nation building. They show how the promise to democratize technological production is intertwined with people's ability to refashion themselves as entrepreneurial citizens (Irani) and self-actualizing citizen subjects [Avle and Lindtner, 2016].

An important aspect in these discussions that has received fairly little attention in HCI is the question of how making potentially proliferates a variety of precarious work and labor conditions [Söderberg, 2013, 2016, Lindtner, 2017]. Drawing from autonomist Marxism and theories of free and immaterial labor, Söderberg [2016], analyzes how the transformation of 3D printing communities Rep-Rap and Makerbot from distributed open source production to a centralized mass manufacturing model made visible how hobbyists and advocates of making "were put to work by the entrepreneur and venture capitalist."

Taken together, these analyses show the persistence and the unintended consequences of techno-optimism. They urge that the implementation of the emancipatory promise of making, while worthwhile pursuing, cannot and should not unfold without a careful tackling issues of labor, economics, gender, class, and power. In a 2016 article, Lindtner et al. [2016], propose a "reflexive-interventionist" approach that draws on feminist utopianism and anthropology of the global. This approach takes seriously critiques of making's technosolutionism, and yet it also embraces making's utopian project as worth reconstituting in broader sociopolitical terms. Both the technosolutionist approaches to making and the critiques thereof, the authors show, are rooted in a shared commitment to intervention and change, "although each construes change and intervention differently." The authors suggest that by bringing together "the interventionist and utopian impulses of the technical and critical agendas" of making a more robust and democratizing agenda could emerge. In a similar vein, Hunsinger and Schrock [2016] tracing alternative lineages of civic hacking that are neither in complete opposition nor in full alignment with powerful institutional entities, urges that we "should be attentive to moments where meaningful change can occur, even if those changes are fraught with forces of neoliberalism and tinged with technocracy." For more on this critique, see section 4.1.2.

3.3 Reframing making: Handwork, appropriation, repair, and maintenance

Another important line of making research problematizes the conceptualization of making as an engineering and innovation only project and foregrounds instead the notion of "handwork,"—century-old practices of human creative work such as cooking, knitting, weaving, ceramic making, metalwork, carpentry, sculpturing, etc. Handwork is used to explore how such intimate and sensual engagements with materials and tools that has been a significant part of human history and culture could impact the development of next generation of digital artifacts, open-source hardware toolkits, and the reconceptualization of craft, making, and engineering. Drawing from craft theorists such as Malcolm McCullough [1996], Glenn Adamson [2007], Howard Risatti [2007], and Richard Sennett [2008] among others, HCI researchers and practitioners seek to (1) reveal empirically novel forms of creative expression often overlooked or even considered illegitimate in dominant narratives about making and (2) on a theoretical level, engage in the task of reimagining making that better accounts for historical practices, material and manual skills and labor, and aesthetic meaning and quality. What emerged is a series of rich ethnographic and design accounts, from knitting [Rosner and Ryokai, 2010], gardening [Goodman and Rosner, 2011], book restoration [Rosner and Taylor, 2011], craft and quality [Bardzell et al., 2012], to leather work [Tsaknaki et al., 2014] among others. These, along with a growing body of work in HCI situate the discussion of contemporary rapid fabrication advancement with traditional slow crafting processes and practices to explore the potential and implication for a more productive integration of the two for future interaction design and experiences. We curate a few of these projects in this section, along the subthemes of creative appropriation and repair/maintenance.

3.3.1 Everyday Creative Appropriation

One form of complex and sophisticated everyday creative expression is appropriation. As an act of taking something for one's own use,

appropriation highlights issues concerning diverse lineage of precedents, creative intentionality and agency, and the contested notions of copies and originals. Philosopher of art James O. Young categorizes 5 types of appropriation: Object appropriation, content appropriation, style appropriation, motif appropriation, and subject matter appropriation [Young, 2010], and HCI's discourse on everyday creative appropriation in the context of making more or less follows this 5-type categorization, emphasizing especially the first four.

Rosner and Bean [2009] connected making to appropriation in their study of a group of IKEA hackers who shared their processes of repurposing IKEA products to create customized objects. Authors show how these IKEA hackers effortlessly move between physical and virtual worlds, engage in appropriation practices, and form new identities. The work also encourages HCI scholars to better support platforms and tools that enable both the performance of collaborative ethos as well as collaborative practices in reuse and appropriation.

In a series of papers that conceptualize the notion of "everyday designers," Wakkary and colleagues seek to make visible the resourceful appropriation of artifacts and environments as well as the ongoing improvisation and adaptation of mundane routines and systems that take place on a daily basis. In their studies of domestic interactions, the authors describe how people "discover and exploit affordance between situations, people, and the physical environment" [Wakkary and Maestri, 2007] to remake artifacts into something more personal, artful, and thus highlights the need for HCI to locate and celebrate the presence of "everyday designers" in the home. In a subsequent study, Wakkary and K. Tanenbaum connect appropriation to sustainability, showcasing how people in their homes engage in creative and sustainable ways to appropriate and adapt designed artifacts. The researchers examined closely three artifacts from their fieldwork—a planner book, a recipe book, and a family calendar—all common artifacts in the homes to show how everyday designers promote renewal and reuse over invention and disposal in mundane act of appropriation in the homes [Wakkary and Tanenbaum, 2009].

Appropriation is a key topic in subculture discourse, dating back to the classic book *Subculture: The Meaning of Style* [Hebdige, 1979],

so it's not surprising HCI researchers use the Steampunk movement as a case to think through handwork, appropriation, and the implication for making. Akah and Bardzell studied Steampunk culture as a locus for the cultivation of identity formation through creative appropriation [Akah and Bardzell, 2010]. They take on the questions of (1) whether technology empowers DIY and handcraft, and (2) how we might use technology as creative resources to empower personal identity, identification, and appropriation in the study. The authors encourage designers to support users in becoming "makers" through a 5-part appropriation-identity design framework: utilize users' existing knowledge, interpret the artifact's function, alter the artifact's interaction, adapt the artifact's aesthetics, and explore their creative freedom. Tanenbaum et al. [2012] extended the concept of appropriation from the individual creative pursuit and (maker) identity construction seen in Akah and Bardzell to appropriation as a design strategy. While billing it largely as an exemplar for design fiction, the authors' study on the Steampunk movement nonetheless has implications for making and DIY, especially when it comes to its material practices. Indeed, half of their concluding 6 implications are related to making/DIY. They write as follows (the following bullets are all quoted):

1. DIY and appropriation techniques encourage, creativity, resourcefulness, and participation in the making of digital artifacts;

2. DIY and appropriation techniques are alternatives to modularity and top-down design with respect to customization;

3. Design and technology objects are ideological in that they consciously or unconsciously express cultural values and political meaning. (p. 1591)

Studies of appropriation draw attention to the intertextual borrowings and transformations of meanings over time. They remind us not just to attend to the forms of making (i.e., the technologies and abstract pathways of innovation or modes of empowerment) but also their concrete contents of maker cultural production.

3.3.2 Repair and Maintenance

The topic of repair intersects prevailing HCI agendas on tools and system development on the one hand and the reflexive turn to traditional craft on the other. HCI/STS scholar Jackson and his colleagues sees repair as "acts of care" wherein sociotechnical systems are maintained and transformed, human values undergo changes, and a complex combination of "organizations, systems, and lives" emerges [Jackson, 2014, p. 231]. According to Jackson, the ethos of care undergirding repair is embroiled in the consistent work of sustaining media objects, systems, and technologies. Care exists as a way to alter, appropriate, and subvert. Moreover, it reveals the more-than-instrumental relationships between human and non-humans and makes important the maintenance of such attachments. In other words, maintenance work not only revolves in the realm of repairing material goods and infrastructures, but also the social worlds we live in (p. 222–23).

In a study on breakdown and obsolescence, Jackson and Kang [2014] use a three-prong strategy of critically reviewing recent theories on posthumanism, empirically studying artists who use found and broken technologies as materials for their work, and authors' own building of an art installation using discarded technologies to challenge HCI's notions of creativity, design, and sustainability. The authors argue that while artifacts get designed, engineered, purchased, and appropriated, they often also get discarded, repaired, and reused because "values get built into technology, but they still take work to maintain—and additional, sometimes alternative values may be introduced through ongoing acts of repurposing and reuse that humans routinely perform vis-à-vis the world of objects around them" (p. 2).

In addition to understanding repair using the lens of sustainability and care ethics, HCI scholars also study repair in the context of transnational studies. Drawing from ethnographic account of repair workers in Dhaka, Bangladesh, Jackson and Kang [2014] observe repair as manifesting three forms of innovation—craftwork, collaboration, and creative repurposing—all are relevant to sustainability concerns. Rather than seeing repair as alternative to technical and engineering expertise, the authors argue they are "forgotten extensions of them, points

of connection and completion through which the abstract design of manufactured goods are made real and sustainable in the world." By maintaining objects that are broken, fixers and repairers help expand the longevity of designed artifacts through repair practices particular to specific cultural and economic contexts. Such repair practices however, as the authors point out, are under attack with increasing circulation of new goods, precarious labor conditions and sociopolitical situations. Elsewhere, Rosner and Ames' [2014] present a comparative study of repair work in California and Paraguay. The authors urge the HCI community to reconsider existing notions of design, arguing that breakdown and repair are "material states" where diverse meanings can be imbricated and created for new roles and practices. They further introduce the term "negotiated endurance" to account for the negotiations that occur where maintenance, care, and repair are concerned and how designers are no longer the only actors engaged in meaning-making processes.

3.4 The cultural production of Makers

The "we are all makers" slogan often seen in making-related conventions (e.g., Maker Faires and other maker gatherings), co-working spaces (e.g., hackerspaces, Makerspaces, Techshops), local meetups and events (e.g., FutureEverything, Ars Electronica) and online knowledge exchanges and alliances (e.g., Creative Applications Network, Lily-Pond, Instructables, and Ponoco.com) claims that one need not become a maker, because everyone already is a maker. The idea behind the slogan is that all of us have in our lives developed material solutions to our problems, have physically made stuff, and so forth, and so we are already makers. But in the same way that everyone "designs" but not everyone is a capital-D Designer, so there is a bit of a sleight of hand in the contemporary use of this slogan. For if everyone is a maker in the universal sense, not everyone has something to showcase at a Maker Faire booth or a clever idea to post on Instructables.com.

This section focuses on that difference, that is, the move from "everyone is a maker" to the more specific appropriation of the identity

of today's maker movement. Appropriation of this identity is achieved through repeated access to and participation in physical and ideological maker environments, basic competence with key maker tools and materials, fluency with maker discourse, and above all a nuanced sense for what counts as "making" and by extension, when to count oneself as a "maker." This move is not unique to making and can be situated within parallel discourses emphasizing how non-experts, amateurs, crowds, and so forth are, thanks to a combination of network and content authoring technologies, producing culture at a scale that rivals traditional media.

3.4.1 Productive amateurs

The idea that massive amateur collectives are able to produce culture at such a scale builds on the metanarrative of technology democratizing innovation, product development, and reflexively itself (see section 2.1, above). It was popularized in Tapscott and Williams' book, *Wikinomics: How Mass Collaboration Changes Everything* [2006], which explored how emergent networks of actors would cooperate to solve a problem—combining the ideologies of open-source software and outsourcing. The book proposed several concepts that enable this phenomenon, including openness, prosumers, peering, ideagoras, and global action. Though criticized for an optimism that slid into hype, the book explicitly articulates a utopian strand that is implicit in much HCI and design research since 2000. Other books around the same time were exploring similar ideas, including Henry Jenkins's *Convergence Culture* [2006b] and Howard Rheingold's *Smart Mobs* [2002].

In the HCI research community, similar ideas were also prevalent. Fischer and Scharff [2000] were calling for products that enable individuals to act as designers. In doing so, they effaced the boundary between everyday design and professional design. Instead, design becomes a "mindset," that is set in opposition to the "consumer mindset." The authors write.

> To create designer mindsets, one of the major roles for new media and new technologies is not to deliver predigested information to individuals, but to provide the opportunity

> and resources for social debate, discussion, and collaborative knowledge construction" (p. 2).

The opposition between design thinking on the one hand and consumerism on the other anticipates similar oppositional structures not only in the maker movement but also in Dunne and Raby's formulation of critical design [Dunne and Raby, 2004]—and of course Tapscott and Williams' "prosumer."

The open source movement was also an important inspiration in this era. Ducheneault's [2005] "Socialization in an open source software community: A socio-technical analysis," focuses on how participants in open source software (OSS) communities "construct identities as software craftsmen." He argues that much of the work done on OSS communities is overly simplified, static, and ignores how participants are socialized into the community of practice, and he proposes, instead, that such work should focus on trajectories of participation. He then describes the processes, rites of passage, and identity markers that a participant develops while working to gain "insider" status in such OSS communities, and that "successfully contributing to an Open Source project depends much more on a complex socialization process than on a show of technical expertise." He compares this process to those of "journeymen" or "apprentices." Ducheneault's "trajectories of participation" was not intended to characterize the maker movement, but it seems to transfer well.

A similar formulation is that of the "expert amateur." This term, which comes from Kuznetsov and Paulos [2010], focuses on ways that online networks cultivate expertise from hobbyists, whether they are DIYers (in Kuznetsov and Paulos' case), amateur multimedia artists [Bardzell, 2007], or video game machinima animators [Pace et al., 2013, Gross et al., 2013]. Much of this work emphasizes the expertise or high quality outcomes of these communities, in spite of their "amateur" status. They also offer implications for the design of content authoring tools. This research highlights ways that many tools are designed with the assumption of a professional community of practice, such as professional developers, graphic designers, etc. In doing so, this research opens up questions of how might content authoring tool design be oth-

erwise without this assumption—a question that makers both in and out of research have taken up with a vengeance!

HCI and design researchers have begun to theorize about ways that designers might intentionally design technologies to empower users to be more like designers. In an influential article, Redström [2008] concludes by distinguishing between two ways that designers at design-time might construe use at use-time.

> With respect to acts of design and acts of use—acts of defining what a thing is—the approaches discussed here represent a spectrum of ideas and ideals. At one end is the by now classic ambition of User-Centred Design to test and try out 'use' during the design process and in advance of actual use—what we might call a *'use' before use* approach. At the other end are accounts where definitions of use through design are meant to be in-/un-determinate, as an attempt to create a larger space of possibilities for acts of defining use through use—what we might call a *'design' after design* approach. (p. 421)

Connecting the dots, it would seem that design after design might include not only the design of user-re-designable objects and artifacts, but also designing tools and (indirectly) sensibilities for their intended users. In many ways, we argue, making has done all three.

3.4.2 Becoming makers

In a series of papers co-authored by Toombs, S. Bardzell, and J. Bardzell, based on a long-term ethnographic study of a small-town hackerspace in the American Midwest, the authors argue that the formation of the maker identity is in part conditioned by makers' own production of maker culture. In other words, makers not only do specific projects, but they also produce self-made maker tools, and they reproduce maker discourse and ideology through the initiation of others into the maker project. As discussed in section 2.2.3 above, Bardzell et al. [2014] collected and studied what makers identified as self-made tools. They found that the ad hoc creation of tools, where no usable tools

existed or were ready to hand, was one of the ways that participants began to feel like makers. In other words, traditional tools became yet one more consumer product that makers could make for themselves.

In Toombs et al. [2015], the authors look at identity formation more closely. They suggest that maker identity is informed by three primary factors: "the development of a tool and material sensibility; the cultivation of an ad-hocist attitude as an approach to making in general; and engagement with the maker community, both in the space and on a larger scale" [Toombs et al., 2015]. Building on this work, Toombs et al. [2015] use feminist care ethics to reveal the interpersonal maintenance work that takes place in such communities, which is often played down because such an ethos conflicts with the libertarian ethos that informs the ideology of the space. Elsewhere, Toombs et al. [2017] took a reflexive turn, investigating researcher–participant relationships in their ethnographic work, finding again that interpersonal care was bidirectional and often tacit, yet crucial to the ongoing development of the research relationship.

Synthesizing all of this research, it seems that the move from "we are all makers" to the more narrow sense of membership within the maker movement (however that is construed), appears to involve several features. One is the trajectory from here to there, of course. In the context of making, that entails access to tools and technologies, commonly found in makerspaces. It also requires the acquisition of a material sensibility as well as skill with tools in question–and maker pedagogy is seen as innovative in this light (see Section 3.1). But it also entails inculcation into an ideological project (again, see Section 3.1), one where consumption is set in opposition to making, along the axes of passive/active, buying/doing, borrowing/owning, and perhaps above all disempowered/empowered. To propagate the ideological project requires the production of discourses of empowerment, often framed in the narrative of the "new" power of network-enabled collectives as articulated in *Wikinomics* and notions of the "expert amateur." The trajectory for any given individual is still challenging, however, and thus relations of care provide a social scaffold to facilitate movement through it.

4

Critiquing Making and Critical Makers

Throughout this survey, we have identified several arguments in support of making and pointed out along the way some critiques of those arguments. For example, several times we've seen how scholars question the technosolutionism and over-optimism of many maker accounts. In this section we take a step back further to focus on the critiques, to see what they have in common, what together they unconceal for us, in hopes that by doing so we are better positioned to pursue making research in HCI in line with our values.

We also note that beyond scholars critiquing maker discourses, makers themselves use their practice to critique making, design, and social phenomena touched by making. In section 4.1 we address four major critiques of the maker movement, and in section 4.2 we take a look at two critical movements within making: critical making and feminist unhacking.

4.1 Critiquing Making

Research in HCI and STS critiques making using three broad themes: The tendencies towards technosolutionism in making practices and

discourses (including research), the ways that a "global" conception of making is tied to contingencies of making in the U.S. and Western Europe; and the ways that "the maker" has been construed as an entrepreneurial subject.

4.1.1 The Critique of Technosolutionism in Making

As we saw in section 3.2, many critiques of making focus on its tendency towards technosolutionism and (often) marginalizing practices under the slogan of democratization; much of this work is from outside HCI and draws from making research in Science and Technology Studies (STS), cultural studies, and media studies.

The *Journal of Peer Production*, an online open-access journal, has devoted several special issues to unpack the implications of making, hacking, and other forms of peer production for positive social change where researchers tackle issues such as bio/hardware hacking (Issue 02 in 2012), shared machine shops (Issue 05 in 2014), feminism and [un]hacking (Issue 08 in 2016, more on this later), and peer production and work (Issue 10 in 2017). Edited by Jeremy Hunsinger and Andrew Schrock *New Media and Society's* special issue on "The Democratization of Hacking and Making" (2016) identified several themes constituting the issue of democracy and hacking/making, including frictions between individualism and communalism in hackerspaces, the inefficacy of hackathons as an approach to civic change, the cooption of countercultural and adversarial hackers by mainstream culture and industry, frictions between Fordist consumption and creative re-use that play out in the social life of things. Taken together, the special issue editors conclude that these contradictions play out elsewhere in society itself, including in higher education, and as such the editors conclude, "It is in light of the applicability of their analyses and arguments to larger society where many of the articles in this special issue on the democratization of hacking/making really shine. They are metaphors for larger issues and questions that democratic cultures and productive cultures must recognize and confront" [Hunsinger and Schrock, 2016, p. 538].

Johan Söderberg and Alessandro Delfanti, editors of the special section for *Science, Technology, and Human Values* likewise consider

making and hacking in relation to social movements, cultural identity, and civic change. They propose the notion of *recuperation* as a theoretical lens to understand the life cycles of IT innovation in the context making and hacking. For example, HCI/STS researcher Lindtner illustrates how Chinese makers exhibit in their practice the principle of "hacking with Chinese characteristics," one that is distinctive from the making narrative perpetuated by Silicon Valley and that focuses instead on *making do* and mass production [Lindtner, 2015b]. This research emphasizes what happens when optimistic discourses of making encounter the empirical realities of our social worlds—problems and structures in the latter tend to persist.

In short these works collectively take the democratic promise of making and hacking at face value, holding maker/hacker practices to account for them. If making democratizes, why are there barriers to entry for disadvantaged populations? If making is a global phenomenon, why is it pursued according to the values and ideologies of California's Silicon Valley? If making empowers individuals to express their personal values and aesthetic sensibilities, why are they inculcated into an entrepreneurial subjectivity? And in spite of all the grand promises made, why are the outcomes of making and hacking so far mostly underwhelming?

4.1.2 Decentering Dominant Narratives and Genealogies of technology design, innovation and production

An expanding body of HCI research on making has begun align with and further expand prior research that has challenged developmental narratives that construe regions outside the West or what is often called the Global South as lagging behind modern technological progress and hence in need of foreign aid and intervention. These projects have shown that stories of technological progress and ICT4D mask political and economic interests of powerful elites from tech industries, corporations, governments and non-governmental agencies. Stories of technological progress and innovation often induce a sense of excitement and promise, portraying the proliferation of technology use and design as carrying the means to provide more people with social and economic benefits.

Making, as we have shown in section 3, has been portrayed in similar ways, feeding into a much broader story of designing better futures by means of expanding technology production.

This approach has been critiqued in maker related HCI research in the two ways: first, researchers traced genealogies of making and hacking that while entangled with histories of colonialism and post-colonial processes challenge any sentiment of there being only one true hacker or maker counterculture, i.e. one rooted in the notorious California Internet counterculture of the 1960s and 1970s (e.g. Houston et al. [2016], Lindtner [2015b], Lindtner et al. [2015], Jack and Jackson [2016], Kera [2012], Bardzell [forthcoming], Sun et al. 2015). A second and interrelated line of research has traced in ethnographic fashion how Western-centric notions of innovation and technological progress are being contested not only by scholars but also by practitioners and writers active in regions such as China, Africa, Latin America, and southeast Asia (e.g., Lin and Lindtner [2016], Avle and Lindtner [2016], Avle et al. [2017]).

This body of work has shown that while stories of hacking travel globally and shape imaginaries of resistance and intervention, they also subsume and render invisible (or as less relevant) other stories and genealogies of technology production, driven by different sets of aspirations and goal). For example, Lindtner and her colleagues' [Lindtner et al.'s 2015] account of the history and culture of technological production in the South of China challenges perceived binaries of "designed" or "created in" the West versus "manufacturing in" or "assembled in" China or other parts of the so-called developing world. Similarly, Jackson et al.'s [2012] ethnographic account of the design and repair expertise of mobile repair workers in rural Namibia, Africa, challenges perceived notions of where to locate design. Sun et al. (2015), drawing from ethnographic research with a group of radio hackers in their 50s, 60s, and 70s in China, showed that values of resourcefulness and DIY were central to propaganda and ideology discourse in China in the 1950s and 60s. These histories and legacies, even when silenced, shape practices in China today, and provide an alternative account to more familiar histories of DIY making that place it as emergent from within Western lineages of the avant-garde, pragmatism, or activism. Kera

[2012], drawing from ethnographic with DIYbio collectives in Indonesia, examines how various dichotomies such as traditional and modern and West and East are dismantled through the practices of DIYbiologists in Indonesia. DIYbiologists in Indonesia navigate international networks of art, science and technology, showing how innovation is lesser of a disruptive force but an outcome of community building and vernacular knowledge-making practices in Indonesia. Her work contributes to how DIY making is not only particular to western regions, but also constituted through the traditions particular to specific genealogies and cultures in non-western regions (See International Impact).

Researchers in this space have reminded how many of the dominant ideals of design and innovation propagated in the West are contingent on expertise in manufacturing rendered invisible and devalued [Lindtner et al., 2015]. They have also attend to culturally embedded practices of citizen science in Indonesia [Kera, 2012], and explored participatory urban citizenship through making and public futuring in Taiwan [Freeman et al., 2017]. This line of research has also shown how particular situated values may conflict with dominant notions of what *makes* a maker. For instance, what counts as intervention into the status-quo is highly contingent on the particular political arrangements and societal transformations that have come to matter and shape specific sites [Lindtner et al., 2015]. The stakes are high: research has shown that governments in some cases dispossess of their homes one group who make but who don't count as "makers" in the global/entrepreneurial sense in order to renovate creative parks for groups who do count as makers in the global/entrepreneurial sense [Bardzell, forthcoming].

4.1.3 Economization of Maker Identities, Entrepreneurial Mindsets

There has been a relatively slow but steady research agenda seeking to understand how HCI as a field constructs "the user" not as an actual person using a product, but as a discursive concept used by a field for self-understanding and self-legitimation (see e.g., Bannon and Bødker [1991]; Bardzell and Bardzell [2015]; Cooper and Bowers [1995]; Cockton [2008]; Irani [2015]).

Similarly, "the maker" has also emerged not only as actual people using these technologies, but as a certain kind of discursive construct, and scholars have analyzed it as such. In "Sustainable Making? Balancing Optimism and Criticism in HCI Discourse," Roedl et al. [2015] use discourse analysis (DA) to analyze nearly 200 HCI publications related to the topic of maker culture. They show how the rhetoric of technoscientific progress shapes how HCI researchers understand and construe makers. They argue that such a move leads to two deeply held understandings that constitute

> the maker as an empowered *subject* (i.e., an individual subjected to certain material and social conditions, who is also the *subject of*, or agent of, skilled and purposeful action within those material and social conditions): the maker as a materially empowered subject and the maker as a socially progressive subject" (Roedl et al. [2015]; emphasis in the original)

The construction of this materially empowered and socially progressive subject becomes the basis for claims that making could contribute to sustainable IT, e.g., through practices of repair, upcycling, and DIY. But the article continues to show that material and legal obstacles powerfully, even overwhelmingly, undercut this subject from achieving such a potential.

Other researchers have traced the construction of "the maker" and explored its consequences in other ways. For example, Sivek examined the branding and marketing strategies used by *Make Magazine* to cultivate a collective identity among its readers to further sell its media products "through the use of key themes of American ideology and even nationalism, while also motivating individual readers to participate in the 'making' project for personal fulfillment and self-actualization" [Sivek, 2011]. Sivek asks if this process of turning making into a branding strategy possibly "diminishes or removes [making's] potential as a critical act" by turning its participants into simply "one of a branded, imagined community, feeling that he or she is acting against the powers that be, but in fact often simply acting in just the kind of small ways that don't threaten those powers" [Sivek, 2011].

Such work often involves thinking through how so-called "peripheral" designer practices are positioned in juxtaposition to the dominant IT hub of Silicon Valley and what is at stake in doing so. We see this clearly in Avle & Lindtner's [2016] ethnographic work on tech entrepreneurs and makers in Accra, Ghana and Shenzhen, China, which describes how these entrepreneurs and makers position their practices in alignment with vs. opposition to Western-centric narratives of what defines proper innovation and design. This includes thinking through how design is not only about producing artifacts but also gaining seller access to global markets as well as individual and national aspirations of legitimacy. All of this, in turn, reveals the inseparability of tech production and meaning-making processes. These alternate narratives allow the authors to question assumptions of what counts as innovation and design, and to propose HCI design theory that is more inclusive of diverse design practices and cultures.

How dominant ideologies of hacking and making interact with notions of citizenship in marginal sites of innovation are also central to Lilly Irani's [2015] analysis of hackathons in India. Irani [2015] argues that hackathons – short-term marathons for developing digital and non-digital responses to specific issues – often (even usually) do not produce solid prototypes or lead to real products, but that "they always produce entrepreneurial subjects." These subjects are effected by the ways that the hackathon

> manufacture[s] urgency and an optimism that bursts of doing and making can change the world. Participants in hackathons imagine themselves as agents of social progress through software, and these middle-class efforts to remake culture draw legitimacy from the global prestige of technology industry work practices. (p. 2)

Middle-class practitioners in hackathons actualize their aspirations by engaging in entrepreneurial-like practices influenced by the visions and values crafted around Silicon Valley's 'success' [Irani, 2015]. An STS sensibility embeds research on local DIY maker and digital cultures within a broader context of global innovation practices.

Haywood [2013] presents an account of how what is loosely called the "hacker ethic" can play out in a particular scenario. Through a study of participants in a humanitarian 'hacktivist' event, he problematizes the typologies traditionally used for describing hackers as deviant and centered in North Atlantic societies. Haywood [2013] proposes 'social geek' as a "more heterogenous and perhaps more realistic imagining of the hacker," foregrounding the social and democratizing motivations for symbolically performing within a hacker ethic, rather than technologically deterministic ones.

Feminist theory and methods have also influenced some of these decentering the West projects on making in HCI. Informed by feminist utopianism and area studies, Lindtner, Bardzell, and Bardzell offer a reflexive-interventionist approach to simultaneously take seriously the critiques of making's claims as technosolutionist while also embracing its utopian project as worth pursuing [Lindtner et al., 2016]. Bardzell et al. [2017] provide a critical analysis of several "encounters" between culture and creative industries (CCI) policy in Taiwan and its maker scene, informed by feminist geography, feminist border studies, and literary theory. These encounters reveal misalignments that undercut political efforts intended to support making. The authors argue that supporting any creative culture, including making, entails a serious commitment to understanding its culture, including its cultural contents and their means of production.

Collectively, these critiques of making summarized in these three sections helps show the interrelationship of Western conceptions of subjecthood, Western neoliberal understandings of (tech) labor, a preference for technology over the social, and a marginalization of anything outside of it as not-making, not-entrepreneurial, and not-technical. This has consequences that undercut making's stated goal to democratize. It makes it more difficult for non-Western sites of innovation to participate in the global market as producers and innovators; it entices global investments and media coverage with promises of sweeping social change (greater access to technology and innovation, regional prosperity and dignity on the world stage, and sustainable living) that it cannot deliver; and in some cases literally throws poor people out of their homes to make way for makers.

4.2 Making as Critique

Three well documented outcomes of making are the pleasure in engaging in a creative hobby, the conceptualization and prototyping of concepts that might eventually become products, and professional development. A fourth is the idea of making as a research activity, that is, using maker practices as part of a research method, a process of inquiry aimed at novel contributions to knowledge. This sense of making parallels a trend in design that goes by different names, including research through design [Zimmerman et al., 2007], practice-based research, and constructive design [Koskinen et al., 2011]. We briefly introduce research through design before surveying two strands of making in this section: Feminist making and critical making.

4.2.1 Research Through Design

In the 1990s, designers and design researchers made arguments that design could itself be an approach to research. Neither the object of research (as in studies about design and designers), nor the reason for research (as in research undertaken to support a design project), research through design's intended outcome is research, that is, some kind of knowledge contribution, and design practice—design methods—are viewed as research methods, and design artifacts are the medium (or at least one medium) of research articulation. In a seminal, if all-too-brief piece, Christopher Frayling [1993/4] defines it as a form of inquiry

> where the end product is an artifact—where the thinking is, so to speak, embodied in the artifact, where the goal is not primarily communicable knowledhe in the sense of verbal communication.

DIY making research in HCI has been fueled–often indirectly–by these explorations of RtD and of materiality. Such approaches have helped legitimize an approach invested in the production of things, artifacts and prototypes as central to the advancement of the field of HCI.

Against such a backdrop has been the emergence of what might be characterized as research-through-design approaches to critique. That is, rather than critique in the form of a verbal treatise, these practices seek to do critique through the production and dissemination of design artifacts, notably including critical design [Dunne and Raby, 2004] and speculative design [Dunne and Raby, 2014]. These propose alternative presents and futures in the hopes of stimulating debate as well as new design values and tastes, seen as more beneficial to society.

Analogously, two threads of making seek to contribute to knowledge by blending critique and making: feminist making and critical making.

4.2.2 Feminist Making

Emergent critical research on making not only makes visible non-Western forms of making to critique dominant frames of making, but it also challenges any singular making genealogy. This is achieved by leveraging feminist principles of plurality and participation. For example, Fox et al. [2015] challenge characterizations of making as white and masculine through their interview and observational studies at feminist hackerspaces across the Pacific Northwest. They show that members of these spaces engage in collaborative design to reposition themselves as well as their making practices (e.g., weaving and identity workshops among others) with and against dominant understandings of hacking and technological practices. By contesting dominant notions of making/hacking that often privilege particular ways of conceiving the technical, the study of feminist hackerspaces reveals a more dynamic and ambivalent understanding of what technological work is.

In a special issue on Feminism and (un)Hacking for *Journal of Peer Production* in 2016, editors Nguyen, Tupin, and Bardzell curated a growing body of research that sits at the intersection of making/hacking and feminist thought. They argue that such an agenda "is gendering of techno-labor, to facilitate emancipatory efforts, to cultivate alternative perspectives, and to make visible the infrastructural relations of technology" [Nguyen et al., 2016]. The collection of articles in the special issue show that many feminist hackers and makers seek to make visible the lack of gender diversity within these making and co-working

spaces, and one way to intervene is through the design of women, queer, and trans-friendly spaces so that these people can make/hack. These articles also illustrate that making/hacking bridges the divide between craft and care (stereotypically feminine practices) on the one hand and technology and engineering (stereotypically masculine) on the other to open up possibilities for new conceptualizations of making/hacking that resist such a binary. In one of them, Forlano [2016] also questions existing claims around what constitutes hacking and technology through an ethnographic analysis of her engagement with medical devices as a Type 1 diabetic. Drawing from science and technology studies with feminist studies, she argues for a feminist hacker ethic(s) that foregrounds the body as an "important site of socio-technical engagement" and the inclusion of disabled identities. A feminist hacker ethic, Forlano elaborates, attends to "inherent inequalities and invisible labor present in these relationships: human/non-human, proprietary/non-proprietary, digital/material, smoothness/friction, broken/unbroken, quantitative/qualitative, visible/invisible, public/private."

Research has also shown how hacking/making is intertwined with gender identity, an ongoing topic of inquiry in feminism. This line of making research can be seen in Buechley and colleagues' documentation of a 2-year history of the development and use of an open-source toolkit, Lily Pad Arduino [Buechley and Hill, 2010], which gave rise to the emergent field of electronic textiles, or e-textiles—clothing, furnishing, and/or architecture with embedded computation components. The authors show that 90% of Arduino projects were led by men and that 65% of LilyPad Arduino projects were led by women. The contribution of development of LilyPad Arduino lies in the fact that it takes an existing technology (i.e., Arduino) and innovates it for the domain where women is the dominant group (i.e., textiles and fashion).

Included in an anthology on e-textiles, *Textile Messages* (Buechely et al., 2013), Bardzell presents a research through design account that examines the issue of body and e-textile technology. She describes "Sparsh," an LilyPad Aruino-enabled Indian sari garment that the research team deployed in Indian homes to understand the felt experience of homemakers. She distinguishes between *feminist* from *feminine*

technologies, where the former are "tools and knowledge that enhance women's ability to develop, expand, and express their capacity" (Layne et al. [2010], cited in Bardzell [2013]) while the latter are "technologies associated with women by virtue of their biology" (Layne et al. [2010], cited in Bardzell [2013]). The distinction is important, because "if and when such e-textiles are understood to reinforce traditional stereotypes, their femininity could be regarded as regressive. Conversely, inasmuch as e-textiles enable designers to develop and expand embodied interactive experiences, or be used to generate strategies to increase the participation of historically marginalized users, they can be understood as feminist technologies" [Bardzell, 2013].

Ultimately, feminism enables the shift away from user research that are objectifying towards the engagement of embodied and subjective experiences. In an empirical account of using e-textiles for teaching programming to mixed gender groups ages 8–12, Weibert et al. [2014] demonstrate how e-textiles not only increase children's computational literacy, but also allow them to construct gender nonconforming identities as makers. E-textiles, and its accompanying physical and digital materiality, authors argue, allow kids to unsettle gender binary and adopt a more fluid identity as well as encouraged female-identified children to engage in gendered technical tasks. E-textiles thus disrupt the division between what can be considered as "masculine" or "feminine" identities.

Along with the focus on e-textile and gender construction and performance, researchers on making/hacking also engage in leveraging hacking/making for positive social change, especially in the context of women's health, including reproductive health and the experiences of motherhood, self-tracking and learning to know one's body, and human sexuality among others. This line of research is nascent in HCI, and we explore here two notable examples.

D'Ignazio and her colleagues held a "hacking the breast pump" event to open up the design space for postpartum technologies. The result is a co-design process that included over 1,000 mother-submitted ideas to improve breast pumps. The authors argue that hackathons can be a site for intervention: It not only enables critique of existing solutions, it has to the potential also to be generative for alternatives

in a participative way [D'Ignazio et al., 2016]. In a subsequent conference workshop around the topic of "Hacking Women's Health" at ACM CHI'2017, Balaam and her co-organizers, along with 25 participants with backgrounds spanning across design, engineering, and health science, spent 2 days in the makerspace at Denver's Central Public library to improve women's health through technology. Among the artifacts reimagined for women's health include an inclusive parenting digital campaign, hacked sex vibrators, a novel application to visualize menstrual cycles, and a tool for women going through menopause among others. The group also reflected on the challenges and triumphs of researching and designing in areas related to women's health. By leveraging tools and technologies common in DIY, hacking, and making, attendees are empowered to reimagine how women's health technologies could be [Balaam et al., 2017].

4.2.3 Critical Making

Sharing a commitment to making's potentials for creating emancipatory openings with feminist makers and scholars is a group of makers and researchers who characterize their making/DIY/hacking practice as "critical making." They define Critical making as "a desire to theoretically and pragmatically connect two modes of engagement with the world that are often held separate—critical thinking, typically understood as conceptually and linguistically based, and physical 'making,' goal-based material work" [Ratto, 2011]. Ratto is eager to disentangle the term he borrowed from Dunne and Raby's critical design by arguing that that

> critical making emphasizes the shared acts of making rather than the evocative object. The final prototypes are not intended to be displayed and to speak for themselves. Instead, they are considered a means to an end, and achieve value though the act of shared construction, joint conversation, and reflection. [Ratto, 2011]

Accordingly, critical making practitioners privilege practice-based engagement with materials and tools for social good. By shifting the

attention away from one-off end products (i.e., the technological artifacts) and instead focusing on the process of collective and participative experimentation, critical makers reorient making/DIY as a means for social analysis, critique, and intervention.

This position has been embodied in a series of zines put together by Garnet Hertz [2017, 2014] and further elaborated in an edited volume *DIY Citizenship: Critical Making and Social Media* [Ratto & Boler, 2014]. The work included in these sections emphasizes contiguities over disruptions in the maker movement, pointing to counter cultural movements in the 1960s, alternative music zine subcultures, and so forth. Emerging forms of media enable individuals and communities to critique the status quo and propose alternative ways of being at scale. In other words, making is uniquely positioned to re-engage with civic matters and shape societal and economic concerns, all the while remaking and upgrading the nation itself.

5

Conclusion

In this survey, we have avoided offering a traditional definition of making, one comprising necessary and sufficient conditions. Such a definition essentializes making, so that it transcends time and space. Instead, we have sought to survey what making has meant in different times and places, both within the field of HCI and more globally as an idea with contemporary currency. This approach situates making within various projects and agendas. Taking one step further towards synthesis, we can also cluster some of HCI's agendas of making. The first is a utopian agenda of making, which emphasizes individual empowerment, learning, and economic growth. The second is a more critical agenda, seeking to show how, when, where, and why making fails to deliver on some of its own promises. And finally there is an emerging agenda, one with the benefit now of a decade of intense research and investment, that seeks to pursue utopian agendas but made wiser by the additional experience and the outcomes of the more critical research.

5.1 The Utopian Project of Making

The utopian project of making includes several key arguments, as follows:

1. Making democratizes computing, production, and creativity
2. Making provides a learn-by-doing pedagogy that stimulates student interest in STEM fields and that can reinvigorate design, HCI and engineering
3. Making is a driver of economic growth

Of the three, the democratizing claim is arguably the most aspiring and can even be argued to subsume the other two. As we showed in 2.1, this techno-optimistic claim has a long heritage in IT, often used to legitimize and generate interest around new technological capabilities. For that reason, we want to take the time to work out some of its arguments in detail here. We've synthesized the diverse claims that making democratizes into four (often interrelated) arguments, as follows.

The *empowerment through tools* argument states that new tools and infrastructures allow people who in the past couldn't do X at all, to do X now. For example, they might be able to fabricate objects themselves that in the past they would have to buy from someone else, to repair something in the past they would have thrown out or taken in for repair, or to fabricate devices that don't exist in the market. This is perceived as democratizing because it increases public access to capabilities previously only enjoyed by the few (e.g., manufacturers or authorized repair specialists).

In the *empowerment through personal growth* argument, making is claimed to empower people by changing their attitudes towards computing and/or their identities as users. This includes making more people interested in computing, making computing personally relevant or meaningful to individuals, giving them hands-on experience with fabrication tools and materials, and learning to think with/through technology at a young age. It is indirect because making here acts primarily through shifts in attitude, self-perception, and perhaps above all,

self-efficacy; this creates an empowered disposition, which then can be enacted throughout that individual's future.

The *empowerment through discursive participation* argument claims that participating in making activities also qualifies one to engage in reflexive work on defining and shaping the present and future of making as a movement. For example, feminist makers have questioned the set of practices that "count" as making, critically observing that included practices tended to be gender-coded as masculine, and then intervening to add to that set practices that tend to be gender-coded as feminine. Makers outside of the U.S. and Western Europe have similarly called into question ways that making is constructed, and asserted that other constructions are also valid. In both cases, the participants contributing to ways that "making" is constructed and disseminated as a sociotechnical practice is expanded (i.e., democratized), and more practices and people begin to "count" as making/makers, which is also democratic.

The *improved market access* argument claims that making provides individuals and groups opportunities to access markets that previously they were excluded from. For example, making helps individuals build or brush up on technical skills, helping them qualify for better jobs [Muro and Hirshberg, 2017]. We have also seen how regional IT hubs have hoped that making might stimulate the kinds of innovation that would allow them to offer products to international markets directly, as opposed to merely manufacturing things designed in the West.

The first three arguments have to do with becoming a maker, including the technical, attitudinal, and discursive dimensions of doing so. They also, as we have argued, emerge from a century-long metanarrative in which technological developments are framed as emancipatory and democratizing. Our survey has also shown how HCI research has contributed to each of these. Technical HCI contributions have introduced new tools; empirical contributions have clarified what maker practices actually look like on the ground, while also documenting some of the tensions and contradictions within making (e.g., feminist and non-Western makers' resistance to dominant maker narratives from Silicon Valley manifest in, for example *Make Magazine*). Critical stances have emphasized barriers to entry, broken promises, and also

opportunities to do better. It is worth stressing that these contributions are not exclusive. For instance, we have covered in this survey a series of technical approaches to making that are informed by empirical results, while motivated by desires to intervene and committed to providing critical insights.

The fourth democratizing argument is more recent, that is, the claim that making offers some form of improved personal or collective access to the marketplace via jobs, entrepreneurial activities, and/or leveraging regional advantages (e.g., access to physical resources, location in transportation networks, and cheap labor). The link between the first three forms of empowerment-as-democracy and entrepreneurship has been a focal point of more critical research about making.

5.2 Paradise Lost

Our survey has also covered three major criticisms of making, as follows:

1. Making is technosolutionist, that is, it seeks to offer technical solutions to complex sociological problems.

2. Making is entangled in and replicates power structures, including unequal access and benefits to different social groups, but its depoliticized discursive tendences allow it to "unsee" how it perpetuates social injustices.

3. Much of the legitimation work of making has been situated within a capitalist and neoliberal project, situating much making within conditions of precarity, and this undercuts making's ability to democratize.

Again, the technosolutionist criticism is probably the most powerful critique of making, and it can be seen to subsume the second and third criticisms. That is, if making really did solve social problems, then power structures, unequal access/benefits, and the precarity brought on by neoliberalism would be moot. But as we showed in sections 3.1 and 4.1.1, much maker discourse doesn't even address its own problems,

weaknesses, or failures. And as we showed in sections 4.1.2 and 4.1.3, some of these problems are quite serious, e.g., the ways that traditionally feminine forms of making and handwork don't "count," or the ways that innovation in Africa, India or the Far East are *a priori* framed in ways that marginalize them and often fail to recognize or even make discursive space for their achievements. Stated more positively, if we can create discursive space for such achievements, we thereby enrich and broaden the capacities of "making."

The link between empowerment and entrepreneurship is worth some extra attention. While it is not universal in maker discourse, it is nonetheless ubiquitous, and it is worth critically examining (see, e.g., Neff [2012], Irani [2015], Lindtner [2015b], Avle and Lindtner [2016], Bardzell et al. [2017], Lindtner and Avle [2017]). It is worth observing in this context who, besides HCI researchers in published academic papers, is supporting and evangelizing making. For example, industry partners that have been centrally shaping the HCI community such as Intel and Microsoft have made significant investments, creating their own platforms such as Intel's Edison and hiring researchers to study making cultures (indeed, the author team who wrote this chapter first came together under the auspices of the Intel Science and Technology Center for Social Computing). Thus, HCI's approach to making–and the formulations of democracy that it champions–cannot be disentangled from industry interests, projects in entrepreneurship, and the ideologies of DIY and empowerment [Lindtner et al., 2014]. As we showed in Chapter 4, industry involvement has led some researchers to question whether the role of markets and entrepreneurship actually undermines the democratizing potentials of making.

5.3 Paradise Regained?

We now turn to our thoughts on what we believe should be the future of HCI making research, one that returns to some of the utopian qualities of early making discourse. In doing so, perhaps we are ourselves replicating one of the world's most oldest narratives–one that begins in a utopian state of innocence, is followed by a fall/sin, and

then works toward a redemption–a structure that is equally true of Milton's *Paradise Lost* (which retells the story of Adam and Eve), the original *Star Wars* trilogy, and more appositely the Hype Cycle (which posits for any technology an early spike of hype, followed by a trough of disappointment, then a slope of enlightenment, and last a "plateau of productivity," or, as the storytellers might put it, "happily ever after").

As we wrote in the beginning, we remain attracted to making's utopian narrative. It's hard to deny that new tools and technology's empower people to do things they couldn't before, and that doing so can heighten their confidence and self-efficacy. As a community, we should build on that. But it's also hard to deny that some benefit more than others in the maker narrative, that not everyone gets to be empowered, and that making sometimes perpetuates social injustices or provides cover for capitalist exploitation in the name of entrepreneurship.

Thus, we advocate that the maker research and practice agendas move forward, but that in addition to pursuing technical capability and excellence for their own sake, HCI research commits to the following:

Envisioning how emerging technologies can support more inclusive, democratic, and (truly) empowering making practices. Such envisioning is central to HCI today, but it is often framed around empowering individuals to solve domain-specific problems. While we encourage such work to continue, we also encourage HCI researchers to approach making as part of a broader socio-ideological and technical ecology. Is it possible that the sociotechnical ecologies of making might help support or even perform the "hybrid" role Wakkary et al. [2015] specified for trained designers in linking communities of amateur expertise to making? If technologies such as Mechanical Turk enable an intentional harvesting of collective labor or even collective intelligence in service of employers, is it not possible to imagine and work towards sociotechnical ecosystems that better support a holistic project of making makers—one that not only gives individuals new tools and trains people IT skills, but one that also leverages technologies to translate across expert communities, cultivate maker identities, build self-efficacy, all while seeking to counter trends towards uncompensated labor and economic precarity?

Making as a research method that prototypes alternative maker ecologies. Critical making and feminist un-hacking both enact making as a kind of research methodology that performs a kind of critique. But just as not all research through design is intended to serve critical purposes, so research through making also need not be tied to critical purposes. Making can be deployed experimentally by researchers to investigate alternative spaces, maker pedagogies, intended outcomes, maker subjectivities, application domains (e.g., IoT), sociotechnical relationships (e.g., among makerspaces, industry, governments, and formal education), and so forth. What counts as a makerspace today still seems somewhat narrow; we have too few models of what a makerspace might be.

More robust conceptions of democracy and participation. One need only look to research on participatory design (PD) to see an IT community's long-term struggle with notions of democracy and participation. PD researchers have had to confront challenges in moving PD to locations other than Scandinavia, to places where democratic values are not the same as those in Denmark or Sweden. They have had to confront the ways that they as researchers benefit that are not shared with other participants (e.g., academic prestige, grants). And they have had to confront ways that their methods have been depoliticized and coopted by American industry under the name of "user-centered design." Making research would benefit from a much more serious theorization of democracy, and a much more (self-) critical stance when evaluating intended democratic outcomes. Too much discourse—both popular and in the research literature—tacitly endorses the idea that by giving more people more tools, technology is democratized. There is of course an element of truth to this, but it is too thin, and leaves too many people behind, to be acceptable on its face.

More proactive and systematic commitments to social justice. As researchers, we have often heard maker groups respond to the question of why they have almost no female, minority, or low-socioeconomic status members by saying, "hey, our doors are open to anyone." We ask whether HCI has its own version of this attitude. Inspired by feminists and other activists, we wonder how HCI can participate in the

development of infrastructures and institutions that give meaningful weight to those who are traditionally marginalized. We ask what concrete steps are being taken to address these concerns.

Commitment to a broader understanding of meaning and value. Much of making has been framed in terms of market values–Obama's hope of bringing manufacturing back to the American Midwest, the vision of making as filling in a key stop along pathways of innovation and start-ups, and the idea that making will prepare employees of tomorrow. But however important markets are to our ways of living and being, they are not coterminous with them. We argue for a more aesthetic understanding of meaning and value, one that speaks more deeply to human needs, ways of living, and styles of expression. This applies to maker learning and education. Making offers tremendous opportunities for learning-by-doing, material engagement, and personal experimentation. If those opportunities are more tightly coupled with meaning, significance, and expression, they are more likely to contribute towards other benefits, including broader access, interest in STEM, and so forth.

Work towards the development of making as a narrative. We have stressed throughout this survey that making is not just about the construction of tools and projects using those tools, but it is also a narrative–or set of narratives–that we use to come together, to enlist others into sympathy, to make diverse stakeholders come alive to the project. But narratives tend to have protagonists and antagonists, and they tend to foreground and background relevant information for effect. What sort of narrative should research help produce that will best support the unfolding of making in a way that reflects our values? Narratives of democratization and empowerment are attractive, but they only support our values insofar as they have some teeth, some impact. Collectively, HCI researchers (including ourselves) can work to improve the maker narrative.

As we developed these arguments and composed this prose, we inevitably began to ask ourselves and each other how much of this is about making, and how much about HCI more generally. After all, making is hardly the only locus of HCI research where there are strong aspirations towards democratization and participation, constructivist

modes of education, and individual and group empowerment. That is, making is in many ways typical of the emergence of new paradigms in HCI, rather than a unique exception.

These prompted several questions for us:

1. What does HCI research on making help us see about our own field?
2. What has HCI unseen?
3. What are the consequences of HCI's broader democratization project?

We have begun to develop our own answers to these questions throughout this survey, synthesizing them (for now) here in the Conclusion.

But following the hallowed traditions of participation and democracy, we conclude by turning this back to our readers. How should HCI answer these questions? Whither shall we go?

Or: What should we make together?

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