Title
Strange and Unstable Fabrication

Author
Devendorf, Laura K

Publication Date
2016-10-01

Strange and Unstable Fabrication

by

Laura Kay Devendorf

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Information Management and Systems

and the Designated Emphasis

in

New Media

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Kimiko Ryokai, Chair
Professor Jenna Burrell
Professor Rosemary Joyce

Fall 2016

ABSTRACT

Strange and Unstable Fabrication
by
Laura Kay Devendorf
Doctor of Philosophy in Information Management and Systems
and the Designated Emphasis in New Media
University of California, Berkeley
Professor Kimiko Ryokai, Chair

In the 1950's a group of artists led by experimental composer John Cage actively engaged chance as a means to limit their control over the artworks they produced. These artists described a world filled with active and lively forces, from the sounds of rain to blemishes in paper, that could be harnessed in creative production to give rise to new aesthetics and cultivate new sensitivities to the everyday. This approach to making was not simply act of creative expression but active attempt at creative expansion—a way of submitting to a world of creative forces beyond the self for the sake of seeing, hearing, or feeling things anew. I use these practices as a lens to reflect on the way human-computer interaction (HCI) researchers think about and design for making, specifically as it relates to the present day "maker movement." I focus on how the design of digital fabrication systems, like 3D printers, could make room for creative forces beyond the maker and why such modes of making are worth considering in HCI research. Since digital fabrication technologies have catalyzed the maker movement and are often described as key instruments for "democratizing" manufacturing, this project joins broader efforts to reflect on values in maker technology as a means of expanding the design space of digital fabrication in ways that could potentially increase the diversity of participants associated with the movement.

By weaving through post-anthropocentric theories of the new materialisms, design practice, art history, and HCI, I contribute a theory of making that accounts for the creative capacity of nonhumans as well as design tactics to make room for nonhuman forces in the design of digital fabrication systems. I argue that nonhumans exert material-semiotic forces upon makers that shape their perspectives on stuff and culture in tandem. I then suggest that tools that are both strange and unstable create a space for makers to perceive and work with these forces in ways that honor the unique life and agency of nonhuman matter. As a whole, this work adds dimensionality to HCI's existing focus on making as a process of self-expression by suggesting new design territories in fabrication design, crossings between critical reflection and creative production. I close this work by speculating on how tools that trade control, mastery, and predictability for chance, compromise, labor, and risk could become valuable within a broader landscape of making.

CONTENTS

ACKNOWLEDGEMENTS

This dissertation represents a journey that draws from the insights, thoughtfulness, and generosity of so many. At Berkeley, I have been truly lucky to work with inspiring professors and an amazing cohort of students. My dissertation committee—Kimiko Ryokai, Jenna Burrell, and Rosemary Joyce—have supported me and my work as it has formed and reformed and have always offered thoughtful feedback on new avenues to explore along the way. I am particularly thankful for the academic and institutional support offered by Kimiko Ryokai, whose poetic imagination, amazing attention to detail, and suggestion that there is always one more revision, design improvement, or practice talk to do has pushed me creatively and intellectually. I have also had the pleasure and benefit of having a foot in many different academic groups including the School of Information, Berkeley Institute of Design, Hybrid Ecologies Lab, and Berkeley Center for New Media. The School of Information has always been home and I have been incredibly lucky to be mentored by, work with, and otherwise chat with my fellow I School students. I own a particular debt of gratitude to Daniela Rosner, Elizabeth Goodman, Elisa Oreglia, Ashwin Matthew, Sarah Van Wars, Nick Doty, Richmond Wong, and Noura Howell. Another debt is owned to Paul Duguid, Nancy Van House, and Coye Cheshire who all went out of their way to support our unique academic community with their amazing ability to listen and enthusiasm for such a wide range of interests and ideas. I thank Björn Hartman and Eric Paulos for welcoming me into broader design communities on campus, helping develop my research, and supporting formal and informal collaborations with their students, particularly Cesar Torres, James Pierce, Joanne Lo, Pablo Parades, Rundong (Kevin) Tian, Shiry Ginosar, Valkyrie Savage, and Tim Campbell (whose spirit, kindness, and strength I miss and will never forget). The Berkeley Center for New Media and broader campus network offered yet another cross-section of inspirational colleagues who were kind enough to work with me throughout this journey. I am particularly thankful for my collaborations with Greg Niemeyer, Abigail De Kosnik, Marcia Linn, and Ron Real whose kindness, guidance, and vision will serve as a model for my own academic career. A very special thank you is also due to Chris Myers for his never ending focus on making prototypes more beautiful and who, along with Noura Howell, I can never thank enough for picking up the soldering jobs that I was too pregnant to complete.

Family has also played an important role in shaping my experiences as a graduate student. I am also deeply thankful for my Mom who (very literally) demonstrated the courage, determination, and commitment required jump over walls that get in the way of her goals and my Grandma Nadine who instilled her creative, can-do, and thrifty spirit in me from a very young age. If it were not for the support, wisdom, inspiration and laughter of my husband, August Black, this work would not have been possible.

To Marjory and Frances,
Thank you for showing me the beauty in uncertainty

INTRODUCTION

> The mind of the beginner is empty, free of the habits of the expert, ready to accept, to doubt, and open to all the possibilities (Suzuki et al. 2011)

Within the field of human-computer interaction (HCI), programs of research on creative practice often describe making as a process of growth through expression. This growth is framed as linear progress that is put in motion by a maker's desire to know more, do more, and attain mastery within domains as diverse as pottery and electronics. This dissertation presents an alternative framing of making as *creative expansion* and locates growth in a maker's active attempts to become a beginner and un-know the familiar or undo the habitual as a means to see, feel, and work with the world as though it is being encountered for the first time. Such practices are common within contemporary art practice but have yet to meaningfully impact the design of digital fabrication tools and they are important to consider if design researchers are to harness the potential of making as a critical practice of inquiry into materials and culture.

A view of making as creative expansion locates creativity in the world beyond the maker and attempts to create a space for the active and lively forces of the world, whether it take the form of wind, trash or weeds (to name a few), to strike upon a maker and inspire new ideas and insights. As such, it frames making as a method of becoming to the present to a world of active and lively materials as opposed to a method of adding ones mark or creative signature to the world. In relationship to the maker movement, where makers share a "do-it-yourself" spirit and engage things like digital fabrication technologies to accomplish their visions, such work situates itself within the nonlinear, messy, and serendipitous moments in which one comes up with the "it" that they will go on to do themselves. In doing so, designing fabrication systems through the lens of creative expansion presents opportunities to trade traditional technological concerns of control, mastery, and efficiency with more poetic concerns like chance, vulnerability, and curiosity.

Becoming Sensitive to Vibrant Things

The thought of ideas coming to makers from the world, rather that being born in a maker's mind, resonates with post- or non-anthropocentric scholarship that seeks a comprehensive account of the agential role of nonhumans in the production of forms. Political scientist Jane Bennett, who is associated with a branch of a research called the new materialisms, presents the term "thing-power" to "gesture toward the strange ability of ordinary, man-made items to exceed their status as objects and to manifest traces of independence and aliveness, constituting the outside of our own experience" (Bennett 2010). For Bennett, things that shape or inspire us are "vibrant things with a certain effectivity of their own, a perhaps small but irreducible degree of independence from the words, images, and feelings they provoke in us." Through this lens one can see human creative practitioners with particular physical and mental trajectories traveling through the world and spontaneously coming in contact with things that have their own lively pulsations and currents. In the moments in which two (or more), perhaps thing-powerful, entities intersect, a fertile ground for ideas is established. Bennett characterizes these moments of recognition or connection between humans and matter as mystifying and enchanting to underscore human limitations in fully knowing or

explaining the life of matter or what it might mean to be a thing. Alternatively, she frames a human's limited capacity of understanding as an opportunity for awe and inspiration.

While a growing body of design researches in HCI are engaging post-anthropocentric theories to inform the design of artifacts of various sorts (Leahu 2016; Leahu and Sengers 2014; Bowers, Bowen, and Shaw 2016; Giaccardi et al. 2016; Carl DiSalvo and Jonathan Lukens 2011; D. K. Rosner 2010), this project uniquely applies these concepts to inform the design of digital fabrication technologies. Work drawing from nonanthropocentric theories tends to be motivated by critical aims, where the point of design is to suggest new territories for research while at the same time, reflecting on assumed values held by designers that concealed those design territories in the first place. While all of this research seeks a greater or more agential role for nonhumans in design and fresh understandings of human-machine-material relationships, there are differing perspectives on what humans can know of this agency and how it can be engaged within the design of tools and interfaces. Specifically, recent work has explored Graham Harman's object oriented ontology (Harman 2011), especially as it is taken up by Ian Bogost in relation to specifically technical subjects like sensors and software (Bogost 2012), as a means of designing technologies that attempt to place humans into the felt experience of nonhumans. For instance, "thing ethnography" is a method for informing design by studying a thing's perspective of particular contexts (Giaccardi et al. 2016). The researchers mount cameras on various objects and track video feeds in order to unearth new connections that may not have surfaced by following human actors. Similarly, DiSalvo and Lukens describe an interface that allows students to take on the perspectives of robotic foragers as a means of supporting deeper understandings of the computational controls which characterize a robot's way of seeing the world (Carl DiSalvo and Jonathan Lukens 2011). In both cases, new perspectives are fostered through perspectival shifts from a human to a nonhuman through modalities of sight. While these approaches provide new insights for designers and users, the way they reassert a human sensory apparatus and cognitive framework onto the unique and, what Jane Bennett refers to as the "not-quite-human" life of objects, focuses inquiry into the felt life of another as opposed to productive entanglements between disparate lives.

Bennett's description of "vital materiality" suggests a different approach for addressing nonhuman agency by arguing that nonhuman life "refuses to dissolve completely into the milieu of human knowledge" (Bennett 2010, 3). Humans may never fully understand nonhuman life and thus, encounters with nonhumans are somewhat mystical, strange, and enchanting. By embracing Bennett's acknowledgement of the "out-side" of human understandings of thing-power, I am less concerned with what a particular thing feels or sees, and instead, attempt to make room for the human to engage the nonhuman in making in a way that honors the unique and independent life of matter. Connecting, or perhaps entangling, human and nonhuman agencies in making is intended to stretch a makers' imagination through an attention to other lives that have the ability to propel and/or resist the makers' own intentions. By making space for these other lively forces in making, I seek a role for tools in creative practice that is more like a microphone than a hammer: a tool for listening and attending to lives beyond the maker for the purposes of expanding one's creative imagination. Thus, the questions steering this project concern the nature of

nonhuman agency and how digital fabrication technologies can sensitize makers to recognize and attend to nonhuman agency in making.

The Role Tools can Play in Sensing and Working with Vibrant Things

Tools have the ability to shape both action and perception and in this capacity, it is reasonable to assume that they can shift a maker's attention to noticing nonhuman forces as well as their ability to work with such forces in particular ways. Philosopher of technology Peter-Paul Verbeek writes, "When a technological artifact is used, it facilitates people's involvement with reality, and in doing so, it co-shapes how humans can be present in their world and their world for them" (Verbeek 2006). He goes on to describe how technologies that mediate perception manifest intentionality by, "[amplifying] specific aspects of reality while reducing other aspects." Consider the design of two tools for removing weeds from a garden. The first consists of a spray bottle that allows the gardener to, at a distance, shoot chemicals on the weed that result in its death. The second consists of gardening sheers that the gardener must bring into physical contact to the weed in order to snip and kill it, at least temporarily. The selection of either tool is assumed to be motivated by the desire to kill the weed and in the first case (the spray bottle of chemicals) the gardener is able to easily execute this desire by spraying the weed without much difficulty. But in the second (gardening sheers) the gardener must physically move themselves to the weed. They must come close to the weed and are likely to have to touch the weed. In this moment, I argue that the gardener has a greater capacity to be struck by the life or thing-power of the weed because its physical presence, its smell and structure, has been amplified within their perception. In coming into close proximity with the weed, they may begin to see it as what poet Ella Wheeler Wilcox once wrote as "an unloved flower" (Wilcox 2012). If the thing-power of the weed is powerful enough to the gardener, they may begin to question their perception of it as a weed at all and imagine new uses for the plant. In this sense, the tool does not determine a specific relationship to the weed, but creates a space for potential connections between weeds and people. The cultural connotation of a particular plant as a weed may be stripped away, thus allowing it to take on new roles within the imagination of the maker.

Experimental Art Practice as a Model for Creative Expansion

Contemporary art offers several tactics that demonstrate a variety of ways that nonhuman life can be engaged within processes of creative expansion as well as the material and cultural effects of those engagements. There is a particular lineage of experimental art practice that becomes clear with Futurist theater and persists into the practices of participatory and social practice art, that is characterized by a shift in thinking about an artists role in the production of forms and experiences (Goldberg 2011; Dawkins 2011). Where traditional practices frame the artist as the sole creator of forms that they present to audiences, experimental practices are characterized by intentional measures to limit authorial control and the production of unique works that are experienced simultaneously by the artist and the audience. Such practices are contextualized as a response to Modernism, which lauded the artist as a creative visionary and giver of forms. Such figures are perhaps best characterized by iconic visionaries like Frank Lloyd Wright or Ayn Rand's depiction of Howard Roark in *The Fountainhead* who "struggles for the integrity of his creative work against every form of social opposition" (Rand 1963). Where such visionaries can be seen to work toward the realization

of their individual creative vision against all odds experimental artists engage a reciprocal approach that radically embraces oppositional forces that may otherwise be seen as resistant to the visionary.

The experimental music compositions of John Cage exemplify this approach. Describing his approach to experimental composition, Cage writes:

> …where it is realized that sounds occur whether intended or not, one turns in the direction of those he does not intend. This turning is psychological and seems at first to be a giving up of everything that belongs to humanity—for a musician, the giving up of music. This psychological turning leads to the world of nature, where, gradually or suddenly, one sees that humanity and nature, not separate, are in this world together; that nothing was lost when everything was given away. In fact, everything is gained. In musical terms, any sounds may occur in any combination and in any continuity
> (Cage 2011, 8)

This quote is reflective of a monist approach to art making, where the world of stuff beyond the maker is actively engaged to produce works that are capable of radically expanding the field of what art and making can produce in terms of forms and meaning. If read through the framework of Bennett's thing-power, we see Cage engaging chance as a mechanism to make room for the lively capacity of things to shape the work that develops. The "psychological turning" of the artist towards the world beyond him or herself holds a wealth of ideas, inspirations, and forms that is much wider than the landscapes within his or her own mind.

Cage's decision to limit authorial control had aesthetic and social implications. In terms of aesthetics, Cage argued that engagements with chance created a space for a collective experience by allowing both artist and audience to experience the artwork as it unfolded. He also saw beauty in noise and the unintentional and felt that experimental composition would strike something more primal then carefully planned and orchestrated harmonies. Fred Turner suggests that Cage and his contemporaries at Black Mountain College worked towards a "democratic" idealism in response to the authoritarianism and atrocities of World War Two (Turner 2013). Not only did chance-based and indeterminate composition work against the idea of an artist as an authority figure, it was also seen to create "therapeutic" experiences centered on the idea of accepting the world on its own terms.

Records of Cage's performances shed light into particular mechanisms that created space for nonhuman participation in artworks. In the 1940's Cage began to "prepare" pianos by placing objects on the strings in order to create semi-predictable percussive sounds by striking piano keys. In 1951 he composed *Music of Changes* in which musical decisions were determined by the chance operations of *I Ching*, an ancient Chinese divisional text (Cage 1951). In the 1960's, Cage performed *Water Walk* by assembling a large number of ordinary household appliances, including five unplugged radios, an iron pipe, a bathtub, a soda siphon, an ice bucket, a vase with flowers, a tape machine, a garden sprinkler, a pressure

cooker and then walking from object to object, using each in its commonplace way. The sounds created by his "playing" each thing produced a vibrant cacophony that was wholly different than anything a musician might have played on a musical instrument (Cage 1960). In his most controversial piece, *4'33",* David Tudor sat silently for 4 minutes and 33 seconds in front of a piano, doing nothing, while the sounds of the room and beyond constituted the performance. In each piece, Cage harnesses active potentials in everyday objects though a balance between chance and certainty. It is as though Cage provides an outline and invites particular kinds of performers, both human and nonhuman, to color within those lines. I see Cage as an orchestrator of chance events or a crafter of chance as opposed to a composer in the traditional sense. By bringing lively forces into resonant and dissonant relationships, he specified a field for possible outcomes while making room for unique "objects" to emerge.

While Cage's practice serves as a model for post-anthropocentrism in making, musicologist Benjamin Piekut describes how Cage's politics and writings maintain modernist "uncritical" separations between the social and the natural, specifically as Latour understands them in *We Have Never Been Modern*. In Piekut's terms,

> … [Cage's] compositional practice contradicted this modernist ontology of nature at every turn by actively forming that world that he purported merely to discover. At work in his studio, Cage took part in an ecology of entities that mutually enhanced and defined one another through the event of the experiment. In other words, the human never simply "disappeared," and the nonhuman was never simply "revealed."…his compositional process was indeed uncertain, but not in the way that he thought it was. (Piekut 2013)

This distinction between the practice and politics of Cage emphasizes power differentials between humans and nonhumans in making. Since this dissertation is ultimately concerned with designs for human makers, and has a goal of equipping humans with tools that allow them to become entangled with nonhuman agencies in making, nonhuman life is ultimately engaged towards human ends. Thus, the *goal* of the tool is not one of removing the human, or depicting nonhuman life, but working within the reverberations between human and nonhuman and seeing those spaces as productive of different kinds of inquiries and forms than are typically associated with innovations in "maker" technology.

Anthropocentrism and Expression in Fabrication Tools

My focus on creative expansion and the way it engages nonhuman agency contrasts an existing anthropocentric impulse in the design of fabrication systems. This anthropocentric impulse is perhaps best illustrated in the design of a commercial 3D printer. Consider the MakerBot 3D printer, a consumer-oriented model of 3D printer that is sold at popular retailers like the Home Depot. The MakerBot 3D printer is one machine within a broad category of computer-numeric controlled (CNC) machines. CNC machines and their associated software translate digital models into a list of instructions that a machine can perform to create a physical version of that digital model. The language used to specify the movements (what are technically referred to as tool-paths) of these machines is called G-Code. G-Code offers a standard set of codes to tell machines things like where to move,

how fast to move, and, depending on the machine, where to add or remove material. Creating the mechanics and algorithms for translating a digital model into a list of G-Code instructions intended for a particular machine is a key design challenge when developing CNC technologies. Currently, the heuristic that has driven development in CNC machines, including MakerBot 3D printers, has been fidelity to the pre-specified digital model.

The focus on accurate replication of a preexisting model leads designers of CNC systems seek to eliminate sources of uncertainty that could potentially alter the form from what has been specified digitally. In other words, it drives designers to identify methods to tame the material world so that it will passively take on any shape or form. Echoes of this vision of passive materials can be heard in the rhetoric of engineer and maker movement evangelist Neil Gershenfeld, who imagines that, "personal fabrication will bring the programmability of the digital worlds we've invented to the physical world we inhabit" (Gershenfeld 2007). While this vision has certainly ushered in powerful new innovations, forms, and processes of creation, it is also one that frames the human maker as the locus of innovation and creativity and their building materials as passive receptors or containers for makers' expressions. By making room for the inherently unpredictable voices of nonhuman materials, whether they propel or resist a maker's own intention, fabrication systems may cultivate a different relationship between the maker and the world within which they are embedded. Instead of orienting making around human vision, designing through the lens of creative expansion creates a space for tools to provoke attention to the world by embracing the inherent unpredictability of nonhuman forces as creative resources as opposed to obstacles. In doing so, different experiences of making may come to the fore. Where attempts to predict and control form may focus a maker's attention on the alignments between ideas and object, embracing form as indeterminate and the nonhuman world as active and alive can cultivate an attention to forces beyond the self that sensitize and make maker's present to new sources of inspiration. As such, tools for creative expansion situate themselves within the nonlinear flows of a creative practice where one instance of noticing sparks an idea and that idea sparks attention to a different set of phenomena, which spark new ideas, and so and so forth.

Engaging Nonhuman Forces for Creative Expression

Within digital fabrication research communities a growing body of interactive, hybrid, and human-assisted fabrication systems have begun to make space for nonhuman life in making and represent a move away from anthropocentric design positions. Willis' "interactive fabrication" systems showcase various ways that fabrication machines can be engaged towards open-ended ideation (Willis et al. 2011); explorations of "interactive construction" have focused on efficient human-machine collaborations (Mueller, Lopes, and Baudisch 2012; Mueller et al. 2013; Mueller et al. 2014); and human-assisted fabrication devices guide humans in the production of accurate large scale models (Yoshida et al. 2015; Agrawal et al. 2015) and models produced in mobile contexts (Roumen et al. 2016) that are still unfeasible with current 3D printing technologies. Also worth noting are systems that work with broader material sets, like 3D printing with felted wool (Hudson 2014); a suite of tools created by Takeo Igarashi and collaborators that translate digital models into knitting (Igarashi, Igarashi, and Suzuki 2008), sewing (Mori and Igarashi 2007), and bead-work

(Igarashi, Igarashi, and Mitani 2012) patterns that can be produced by hand; or projection systems that assist novices in sculpting detailed objects (Rivers, Adams, and Durand 2012) or cutting complex patterns with a hand-held tools (Rivers, Moyer, and Durand 2012).

Work falling under the banner of hybrid-craft (Zoran et al. 2014; Zoran 2013; Efrat, Mizrahi, and Zoran 2016; Torres, Li, and Paulos 2016; Jacobs and Zoran 2015) comes the closest to addressing the role of material agency in shaping forms and makers. Such work tends to draw from craft, or "traditional craft," to acknowledge the power of nonhuman stuff in shaping the forms humans produce and the sensitivities they develop through making. In drawing from the descriptions of craft offered by Tim Ingold (Ingold 2013), Richard Sennett (Sennett 2008), David Pye (Pye 2007), and Malcolm McCullough (McCullough 1998) to name a few, these researchers explore opportunities for creative production that emerge by intermingling digital and physical production processes. Such work appeals to hybridity as a way to combine the best aspects of digital and physical production processes. For instance, in their developing of a hand-held CNC milling device called FreeD, Zoran et al. seek a mode of work that combines "qualities of [digital fabrication and craft] traditions: minimizing fabrication risk by using a small degree of digital control and automation while allowing authentic engagement with raw material to achieve unique results" (Zoran et al. 2014).

A growing body of hybrid-craft research grows out of concerns of deskilling expressed by theorists associated with the Arts and Crafts movement (e.g. Morris 2010). As a response, the work attempts to blend computation and physical materials in ways that preserve the ability for makers to experience the "life" of the materials with which they work. In many cases, the best of both worlds approach to hybrid design places technology in service to the human maker, perhaps by reducing the capacity for errors or providing guides that allow a novice maker to create objects that were once only attainable by more expert makers. In this sense, the hybrid can be seen to perpetuate ontological distinctions between humans and machines in the process of breaking them down (Devendorf and Rosner 2016). The human tends to play the role of the creative, expressive, sensitive manipulator of materials and the technology tends to play the role of scaffold or guide, helping the user work more productively with their materials. The life of materials is engaged as a means of learning about those materials in order to work more productively with them. In this sense, nonhuman life is evoked within the framework of developing human skill and mastery within a particular material domain. In a related sense, the design of the tools privileges making as a process of narrowing in on a particular idea or concept as opposed to the more radically open-ended orientation of creative expansion.

Engaging Nonhuman Forces for Creative Expansion

Where drawing from craft foregrounds making as an act of creative expression though concerns of fluency, mastery, and skill, my engagement of experimental art practice foregrounds creative expansion—a move to actively work against skill, habit, and routine in order to give rise to new ideas and sensitivities. While the aforementioned work in fabrication design has distinct and verified benefits, there are broader roles of agential matter to play in making. Specifically, tools can sensitize makers to a broad range of vibrant

materials (not just a few select materials) and seek a place in experimental practices where the focus may be on ideas, themes, and relationships to culture as opposed to the efficacy of expression in particular productive domains.

The limits of focusing on craft and creative expression in making workflows have been acknowledged within HCI's research programs on making, particularly in relationship to studies of creative practices and repair and appropriation (Jackson and Kang 2014; Maestri and Wakkary 2011; D. K. Rosner and Turner 2015; D. Rosner and Bean 2009). In their study of artists who generate work through the repair and repurposing of broken or junk technologies, Jackson and Kang argue that HCI would benefit in shifting its view of making "from a position of conceptual mastery and authority towards a flatter and more distributed model in which the artist/designer operates as participant and co-creator in a mixed world of people and things" (Jackson and Kang 2014). Rosner and Turner surface links between processes of repair and the "ideological legacy of the counterculture" arguing for consideration of repair as integral to innovation (D. K. Rosner and Turner 2015). In a study of the use of industrial robots in the studio of a fine art furniture maker, Cheadle and Jackson provide a counter-narrative to positions that treat technology as a threat to the artist or craftsman's expressive capacity writing, "In the [Artist's] studio, creativity can be found emerging within and through the use of a remediating tool, meeting the artist and his medium and sparking a creative capacity not possible before such computational and robotic intervention. [The robot] collaborates with the design work of [the artist] in a way no other studio member does. And in doing so, it reduces the ontological gap some see between the human/object relationship" (Cheatle and Jackson 2015). In this sense, there is a greater opportunity for tools to work in collaboration with, as opposed to in service to, the maker by engaging them in a generative capacity to explore broader creative territories that are simply not possible by human alone.

Ontologically flat systems for human-machine-materials collaboration have been explored through the lens of improvisation primarily as it is informed by digital art practice or jazz (Bowers et al. 2014). Such work acknowledges the fluidity of human or nonhuman categories in making, allowing for cuts across categories of user and performer (Leong et al. 2011), and artist and designer (Taylor et al. 2013). Bowers et al. also draw from the new materialisms to articulate a multiplicity of outcomes and processes of making, suggesting a conceptual shift from making, singular, to "many makings" (Bowers, Bowen, and Shaw 2016). Bowers acknowledges that different lineages or traditions of improvisation color analysis in particular ways. As such, engaging experimental art performance as a model of creative expansion, as opposed to jazz improvisation, may make particular concerns present that other approaches to improvisation may sideline (Bowers et al. 2014). In my own experience, perspectives from performance art, specifically those that have seek aesthetic engagements with the "everyday," are uniquely positioned to frame making as dialog with materials and culture.

In a similar spirit to this project, Rosner and collaborators have begun to explore digital fabrication practices as human-machine-material collaborations though the co-design of machines and/or products. Reflecting on the co-design of a fabrication system for ceramics called *Arc*, Saegusa et al. attend to the symbolic dimensions of working with particular tools

in particular contexts, specifically exploring what it means to collaborate with a machine in the production of ceramic object. Reflecting on their design and the themes of mimesis that motivated it, they write "…what you can see and what you get from digital fabrication is less a matter of function than a capacity for creating a symbolic hold on the thing being reproduced" (Saegusa, Tran, and Rosner 2016). In another study, Rosner et al. explore digitally fabricated ceramics to reveal productive tensions between malleable code and more rigid clay. They argue that, "Investigations of tangible design might take advantage of those seams [or tensions] by observing how an object comes into being through this resistance, surfacing new discontinuities of the digital hand"(D. K. Rosner, Ikemiya, and Regan 2015). These reflections highlight important facets of making that are sidelined with a focus on developing material skill. Namely, they show how the symbolism of doing something a particular way or attending to what it means to produce objects in collaboration with technology can be engaged in a reflective capacity through productive tasks.

Creative Expansion and the Design of Tools for Fabrication

My call for the consideration of creative expansion as a conceptual framework for the development of fabrication tools takes both theoretical and practice-based forms. Chapter 2, *Weaving Theory and Practice*, discusses my methodological approach to designing and studying tools for creative expansion. Chapter 3, *Making and Being Made through Material-Semiotic Inquiry*, presents a theory of making that frames nonhuman forces as material-semiotic forces. My theory draws heavily from existing new materialist theories of making but differs in its attention to the semiotic as well as material to foreground making as a method of inquiry into stuff and culture in tandem. I argue that attention to semiotics is important to consider if designers are to open broader design territories and grasp a fuller role for nonhuman agency beyond human skill acquisition. Materiality and semiotics are deeply entangled and considering one without the other limits the scope of forces that are able to shape and sensitize makers.

Chapters 4 and 5 present design tactics to support creative expansion in tool design. Chapter 4, *Designing Strange Tools to Work Against Habit*, concerns how tools can be designed in a way that leads users to notice nonhuman forces in their daily life. Drawing from the design and study of AnyType, a mobile application for producing novel typefaces, I argue that tools that require a maker to do something in strange and unusual ways allow habituated objects to transition into subjects of material-semiotic inquiry. The capacity of things, games, or prompts to make the familiar strange has been acknowledged in art and design practice, but has not yet informed the design of fabrication systems for making. I suggest that using fabrication systems in ways that provoke strange engagements can be a useful tactic for opening perception to the everyday. Chapter 5, *Designing Unstable Tools to Provoke Experimentation*, presents a second design tactic targeted at encouraging open-ended and nonlinear experimentation by conceptualizing the tool as an unstable entity. Unstable tools, I argue, make it difficult to conceptualize the final product a priori and suggest engagements with materials for which there is no precedent. Placing barriers in the way of conceptualizing an output heightens a maker's attention to the forces affecting them at any given moment. The strangeness of the action with those materials also creates a wider space for users to interpret how the tool ought to work. Together, these design measures increase the

adaptability of the interface to multiple domains of practice and give makers the flexibility required to include nonhuman forces in making. The tool creates space for material-semiotic forces to push upon makers in ways that maker's find to be particularly valuable to their creative practice.

In conclusion, Chapter 6, *Reflections and Aspirations for Creative Expansion in HCI,* reflects on the concept of creative expansion and the possibilities it presents for future research. Specifically, it reflects on the nature of tools for creative expansion, the challenges of evaluating tools that actively resist goal-based practices, and the role such technologies might play without the broader sociotechnical landscape of the maker movement.

WEAVING THEORY AND PRACTICE

In this dissertation, I draw from my experience designing and studying tools for making, contemporary art history, and new materialist theory to draw attention to creative expansion (as exemplified by experimental art practice) as a subject worthy of deeper exploration in the design of fabrication tools. My argument takes the form of a manifesto, articulating a different way of understanding making and suggesting design tactics that can help designers think about the relationship between tools and creative expansion. I position this work around the design of a *tools* as a rhetorical move to rethink something that has come to stand for a particularly narrow description of function within a domain (creative practice) that defies mechanistic or strictly productive qualities. It is a strategy to connect, or perhaps lure, researchers largely concerned with functionalist, instrumental, or traditional approaches to see an extended capability of the tools they are building—one that is well positioned to ask questions about culture in addition to materials.

The approaches outlined in this dissertation grow out of a view of creative practice as a "third-wave" HCI concern. Third-wave HCI describes a shift from investigations of workplace values, like efficiency and productivity, to broader connections between culture and technology that place a premium on "experience and meaning-making" (Bødker 2006; Bødker 2015) Furthermore, third-wave HCI often concerns itself with "wicked problems" (Rittel and Webber 1969), where no clear pathway towards a well defined "solution" state exists. Creative practice is a "wicked" domain because determining what people want or need from tools in these practices is highly subjective and fluid. People who value slow, methodical, and labor-intensive practices counter seemingly universal technical values like efficiency. Furthermore, aspects of one technology that may appear to some as broken are precisely what makes it appealing for someone else. Some researchers attempt to reduce the complexity or contradictory values in creative practice by focusing on a specific domain (like sculpting or dressmaking) and modeling needs and values on normative practices in that domain. As such, this work often, explicitly or implicitly, imposes problem formulations on creative work and offers the tool as a solution to those problems. Examples include support for beginners in new domains or ways of making existing practices more efficient. While this work is beneficial, the impulse to reduce the complexity of creative practice through problem identification narrows the work a tool can be seen to perform in creative practice. Accepting the messy and complex landscape of values in creative practice requires different design methods and evaluation strategies from those that are oriented around a simplified model of values in making. By engaging inductive methods of designing and evaluating tools within a broader practice of research through design, I attempt to harness complexity as a resource to locate more radical and perhaps uncharted territories of tool design.

Reflecting on Making through Tool Design

Research through design (RtD) (W. Gaver 2012; Zimmerman, Stolterman, and Forlizzi 2010; Zimmerman, Forlizzi, and Evenson 2007) is a methodology rooted in recognition of art and design as valid and important ways of knowing and producing theories. Christopher Frayling frames "research through art and design" as "materials research," the work of studying the behaviors of materials, "development work - for example, customizing a piece of technology to do something no one had considered before and communicating the results" and "action research" which involves contextualizing the "step-by-step" processes of a particular

experiment (Frayling 1993). Within the past decade, several researchers have explored research through design as an approach to HCI research. While some researchers advocate increasing formalization and standardized methods in order to legitimize RtD as a HCI research methodology (Zimmerman, Stolterman, and Forlizzi 2010; Forlizzi et al. 2011), I align with Gaver's opinion that the impulse towards formalization runs the risk of undermining the potential of RtD to honor the complex relationships between designed things and the cultures in which they are situated (W. Gaver 2012).

Gaver acknowledges that the theoretical contributions of RtD are different from those produced through behavioral and social scientific research methodologies. Where science seeks unfalsifiable truths or facts, RtD sees the design artifact as the fact, or, as what Stolterman refers to as the "ultimate particular" (Stolterman 2008). These arti-facts and the theories they articulate are not generalizable in a scientific sense due to the specificity of the design object in relationship to its domain. In Stolterman's words, "Each system, each design, even if exactly the same as another, makes up an ultimate particular that has to be understood in a designerly way as evoking emergent qualities in the composition made up by the system and the organization together" (Stolterman 2008). Because of the contingent nature designed artifacts, Gaver describes theories generated through their design as underspecified and provisional. What makes a good theory in this sense is its "fertility." In Gaver's words, "research through design should be appreciated for its proliferation of new realities, and its theory considered as annotation of the artefacts that are its fundamental achievement" (W. Gaver 2012).

As RtD, my practice of designing tools is oriented towards identifying new worthwhile territories to explore and fertile theories of design as opposed to a set of decontextualized "principles" to be adapted to multiple domains. It is an inspirational, in addition to an informational, project. Along these lines, this dissertation's attempt to use creative expansion as a lens to study how tools can radically engage forces beyond the maker seeks to identify a new design territory and qualify why or how that territory matters in the lives of makers of different sorts. I assess the relationship between tools and user experience, and the degree to which that experience mattered to users, by designing tools as probes and qualitatively evaluating a user's experience with those tools.

A Chronology of my Research Process

My particular approach to RtD has meandered through art history, theories of making, and the design and evaluation of tools for making. While the experiences that inform this work extend far into the past, prior to my studies as a PhD student, a convenient starting point for the work in this dissertation begins with the design, development, and study of two tools for making. In 2012, Kimiko Ryokai and I designed and studied AnyType (Devendorf and Ryokai 2013), a tool for creating novel typefaces that revealed connections between defamiliarization in design and semiotic thinking. Next, in 2014, I created Redeform (Devendorf and Ryokai 2015a), a system for 3D printing by hand with everyday materials which demonstrated roles for technology in creative practice that had yet to be engaged in HCI. The two studies were related in the sense that insights from my study of AnyType inspired the design of Redeform. After conducting the user study with Redeform, I

participated in a reading seminar focused on new materialist theory where I began to see my approach to nonhuman agency as different from other tools in HCI. Additionally, I began to see connections between experimental art practice and new materialist conceptualizations of making that were fruitful for generating new ideas about design in HCI (Devendorf and Rosner 2015). I deepened my thinking about nonhuman agency and connections with performance art, new materialist theory, and norms in tool design, by using Redeform within my personal art practice over a span of almost two years (Devendorf, De Kosnik, et al. 2016).

Designing Tools as Probes

The tools that I designed and studied are best understood as probes, which is a particularly useful approach for reflecting on the implicit values that a designer brings to a design task (Sengers et al. 2005). The concept of the tool as a probe pushes design in a direction that radically accepts the complexity of creative practice. Rather than attempting to assess the values of creative practice a priori, designing a tool to support those values, and bringing in users to tell me whether or not my approach was correct, I sought a mode that would offer interpretive flexibility (Sengers and Gaver 2006) as a means of letting values emerge in relationship to the tool at hand. My designs reflected my opinions and were motivated by my curiosity about what might be possible or what I personally felt to be valuable in making. Inviting users to respond to these ideas was an effort to expand my own thinking.

Gaver et al. originally introduced the term probe, in the form of "cultural probes," as a designer-led method for eliciting information from a subject population that might not have been captured through traditional interview or observation techniques (B. Gaver, Dunne, and Pacenti 1999). Each cultural probe consists of a carefully curated set of materials for the subject population to *do* something with. The prompts are crafted such that responses can range on a scale from prosaic to poetic. For instance, one probe described by the authors consisted of a map and a set of dot stickers with prompts that asked participant to place dots on locations where they would go to "meet people" or "day dream." The designers engaged the materials produced in response to the probes as a method of inspiring new ideas and territories they might not have otherwise considered. In this sense, probes are valuable methods, or perhaps tools, for engaging other humans in design and expanding and sensitizing designers to new perspectives.

In the two decades since Gaver et al.'s introduction of cultural probes, several researches have adapted the approach to encompass a broad range of inductive techniques for inspiring designs[1]. Variations include broken probes (Ikemiya and Rosner 2014) and itinerant probes (D. K. Rosner et al. 2016). Hutchinson et al. present the concept of a technology probe as "a particular type of probe that combine the social science goal of collecting information about the use and the users of the technology in a real world setting, the engineering goal of field-testing the technology, and the design goal of inspiring users and designers to think of new

[1] Some have argued that many researchers mistakenly approach probes as a method rather than a methodology by using the exact prompts developed by Gaver et al. instead of generatively creating probes to suit their specific design context and questions (Boehner et al. 2007).

kinds of technology to support their needs" (Hutchinson et al. 2003). In a related move, Sengers et al. suggest that building technology *as a probe* can be a useful strategy to gain insights into larger social patterns with technology by provoking reflection in designers and users (Sengers et al. 2005). Where cultural and technology probes tend to engage the probe as a pre-design activity, Sengers et al.'s concept of designing technology *as a probe* frames the technology/probe as the design deliverable.

Gleaning Insights from Tools as Probes

Both tools studied and presented in this dissertation were created as probes. To study them, I recruited participants who were broadly interested in "making" to use the tool/probes I developed. I recruited participants from a variety of local mailing lists and message boards. Because I sought to identify new ways of conceptualizing the relationship between humans and technologies for making, and to point to new opportunities for design, I sampled participants for a range of different ages and styles in making. These samples were not representative of the population of users for which the tool was intended and the insights that I draw from the sample are not intended to generalize to multiple contexts. Instead, I focused my samples on engaging individuals who had potential to suggest new opportunities and ways of thinking. As such, a broad and diverse sample created the greatest opportunity to locate new opportunities. At the same time, this approach is limited in its ability to prove that such perspectives are broadly held or will characterize future experiences with the technology.

In order to encourage a diverse range of participants' interpretations and uses of the tool, I would introduce the technology and describe that there was no "correct" or intended use for the system. In my experience conducting user studies, I find that some participants come to the study with the idea that I am using them to test the correctness of my design, as though I am going to bring it to market in the near future. In response, they are shy about offering negative feedback or continually look for guidance on what I want them to do with the tool. Beginning studies with a statement articulating that I am interested in their unique approach and interpretation, and that I value good and bad feedback equally, tends to be a useful way to make study participants more comfortable and broaden interpretations.

I capture data from situ observations as well as semi-structured interviews in the form of videos and hand-written notes. The notes mark interesting insights with a timestamp and allow me to quickly revisit the statement in the video. The interviews are focused on the qualities of experience around each tool/probe. Following the guidance outlined in (Weiss 1995), I approach interviews as "qualitative interviews" and tailor each interview to the research participant in order to "gain in the coherence, depth, and density of the material each respondent provides." Weiss argues that such approaches are able to "provide readers with a fuller understanding of the experiences of our respondents" and thus, are well suited to articulate the unique relationships between the tool and the user. Because creative practice is a highly subjective and individual endeavor that winds continuously through daily life, I find qualitative interviews best suited to honor individual inquiry. Specifics about the subject populations and the particular concerns that drove each interview will be discussed in more detail along with the description of each design.

I analyzed the data from the studies in order to draw connections between specific design features, aspects of user experience, and the practices of tool-use that ensued. Weiss' description of "issue-focused" analysis best describes my analytical approach. Issue-focused studies contribute perspectives on an issue across multiple research subjects. In my studies, the "issue" I was concerned with was the response to my design and, specifically, how it shaped the experiences and outcomes of making. The connections I drew emerged by looking across data captured from participants and coding emergent themes that connected particular features of the design to particular approaches and experiences. The codes emerged from notes I made during observations, watching sections of videos, summaries that I wrote after each interview to recap key insights, data logs on the tools themselves, transcripts created from videos and interviews, and the artifacts generated by participants with the tool. I performed all of the observations, interviews, coding, and analysis by myself continually throughout the study. This allowed me to maintain an ongoing process of reflection on emergent themes, which were further refined in subsequent user studies and analyses.

Communicating Insights

Research papers describing the unique relationship between the design and experience for each tool were published at ACM CHI Conference on Human Factors in Computing Systems (Devendorf and Ryokai 2013; Devendorf and Ryokai 2015a). Each paper communicated the findings by identifying key themes connecting design and experience. Support for each theme was provided by images of the artifacts users created and quotes from users. In this dissertation, I engage these design projects and findings as support for a broader argument about the potential of designing tools for creative expansion. Thus, the presentation of the findings from each study will take a different form than what was already published at CHI. The new form represents my current state of thinking about nonhuman agency and the design of tools for making. These connections have come from re-reading the past studies as well as revisiting transcripts and summary documents created during those studies.

I have chosen to present my current state of thinking as a manifesto that connects historical accounts of contemporary art practice, new materialist theory, and the insights from my studies of tools in order to argue for new directions in future research. Gaver describes manifestos as one of many forms of theory that are produced from a research through design practice. In his words, manifestos "go beyond theoretical treatments drawn from other disciplines or developed from reflection on practice to suggest certain approaches to design as both as desirable and productive of future practice…Typically, such manifestos will describe design practice to illustrate their approach, and borrow theories to justify it, but their primary function is to build an account of a practice to be pursued in the future" (W. Gaver 2012).

This particular manifesto argues for creative expansion as a future research program. I see this as a move towards broader support of such practices but is not an exhaustive account of the many forms that creative expansion can and have taken in art practice. Specifically, in my focus on making space for the nonhuman in fabrication technologies, I have sidelined

concerns of engaging humans beyond the maker as in participatory art. Additionally, I focus on the practices of individual makers, as opposed to collectives or studies in co-working spaces. Finally, I have focused largely on the role of digital and physical materials that are explicitly chosen by the maker in the practices of making but to a lesser degree, the role of place or environments in shaping what is produced. While I intend to branch out into deeper explorations of site specific and participatory forms of fabrication in the future, this particular dissertation represents a first step towards a much larger and inspiring design terrain

MAKING AND BEING MADE THOUGH MATERIAL-SEMIOTIC INQUIRY

The way a designer thinks about making shapes how they design tools for making. Within HCI, there is a long history perspective on making that attend to the lively force of materials in shaping the forms produced. While not explicitly framed around issues of nonhuman agency, Donald Schön's descriptions of design as a "reflexive conversation with the materials of a design situation" (Schön 1983) resonates with more recent accounts of making as a process of "correspondence" (Ingold 2013) with active and agential materials that have become increasingly influential in HCI. Each perspective, whether from art, craft, or design, tunes into particular facets of nonhuman life. HCI's current focus making room for nonhuman forces in fabrication a la "traditional craft" tends to highlight nonhuman agency in relationship to the specific materials associated with a particular craft activity. This prompts questions like how does the potter sense the life of clay? How does a woodworker experience the life in wood grain? Or, how does code give rise to particular aesthetic forms?

A similar impulse runs through new materialist descriptions of making which have also focused on the life of "raw" materials like metal or reeds in basket weaving as they are engaged in craft practices. But if designers and theorists attend only to the materials typically associated with craft, a much broader and diverse landscape of materials we interact with on a daily basis become sidelined. These materials are so pervasive in our experience of the everyday that people tend to look right past them as they go about their daily routines. Yet, the very normality or everyday-ness of these materials, from books and buildings to sidewalks and signage, make them particularly rich sites to inquire about culture. Considering these materials as vibrant things that reach out to and affect us may prompt questions like: what does the placement of items on supermarket shelf suggest about corporate influence, or, where did these street names come from and what does this tell us about the nature of our community? These are the kinds of questions that I see as belonging to the realm of the material-semiotic, which attends to the materiality of given forms as well as the associations and representations that are given off when those materials are placed in particular arrangements.

Without an attention to the material-semiotic in making, the experimental practices of Cage and others begin to look particularly self-serving and esoteric. If one begins to fill in the picture with the backdrop of a society recovering from the horrors of World War Two and the broader lineage of composition that have come to mark Cage's approach as uniquely different, then his compositions represent something more profound. Attending to the material-semiotic reveals a world of narratives and questions to be formed through the juxtaposition, transposition, and opposition of things that give off unique meanings, ideologies, and histories. A first step towards making space for these meanings in the design of fabrication technologies is articulating the role they play in making.

Before I go on, it's important to look back at the histories that have informed the specific attention to the material (instead of the material-semiotic) in new materialist theories of making. The focus on material life and phenomena over things can be understood as a response to a "semiotic turn" exemplified by fields like Marxist materialisms and cultural studies. New materialists take up earlier materialist critiques of "approaches which view material culture as merely the semiotic representation of some bedrock of social relations"

(Miller 2005) by seeking a monist ontology that dissolves dualities between subject and object. Thus, there can be no world of artifacts or objects "out there" that human's give meaning, but a more fluid push and pull and co-shaping between human and nonhuman forces.

New materialists tend to see semiotics, especially perspectives which draw from the linage of Ferdinand de Saussure, as a process that reifies dualist conceptualizations of reality by reducing objects to texts, a move that sees meaning as a human endeavor handed down onto objects. The metaphor of text implies a narrative to be written and read, or a contract between humans formed through objects and representations. In response, new materialist theories of form and making focus on the performativity of materials and the way they are sensed in moments of making. As Barad writes, "Performativity, properly construed, is not an invitation to turn everything (including material bodies) into words; on the contrary, performativity is precisely a contestation of the excessive power granted to language to determine what is real" (Barad 2006). Such a move maintains a life within the material that is unique from human life and attempts to account for this unique being in all its irreducibility. But the turn away from semiotics can be problematic when operationalized in design contexts because it limits a designer's ability to account for making as a form of cultural inquiry and non-textual communication. In this chapter I will argue for a consideration of the material-semiotic as an attempt to work somewhere between a semiotic turn and material turn, seeing meaning as emergent from entanglements of the unique lives of stuff and the unique lives of people.

This chapter addresses key concepts in the new materialisms that underlie my own consideration of making as material-semiotic inquiry. I describe the agency of materials through an agential realist (Barad 2007) and vital materialist (Bennett 2010) lens. I then describe the role agential materials play in making, aligning my own work with theories of making as morphogenesis, a view that locates creativity within materials. Anthropologist Tim Ingold provides his own account of making as morphogenesis through correspondence with active materials. While this specific concept has been increasingly influential in design research (e.g. Torres, Li, and Paulos 2016; Bowers, Bowen, and Shaw 2016), I argue that his formulation of making is limited in the sense that it focuses heavily on materials and form without considering the role that meanings and representations play in shaping the forms human makers produce and the perspectives they glean through making. I provide counter-narratives to examples in Ingold's book *Making: Anthropology, Archaeology, Art and Architecture* (Ingold 2013) to illustrate how an attention to semiotics within discussions of nonhuman forces makes a difference. At the end, I offer my own theory of making as material-semiotic inquiry by augmenting Ingold's concept of correspondence to include vibrant stuff as well as lively signs.

Inquiry Embraces Active Materials

As we go through our daily lives we come in contact with various forms—tables, buildings, people, laptops, leaves—which appear to us as more or less stable or durable entities. They may seem inert and lifeless, as though they were waiting for humans to use them, put them in motion, and give them meaning. But these forms are assemblages of many active materials

with "an inertial tendency to persist" (Bennett 2010) held together by forces pushing and pulling in many directions.

If we were to put on new materialist goggles, so to speak, and look at the world around us, we would see forms as temporary states or precarious places where active materials push and pull against each other as they move on their way towards becoming something else. The table rots, the building crumbles, leaves wilt, etc. As Tim Ingold writes, "Whatever the objective forms which they are currently cast, materials are always and already on their ways to becoming something else" (Ingold 2013). Like hermit crabs, materials are nomadic entities simply "occupying" forms for limited times on their indeterminate journeys. Some theorists describe how materials are in continual states of "becoming" in order to emphasize that they are not traveling towards some known end state or goal. Instead, they are continually becoming new things with no ending in sight.

Perception and Action with Active Materials

Some forms are readily perceptible as unstable. For instance, we watch as the sandcastle we build on the beach is taken apart by the waves, or destroyed under the foot of an excited toddler. Others appear to us as stable entities because of a difference in timescales—the human life span is quite a bit shorter than the "life span" of mountains, for instance. While the new materialisms address matter as lively and active, they acknowledge that humans do not always perceive the world this way. There is a perspectival relationship between the human self and the stuff of the world. When stuff in the world is encountered as inert and passive, it takes on the status of object—a bounded, lifeless thing separate from the self. When stuff in the world is encountered as active, when it "reaches" out and captures our attention and becomes something we consider, question, and explore, it takes on the status of thing. In her book *Vibrant Matter: A Political Ecology of Things*, Political Scientist Jane Bennett frequently returns to a narrative of passing a pile of debris and how, at a certain moment with the things arranged in a certain way, she was able to sense an "energetic vitality" within them. She writes, "objects appeared as things, that is, as vivid entities not entirely reducible to the contexts in which (human) subjects set them, never entirely exhausted by their semiotics" (Bennett 2010:5). In this moment, a connection is formed between the human and the debris, we see the "thing power" of the debris actively reaching out and grabbing Bennett's attention as opposed to her looking at the debris and handing down some meaning onto it. She borrows Latour's label of "actant" to capture the ability for nonhuman stuff to act and affect. Actants affect us in "not quite human" ways.

When the active or lively capacity of stuff is acknowledged, we must seek an origin of this agency beyond the human. This is where Bennett offers her concept of a vital materialism, in which animacy is attributed to something other than the human or a divine spirit (i.e. a soul). Instead, she works from Deleuze to describe an immanent matter-energy that runs through all things, human and nonhuman. This lively force is nomadic, it has no single goal, and it moves along itinerant paths with no particular destination. It animates stuff and is exhibited by a "stubbornness, or inertial tendency to persist." When lively matter intermingles with other lively matter, it forms a complex assemblage; "ad hoc groupings of diverse elements," that attempt to maintain relationships within a turbulent stream of other agential forces.

Agency, then, is distributed across assemblages because, "an actant never really acts alone" (Bennett 2010:21). She goes on to describe assemblages as "living, throbbing confederations that are able to function despite the persistent presence of energies that confound them from within. They have uneven topographies, because some of the points at which the various affects and bodies cross paths are more heavily trafficked than others, and so power is not distributed evenly across its surface... " (Bennett 2010:23). Assemblages are emergent, open-ended and continually becoming something else. They are a "mosaicked" material with emergent properties that operate differently than any individual part. Humans, then, are a particular kind of assemblage of active materials—we are "walking talking minerals" (Margulis and Sagan via Bennett 2010).

Karen Barad's agential realism offers another perspective on nonhuman agencies, focusing on entanglements between the observer and observed. For Barad, "agential cuts" between things, or subjects and objects, are produced in intra-action. In her words,

> "The notion of *intra-action* (in contrast to the usual "interaction," which presumes the prior existence of independent entities/relata) represents a profound conceptual shift. It is through specific agential intra-actions that the boundaries and properties of the "components" of phenomena become determinate and that particular embodied concepts become meaningful" (Barad 2006).

For Barad, things and boundaries between things exist only within broader phenomena. Thus, bounded things represent an "exteriority within phenomena," a local effect within a global happening. Phenomena with particular effects, rather than matter with particular qualities, compose the primary units of reality. It is through phenomena that variable agencies are enacted and "humans" can interact with "stuff" with particular outcomes. Thus, her account seeks a performative understanding of matter; one that investigates what matter *does* rather than what it *is*. By formulating phenomena as the primary unit of reality, she moves away from theoretical frameworks like semiotics or linguistics that begin with stuff and root meaning to that stuff. Meanings still exists, but Barad highlights how they are always contingent the conditions of intra-action.

The backgrounds of Bennett and Barad highlight different facets of active materials, but both resonate with each other. For Bennett, questions of material agency seek application in political theory, in understanding who is to "blame" in any particular event. She seeks a political framework that promotes sustainable behaviors by attending to the lives of nonhumans. For Barad, questions of subject/observer relationships are rooted in science studies and aim to trouble dualist conceptualizations of science as the study of one true reality that is objectively observed. Here, Barad clings to the need for boundaries between things of different kinds in order to allow for cause and effect, but seeks a greater role for the observing subject and observational apparatus in producing those differences. Both positions hold that agency is complicated and can never be itemized and attributed to separate entities. Instead, they assert that agency forms a topology across assemblages or intra-actions. Effects, agencies, and doings are emergent from complex arrangements of active and intermingling human and nonhuman forces.

In regards to my own project of describing making as inquiry through creative expansion, each position makes a different set of aspects clear. Barad's provides glimpses into the role of tools or apparatus and the way they produce relationships between humans and nonhumans. It helps designers retain an idea that there *is* a power differential between humans and nonhuman stuff, but that differential is not assigned to each entity a priori. Different arrangements of humans and nonhumans may reveal different power differentials. The designer of tools for making can be conceptualized as Barad's scientist creating apparatuses that produce phenomena that make particular differences and boundaries between things evident. This position is quite freeing because it allows artists, designers, and makers of all kinds to think beyond the world as a given place and opens a space to consider new and provocative conceptualizations of reality. In this sense, Barad's notions of intra-action tie into Gaver's view of how designs create multiple realities (Gaver 2012) as well as broader programs of critical (Dunne 2008) and speculative design (Dunne and Raby 2013).

Bennett's vital materialism highlights issues of perception and how humans come to sense their worlds as active. It is not enough to say that the world is filled with active stuff, but recognition of this is necessary in order to foster more ethical behaviors in everyday life. As she writes, "The capacity to detect impersonal affect requires that one is caught up in it. One needs, at least for a while, to suspend suspicion and adopt a more open-ended comportment. If we think we already know what is out there, we will almost surely miss much of it" (Bennett 2010). Creative expansion and making, in this view, can be seen as a tactical maneuver to provoke people to become "caught up" in the vibrancy of nonhuman materials. A point she acknowledges by saying, "artisans (and mechanics, cooks, builders, cleaners, and anyone else intimate with things) encounter a creative materiality with incipient tendencies and propensities, which are variably enacted depending on the other forces, affects, or bodies in which they come into close contact." Makers and designers of tools for making who take this into consideration are led to question how tools shape material experience. A tool for engagement with vibrant materials places a primary value on enchantment and other time deepening strategies that can cultivate attention towards nonhuman creativity. Thus, Bennett's framework links into existing design programs oriented around aesthetic experience (McCarthy et al. 2006; Wright, Wallace, and McCarthy 2008) and slow technology (Hallnäs and Redström 2001; Hallnäs and Redström 2002).

Inquiry is Morphogenetic

New materialist theorists seek an alternative to a hylomorphic model of making, in which form is seen as something that is given to matter from the outside. The hylomorphic model renders materials passive, implying that the movements they perform and the shapes they take on are not born of the materials themselves, but imparted to them by another actor with creative agency. In Ingold's terms, "Whenever we read that in the making of artefacts, practitioners impose forms internal to the mind upon a material world 'out there', hylomorphism is at work" (Ingold 2013). To contrast this hylomorphic model, Bennett, DeLanda, and Ingold draw from a view of making as "morphogenesis," a term that originates in the philosophy of Deleuze and Guttari. Morphogenesis describes a process by which form emerges from active materials, thus, nonhumans can be understood to be creative as well. Since all materials are understood to have an animating drive or energy that

propels them into continual states of becoming, the generation of form is not linear or goal directed, but nomadic. As Manuel DeLanda describes,

> We may now be in a position to think about the origin of form and structure, not as something imposed from the outside on an inert matter, not as a hierarchical command from above [e.g. hylomorphism] as in an assembly line, but as something that may come from within the materials, a form that we tease out of those materials as we allow them to have their say in the structures we create (DeLanda 2004).

While new materialists argue that all making is morphogenetic, DeLanda's passage highlights that humans have a choice in how they perceive what they do when they make. These perceptions can range from hylomorphic to morphogenetic positions. When making is approached as hylomorphism, a separation between maker and materials is imagined and the human occupies a position from above, handing down form onto stuff. Many point to Modernism as an exemplar of hylomorphic ideals in making. Within Modernist traditions the "artistic genius" was ultimately seen as the giver of form. He, typically, is able to impart his vision on the world. This is perhaps best illustrated through the practice of Frank Lloyd Wright, who continually designed buildings to suit his vision rather than pragmatic functioning within the landscape. For instance, Wright buildings typically showcase flat roofs in areas with heavy snow, which makes most buildings prone to continual leaking and repair.

Wright's *Fallingwater* offers the most poignant example of the "consequences" of engaging a hylomorphic approach in a morphogenetic world. Fallingwater, a residence designed by Wright in 1935 located in Bear Run Creek in upstate New York, is arguably the most famous architectural landmark constructed in the past century. The house stunningly juts out over a waterfall and has several design features, like narrow hallways that open onto expansive windows, that inspires feelings of awe for nature. But the beams that support the house and hold it above the creek are cracking and have required nearly $11 million dollars of repair in order to keep the house from succumbing to the forces of the creek (Wald 2001). While the house offers a visceral experience of nature, it also ignores nature's ability to thwart human plans. It is the hallmark of a man-made form imposed into a world of active materials and the active materials taking their toll on the structure.

Ingold points to the separation of design from construction as the locus of a hylomorphic impulse in architecture, since the pre-planning of the form, apart from nature, creates an implicit disconnection. The designer, without the material experience of construction, is unable to develop the tacit knowledge that allow him to collaborate more productively with nature. Herein lies an implicit focus on sustainability that argues that working *with* materials, as opposed to acting on them, leads to the production of forms that can last longer or form more harmonious relationships with their surroundings. Yet, despite its structural flaws Fallingwater continues to persist in time, although with substantial help from human preservationists. As long as the building is loved and cherished by humans, it is likely to be sustained in some form similar to the original structure. From a temporal perspective, Fallingwater can be seen to be just as enduring as something created through a morphogenetic approach to making, say, an adobe home. Fallingwater can also be seen as

promoting environmental sustainability in some regards. Present day building materials could feasibly withstand the forces of the water in a way that the materials of Wright's time could not. Perhaps it was Wright's vision that inspired the development of building materials that formed more symbiotic fits with the environment. Furthermore, the feeling of awe or enchantment of nature inspired by the building could be seen under Bennett's framework to foster sustainable behaviors in inhabitants by bringing them into connection with the lively forces of nature around them. In my opinion, a morphogenetic approach differs in the way in which the form serves nonhumans. Fallingwater ultimately serves and is sustained by humans. The adobe structure, while also serving humans as shelter, readily persists in its environment with less human assistance and energy. Thus, a morphogenetic approach can be seen as more sustainable in the sense that it respects a broader set of human and nonhuman actors.

The Fallingwater example also presents a tension between morphogenetic design approaches and traditional notions of innovation. Despite its flaws, Fallingwater is still considered one of the most innovative buildings of the century. As Wald writes in the New York Times, "For American architecture aficionados, Fallingwater is the Leaning Tower of Pisa, venerated for its structural flaws" (Wald 2001). The crumbling of Fallingwater is understood by some architects as a necessary cost of being ahead of ones time. Different approaches to making foster different benefits and limitations. While I agree with Ingold and DeLanda that all making is morphogenic, approaching making as though it were hylomorphic may have the advantage of producing grand future visions as opposed to sustainable solutions for the present. In response to Ingold's criticism of the separation of the designer as planner and maker as builder, there are benefits to *not* having a tacit understanding of the building materials involved. For example, Wright may have been better able to imagine structures of the future precisely because he was not deeply engaged in the resistances and forces of the materials that were engaged to realize his vision. The visions he created may well have directed others to do the "dirty" work to create materials that could sustain such structures.

Morphogenetic approaches to making are capable of producing a different quality of forms with a different functionality, highlighting a set of conditions that hylomorphic approaches leave out. Where hylomorphic modes of making focus on visions for a frictionless future, morphogenetic modes turn towards friction, embracing it as a way to push designs beyond what is conceivable in the human mind alone. A morphogenetic approach resists a desire to impose the future on the present and instead looks laterally, expanding our peripheral vision of the forms that could thrive within the conditions currently upon us.

Inquiry Happens through Correspondence with Active Materials

Inquiry through creative expansion is best understood through a morphogenetic lens because it foregrounds how materials of the world shape human makers. Creative expansion is not goal driven, but represents a general mode of being present to the world and receiving the lively impulses from the things around us. In one sense, inquiry works towards a "beginner's mind," a term originating from Zen philosophy that seeks a practice of receiving the world as it is as opposed to what we think it should be (Suzuki et al. 2011). An intentional movement towards naivety is echoed by Ingold who describes a morphogenetic approach to making as "an art of inquiry…To practice this method is not to describe the

world, or to represent it, but to open up our perception to what is going on there so that we, in turn, can respond to it. That is to say, it is to set up a relation with the world that I shall henceforth call correspondence" (Ingold 2013, 9).

Ingold's concept of correspondence is a rigorous attempt to explain how inquiry takes place in making. It begins with distinction between objects and materials. Objects are regarded as closed, fixed, and more or less stable. We know objects from the outside. When we come into contact with objects, we can touch them, but not feel them. Alternatively, materials are open, mobile, and lively. Correspondence, then, is the process by which a human maker enters into the flows of a material, feeling and thinking *with* the material in order to produce forms. In his words, "In the act of making the artisan couples his own movements and gestures – indeed his very life – with the becoming of his materials*, joining with* and following the forces and flows that bring his work to fruition (Ingold 2013, 31-italics added). Joining with materials entails a mutual forcing of the material onto the maker and the maker onto the material. In correspondence a maker and their materials find themselves porous to the currents of energies of the other. Through a mutual forcing the maker and material are molded. The maker becomes sensitized to the life of materials, internalizes this experience, and is able to draw from this tacit knowledge to inform future endeavors. This view of making attempts to move from an *inter*-active perspective, where humans and materials are considered as separate entities and humans hand down form onto materials, towards and *intra*-active perspective where the performativity of materials is foregrounded and form emerges from the resonant agencies between humans and nonhumans.

Broadening Correspondence to Include Material-Semiotic Forces

Ingold's correspondence goes a long way towards capturing a vision of making as inquiry but his account of making focuses chiefly on form at the expense of substance—it is missing an attention to what it might mean to make something in any particular way. Making is more than physical interactions between human and nonhuman bodies. It can also drive and be driven by meaning. As we make, we can come into contact with things and phenomena that give rise to particular interpretations which affect the subsequent moves we make. For instance, as we paint on a canvas, we may see the colors and shapes in formation as references to other artists or styles of painting. These interpretations are rooted in the material behaviors of the paint as much as the histories and associations formed between the shapes on canvas and the shapes they reflect. The painter can leverage those references to give rise to a particular material and cultural "forms" within the painting they produce.

In order to understand the role of meaning in making, I attempt to move Ingold's concept of correspondence from an account centered on material experience to an account centered on material-semiotic experience. Semiotics describes the study of signs and a sign, as Charles Pierce writes is "something which stands to somebody for something in some respect or capacity" (Pierce via Kohn 2013). Anthropologist Eduardo Kohn offers an application of Piercian semiotics that makes space for life and thought beyond the human (Kohn 2013). He illustrates Pierce's three classes of signs with examples that demonstrate how semiology can be thought about beyond the human. Icons are the first class of sign. Icons are signs that are like the objects to which they refer. Kohn describes the Quichua word/sound "tsupu,"

which mimics the sound of a body falling into water, as an icon. The second class of sign is an index. An index points to something else or signals an association between two things. Kohn illustrates this with the sound of a branch breaking which, to a monkey, is an index that suggests a potential danger and leads the money to flee. Indices, "impel their interpreters to make connections between some event and another potential one that has not yet occurred" (Kohn 2013, 33) The third and most complex sign is the symbol. Symbols, "refer to their object indirectly by virtue of the ways in which they relate systemically to other such symbols. Symbols involve convention" (Kohn 2013, 32). Kohn places symbolic representation, like words within language, as a uniquely human affair. Words in language become meaningful to us by way of our broader understandings of letters, grammar and language. While parts of Pierce's semiology pertain only to humans, we can also see ways to extend meaning beyond the human.

In suggesting the term material-semiotic, I am attempting to frame nonhuman forces as capable of affecting human action through two modalities: physical force (like those exerted by a material upon the maker) and mental forces (like symbols experienced through conscious reflection). The term material-semiotic has been used in Actor Network Theory (ANT), which addresses the co-shaping of stuff and culture, the material and the social. "The configurations we see present in the world emerge through 'networks' of material and semiotic actors" (Law 2008). While key terms of new materialisms, like actant, draw from ANT, theorists of the new materialisms tend to approach questions of nonhuman subjectivity from a different angle. Haraway's concept of a "material-semiotic actor" offers a different perspective than ANT's, which has been engaged in the specific context of creative practice. New materialist scholar Barbara Bolt contextualizes the term within a critical reflection on the role of tools in creative practice,

> Haraway argues that the agency of the world is central for revisioning the world and refiguring a "different" politics of practice whereby the tools of practice are not merely used to achieve an end and matter is no longer resource to be used by humans in order to make an artwork. The central term in Haraway's elaboration is the material-semiotic actor. This actor may be human or non-human, machine or non-machine. What is critical to her position is that the material-semiotic actor actively contributes to the production. Thus an "object of knowledge" is no longer a resource, ground, matrix, object, material or instrument to be used by humans as a means to an end. Rather an object of knowledge is an 'active, meaning-generating axis of the apparatus of bodily production' (Bolt 2007)

This passage calls attention to the capacity of lively materials and signs to produce, in a sense, their makers.

In order to solidify the role of the semiotic in making, consider the following example. In an interview, artist Janine Antoni describes a photograph titled *2038* (Antoni 2000), an image of herself bathing in a trough with a cow that appears to be nursing from her breast. She describes how she was inspired to create the piece after noticing the similarities between

troughs and bathtubs (iconic reference). This similarity presented Antoni with an opportunity to explore the common relationship between humans and cows (the matter-sign affects her idea/action). She focused on the act of nursing because, "I was really thinking about the Virgin Mary and these images we know of her. The Virgin Mary isn't allowed to do anything physical…the only thing she's allowed to do is nurse. And I was thinking…how does that image [of the Virgin Mary] affect my ideas of motherhood: that idyllic moment we know from those paintings but also from Pampers ads of mother and child." (Antoni 2014) In this quote, we see a symbolic reference emerging through a juxtaposition of iconic and indexical references. Viewers, with varying levels of art historical knowledge, can interpret the image within the conventions established by their own experiences with cows, nursing, photography, and so on.

What makes this material-semiotic reading slightly different than a traditional semiotic analysis of an image is the attention to the signs in formation and the way those signs and the materials of the situation (cameras, cows, troughs) coordinated Antoni's actions. While it is fair to say that in this example attention to signs is taking precedence to attention to materials, material forces are still present. Antoni is not approaching making as an exploration into the materiality and capabilities of photography and film (as one might say of someone like Man Ray), but exploring how photography, film, and the scene at hand can act as a conduit through which conceptual notions of iconography and femininity are developed and explored. The signs are the material and the materials are significant. Where a traditional semiotic analysis may have deconstructed the image through the lens of what it represents and may continue to represent, the material-semiotic analysis highlights how matter-signs act and shape decisions throughout moments of production.

In Antoni's descriptions of her process, we also see making take place as a practice that winds through everyday life. Ideas Antoni has without a camera present synthesize and materialize into the compositions she stages in front of the camera. In this sense, making cannot be fully understood in the moments of production—when the maker begins crafting a particular medium. Through the production of works of art and photographs, new perspectives and sensitivities are cultivated that shape what people notice in their everyday lives. These "noticings" then feed into subsequent acts of making. In the process, makers are joining with the flows of materials (cows, tubs, film, etc.) while also joining with the flows of signs. Thus, inquiry in making is not only directed at material knowledge (e.g. how to work with clay), but the nature and being of cultures (e.g. exploring concepts of femininity, male gaze, or motherhood).

Like other materials that Ingold describes, signs are active and lively. They exert "forces" upon a maker that shape their perceptions and actions. In the processes of making, makers can morphogenetically participate in the flows of the material-semiotic in order to tease out emergent forms and meanings. Anne Balsamo applies Barad's agential realism into the domain to interaction design to describe how designers (one kind of maker) craft meaning through an intra-active framework (Balsamo 2011). She writes, "The practices of designing constitute a specific set of intra-actions that make the technologies intelligible." Her adaptation of Barad focuses on the iterative nature of intra-action and how "an intended

purpose, a set of meanings, and an already specified relationship to the material world" emerge through "sedimented" layers of intra-actions. By focusing on the iterative nature of intra-actions Balsamo asserts that inertia connects particular meanings to particular assemblages of humans and nonhumans. As we intra-act with the world, we open access to previous intra-actions, draw connections, and derive meaning though those connections. These meaning are active in the sense that they are always subject to being uprooted or changed, "Intra-actions may be strongly constrained by sedimented layers of previous intra-actions, but they are not strictly determined by those previous intra-actions" (Balsamo 2011, 37).

To relate this back to Antoni's photo example, the meaning a viewer draws from the image will be based on their personal experiences and worldviews. These meanings are not contained in the picture, but emerge though the interplay of the references contained in the work and the viewers' personal experiences and bodies of knowledge. The photo is a kind of apparatus, layered with intra-actions that affect a viewer in ways that Antoni cannot determine. The image, and whatever assemblage of signs it bundles together, will be "banked" within the human viewer, a new layer atop many others, perhaps changing the way the viewer thinks about cows and dairy in the future. In this sense, the signs and their relationships to each other become reworked in each subsequent intra-action. Just like clay, debris, and wind, signs are mobile and flow between humans and nonhumans.

Brian Massumi, reflecting on Deleuze and Guttari, offers a description of meaning as force. In a move similar to layered intra-actions, he discusses meaning as emergent from a "network of enveloped material processes" (Massumi 1992). Using the example of a woodworker creating a table, he argues that signs envelope potentials, "Signs are qualities (color, texture, durability, and so on). And qualities are much more than simply logical properties or sense perceptions. They envelop a potential—the capacity to be affected, or to submit to a force…, and the capacity to affect, or to release a force…. The presence of the sign is a contraction of time. It is simultaneously an indicator of a future potential and a symptom of the past. It envelops material processes pointing forward (planning; being a table) and backward (the evolution of the tree's species; the natural conditions governing its individual growth; the cultural actions that brought that particular wood to the workshop for that particular purpose" (Massumi 1992, 10). Where the concept of layered intra-actions emphasizes stability and permanence, Massumi's description highlights signs in action. In this way, he paints a picture of making as a process of tying together diverse material-cultural pasts to give rise to a array of possible futures. He creates space for intentionality by arguing that all possible futures, including the paths not taken by the maker, become meaningful in the objects makers produce. These objects, Massumi argues are interpretations as opposed to texts to be interpreted: "Interpretation consists in developing what is enveloped in the sign. The woodworker brings the qualities of the wood to a certain expression. His interpretation is a creation, not just a physical object, but also of a use-value, a cultural object, a table for steak and potatoes" (Massumi 1992, 11). While both Balsamo and Massumi highlight making as a process of working through histories of meaningful associations of material-semiotic actors to suggest possible futures (or "technocultures" in Balsamo's text), Massumi's view foregrounds the ability of matter-signs to be in continual becoming. There is no single interpretation or meaning that a designer specifies as correct,

but the designer's interpretation becomes one of many possible interpretations of a culture and use values.

What to do with Dualist Semiotics

Before I go on, I want to address a possible role for dualist accounts of semiotics. While it might be tempting to throw out theories that place a central focus on humans as the producers of meaning, such a move may not be necessary. Dualist accounts can still provide important, yet partial, accounts of meaning and matter. Consider cultural theorist Dick Hebdige's book *Subcultures* in which he analyzes the style choices made within British subcultures of the 1970's to formulate a theory of style (Hebdige 1979). He argues that unpacking histories of particular fashion elements can reveal latent ideologies and hegemonies that characterized life in Britain at the time. The book looks at elements of style, like glam rock make-up, Edwardian coats, or safety pins to describe the histories and associations that are evoked by these style elements and how those histories were deployed to create possible futures. The way he describes meaningful constructions of style highlights the nature of signs as emergent, indeterminate, and mobile. But what these accounts sideline is the role of the material itself in shaping the statement. Attention to the availability of the safety pin and its ability to pierce and hold a collection of things together is downplayed in order to favor the human use of the pin.

If we were to pull Hebdige's theory into this project, we can see that it informs a very crucial part of the intra-action between humans and nonhumans that takes place in making. We simply need to augment such accounts to seek a greater role for the materials in shaping the events that emerged. Since design researchers are always working with materials to produce artifacts, materials already figure more prominently in inquiry than traditional observational methods of ethnography or historical research[2]. In doing so, pure semiotic accounts like Hebdidge's may be well positioned for reflection and refinement through interaction design practice[3]. By making room for the force of meaning alongside the force of materials in correspondence I broaden the scope of Ingold's field of inquiry. Inclusion of the material-semiotic allows inquiry into culture, society, stuff, and self. Through the unpacking and repacking of bundles of meaningful materials we can ask questions about the nature-culture in which we are embedded within and create forms with particular material and conceptual impacts for others.

How Including the Force of Signs Reconfigures Correspondence

Including attention to material-semiotic forces refigures Ingold's original descriptions of correspondence. Recall Ingold's distinction of objects versus materials. Objects are seen to

[2] Many respected anthropologists are arguing for increasing engagement of materials and sensory experiences in studies of culture. For instance, Ingold's *Making* is ultimately an argument for the value of material practice as a metaphor and method for anthropological inquiry. Similarly, a recent publication on "Design Anthropological Futures includes reflections from interaction designers and anthropologists to explore artistic interventions in ethnographic practice (Smith et al. 2016).

[3] I recently used Hebdige's account of style as a lens though which to examine the material-semiotic interpretations of a novel textile display (Devendorf, Lo, et al. 2016).

be inert, passive, lifeless, and closed where materials are active, lively, mobile, and open. Because things are open humans can join with and correspond with them. Early in his book, Ingold asserts that the difference between material and object is: "…a difference of perspective. Householders might think of pots and pans as objects, at least until they start to cook, but for the dealer in scrap metal, they are lumps of material" (Ingold 2013, 19). This quote places materiality in the object in action. The pots are objects until they are engaged in the act of cooking, thus becoming material.

Ingold suggests that some things make their object-ness or material-ness more apparent. This appears most prominently in the way that he compares two artworks, Henry Moore's *Warrior with Shield* and Simon Starling's *Infestation Piece (Muscled Moore).* He describes Moore's bronze cast statue as one that presents itself as an object, "closed in on itself, immobilized, presenting only its bronze-hard outer surfaces to our sight" (Ingold 2013, 91). Alternatively, he presents Starling's piece, which consists of a recreation of Moore's *Warrior,* which had been submerged in a lakebed and covered with mussels, as one that is readily perceived as a material. In his words, Starling's piece "seems to extrude itself into the surroundings, literally oozing from every pore, as though opened up from the inside…the figure may be repulsive to look *at,* but at least we can look *with* it" (Ingold 2013, 92). At the level of the optical experience it is easy to see how Moore's *Warrior with Shield* appears static and permanent while Starling's is obviously in formation. But if we also consider the semiotic force of each piece, then we can see both pieces as alive in different ways.

Though it presents itself to us as static, we can recreate the movement of Moore in the markings on the body of the sculpture. We can "join with" the histories and conditions that may make the piece meaningful in our own life. We can imagine the warrior as someone we know, a veteran, or someone else who has battled with disease, loss, or opposition. In this sense, the closed, unmoving, persistent nature of the bronze medium may serve a particular function, suggesting endurance, or strength. While these flows are not as readily perceived as being in motion, they have an ability to exert conceptual or semiotic force upon us. They may change our feelings about a situation and suggest that a new perception as possible. The "material flux" of Moore's *Warrior with Shield* is not a physical change in state, but a multiplicity of interpretations of the piece. The artwork is in a continual state of becoming as people experience it in different times and cultures. Thus, Moore's *Warrior* is as much open and alive as Starling's, and the very existence of the piece in the book attests to the ability for the piece to live on and draw meaning from experiences beyond the author's intention.

Furthermore, when we consider Moore's reflections on his process of creating *The Warrior*, we see all the marking of making as an emergent process of correspondence with material-semiotic actors. Moore writes about the creation of Warrior as follows:

> The idea for The Warrior came to me at the end of 1952 or very early in 1953. It was evolved from a pebble I found on the seashore in the summer of 1952, and which reminded me of the stump of a leg, amputated at the hip. Just as Leonardo says somewhere in his notebooks that a painter can find a battle scene in the lichen marks on a wall, so this gave me the start of The

> Warrior idea. First I added the body, leg and one arm and it became a wounded warrior, but at first the figure was reclining. A day or two later I added a shield and altered its position and arrangement into a seated figure and so it changed from an inactive pose into a figure which, though wounded, is still defiant... (Henry Moore Foundation 2016)

Moore's description reveals a morphogenetic process of creation including signs among other materials. Experiences with a pebble, a memory of Leonardo, and the body of the Warrior in formation all "exerted" forces on Moore which in turn, directed his forces on the figure. Thus, Warrior emerged from a variety of forces including physical materials like bronze as well as the "force" of meaningful memories.

Corresponding with Material-Semiotic Forces

In much the same way that things make their object-ness or material-ness more or less perceptible, Ingold also seeks a role for tools in setting up the conditions for correspondence. He offers the term "transducer" to describe things that set up a correspondence between two (or possibly more) entities. He illustrates this through multiple examples: a kite that slacks and pulls against a person's hands sets up a correspondence between the person and the air; a potter's wheel, which pushes clay into the potter's hands sets up a correspondence between the human and the clay. These "transducers" scaffold a relationship of correspondence between a human and a material by "convert[ing] the ductus – the kinetic quality of the gesture, its flow or movement – from one register, of bodily kinaesthesia, to another, of material flux" (Ingold 2013, 102). A transducer might be understood as a material amplifier, or an apparatus that somehow animates a material in such a way that the human can perceive its flows as bodily sensation. If we treat everything as a material and make room for semiotic as well as physical forces then we can imagine transducers as something that can also create a links between conceptual ideas, or impulses, and material flux. These links work in two ways, with material flux also pushing back on the maker, shaping their ideas.

The inclusion of semiotic force allows us to challenge another example provided by Ingold. In reference to transduction, he describes two modes of writing a letter, by hand and by computer or typewriter, and argues that writing by hand sets up the conditions for correspondence more readily than typing on a computer:

> The very movement by which the hand tells, when it holds a pen, is annihilated when it strikes the keyboard, for it leaves no trace upon the page. The correspondence of gesture and inscription, of hand and line, is broken. The words of typescript may of course tell you how to move, and even how to feel. They may instruct, like a diagram. However, as assemblies of letters, the shapes of which bear no relation to the percussive or impressive gestures entailed in their transfer to the page, they are static and immobile. (Ingold 2013, 122)

For Ingold, the hand-written letter offers the writer the ability to "join with" language in a way that the typescript does not. But I see typing as an act that sets up its own correspondence with language, yet, one that sets up a different set of actions and perceptions of language. There is no single "true" or "authentic" object called language that handwriting is uniquely able to access—making by hand is no more authentic than making by computer. Within design contexts it could be more productive to question which material-semiotic forces are in correspondence rather than whether or not correspondence is happening.

Consider the difference between a hand-held router and a mechanical computer-numeric controlled (CNC) router. Both tools offer the ability to hollow out sections of wood along paths. The hand-held router requires that a human "steer" the tool, pushing it through the wood in order to cut out particular shapes. The CNC router removes the hand, and mounts the router to a mechanical gantry system that steers the tool through the material, offering no force feedback to the human. With the hand-held router, the user is able to feel the wood as it is being cut. If the router hits a knot in the wood, the maker can feel the kickback through the routing tool. Furthermore, the user must attend to the tool through the length of production, focusing on the action at hand. A CNC router may also hit knots in the wood but the user is not given an opportunity to feel the effects of that event, yet, they may see or hear the tool responding to the knot. The relatively motionless and unfeeling user *is* able to create precise shapes that they may not have the ability to create by hand and the attention they once may have spent attending to the tool and material, they now spend attending to the software that is "driving" the tool. The "feel" here is rooted less to the sensations vibrating through a handheld tool and into a human body, and more towards a conceptual feel of the interacting forces between digitally specified plans, machine, and wood. Both systems impose constraints and the constraints lead to different sensitivities. The hand-tool offers a heightened sensitivity to the forces produced through the joining of power tools and wood and the CNC router offers an attention to the interplay between digital workflows and wooden products. While it might be tempting to argue that one sensitivity or perception is better or more authentic than another, both offer opportunities for inquiry. Yet, inquiry is directed towards different sets of human-tool-material relationships. If a maker's goal is to understand wood so as to mill more productively and encounter fewer errors with regard to a predictable output, then hand tools may be better suited to their goal. If a maker's goal is to question the interactions between digital files and physical forms, and the way in which the machine unpredictably reacts to knots and grain in the wood is seen as productive, then there may not be a need to feel the material by hand.

Ingold's view that technologies that separate the human from physical material are somehow inauthentic or deficient resonates with present day "hybrid" design agendas. Hybrid designs seek symbiotic engagements with digital and physical materials that reinstate the human as a thinking feeling actor. For instance, Alec Rivers has developed a hand-held CNC router that a user drives along a general path while a high-precision CNC head cuts the details (Rivers, Moyer, and Durand 2012). While this technology is certainly interesting, and some might argue that this technology offers the "best of both worlds," I don't see it as objectively better or worse than any other technology for milling. Each new tool sets up potentials for particular meanings and forms to emerge. While Rivers' tool allows something to be done in

a new way and creates a space for the maker to feel the wood while the machine cuts, there are still cases when one might prefer an analog-router or hands-off CNC system as it brings the maker into material-semiotic correspondences that may be better suited to their own lines of inquiry. In short, creating systems that put the maker in a position to feel the materials for the sake of feeling the materials may not always be better in an objective sense. In some cases, the feeling human might even get in the way of embracing what might be uniquely possible with the technology.

If we root correspondence to physical sensation then we also limit the role technology can play in fostering correspondence with the world because digital technology typically offers rather thin physical sensations. Thus, technology becomes something that must operate in service to human sensation if it is able to support correspondence. This is echoed in Ingold's claim that "a technologically enhanced sensitivity, brought into the service of hands-on engagement with materials in making, could genuinely enlarge the scope of humanity, rather than further eroding it" (Ingold 2013, 124). This view implicitly places the human in a position of privilege and reinforces categorical divisions between human and machine, implying that the machine must preserve humanity. By making room for material-semiotic correspondence, I see an opportunity to move away from the human body or hand as the sole locus of correspondence and inquiry. As we move away from technology serving the human, we may be able to imagine new roles for technology that consider the mutual construction of human and machine and make a new set of perceptions about technology and society available.

Towards Tools for Creative Expansion

If we accept making as a process of cutting paths through a complex fields of material-semiotic actors and actants, then the fabrication tools HCI creates can begin to shift from a narrow focus on a mastery with a single material, to looking up, down and around at the lively world within which the maker is embedded. This fertile landscape of material-semiotic entities to be joined with and juxtaposed offers a multitude of sensitizing forces. While the existing impulse in fabrication design that engages nonhuman forces is towards fluency, a consideration of the material-semiotic, specifically as it is engaged in experimental art practices, shows a benefit in reorienting towards naivety. Learning to see, feel, and become enchanted with the world through making a key mechanism in expanding creatively.

The following chapters move from theory to practice, looking at the design of two tools that were able to support or provoke attention to and engagements with lively material-semiotic forces in making. Such tactics reveal how both an attention to the material-semiotic forces beyond the self can create new pathways and territories for tools for making. Such territories extend beyond concerns of productivity or the realization of goals, and instead, turn towards attention and sensitivity to the world of things and their potential meanings.

DESIGNING STRANGE TOOLS TO WORK AGAINST HABIT

> Not satisfied with the suggestion through paint of our other senses, we shall utilize the specific substances of sight, sound, movements, people, odors, touch. Objects of every sort are materials for the new art: paint, chairs, food, electric and neon lights, smoke, water, old socks, a dog, movies, a thousand other things that will be discovered by the present generation of artists. Not only will these bold creators show us, as if for the first time, the world we have always had about us but ignored, but they will disclose entirely unheard-of happenings and events, found in garbage cans, police files, hotel lobbies…An odor of crushed strawberries, a letter from a friend, or a billboard selling Drano; three taps on the front door, a scratch, a sigh, or a voice lecturing endlessly, a blinding staccato flash, a bowler hat—all will become material for this new concrete art (Kaprow 1958)

Allan Kaprow, a student of John Cage, provides an example of an experimental practice that radically engages the everyday. The quote above is taken from his manifesto for a "new concrete art," which speaks directly to human sensation and embodied experience. In this quote, the "odor of crushed strawberries" and "bowler hats" are lively things and "bold creators" to be engaged in the production of art as long as the artist is able to recognize them as creators in the first place. Herein lies the first motivation of tools for creative expansion—awakening a users attention to the everyday, familiar, and habitual in a way that shifts static overlooked objects into lively and "bold" collaborators in the production of aesthetic forms and experiences. This goal resonates with Jane Bennett's claim that, in order to sense impersonal affect or thing power, one must become "caught up" with those powers. (Bennett 2010). In this sense, the aim of a tool for creative expansion is to create a situation for human and thing entanglements. In the terms of Heidegger, I seek tools that turn a world of objects into a world of things that are present-at-hand and can be questioned, and re-imagined in the present context (Heidegger 2008).

Under Verbeek's framework of technological mediation, a tool for supporting or provoking experimental approaches to making can be designed in ways that shape perception and action (Verbeek 2006). While perception and action are closely tied, this chapter focuses specifically on the perspectival dimensions of tools for creative expansion and how they can be designed so that users perceive their everyday worlds as places filled with active and lively things. By reflecting on my design and study of AnyType, a novel mobile application that was able to provoke and support attention to vibrant materials in everyday spaces, and contextualizing the design among broader tools for noticing and rethinking the everyday, I put forth guiding themes to help future designers think through how the structure of a tool shapes the lively forces to which makers attend. Even though such work resides outside of the particular realm of "maker technology," it well positioned to inform the design of tools for "making" in ways that support reflection alongside of production.

AnyType

AnyType is a mobile application that generates novel typefaces based on images and videos that users capture in their immediate environments. While the design began as an attempt to

reimagine a postcard within the realm of mobile communications, studies of the design revealed its ability to engage people in enchanting encounters with familiar things in their everyday spaces. Things like cracks in the sidewalk and moulding in historic buildings became subjects offering interesting textures and meanings. Typefaces created with those textures prompted deeper reflection on the emergent symbolism of text composed of several locally captured textures.

Motivation

My motivation for developing AnyType was to map the experience and meaning associated with sending and receiving postcards in the domain of digital communications. While similarly motivated work in HCI sought to create a postcard-like experience through skeumorphic representations such as capturing a photo and writing messages by hand on a tablet, I took a different approach that started by considering the existing material-semiotic experience of a postcard, and using that as a guiding post for directing development for an application on a digital tablet. I saw postcard sending as meaningful for a number of reasons including the site-specificity of the card, the work a sender had to go through to select and send the card, and the visible marks of wear that signify the postcard's travel across time and space. I acknowledged that communication with digital tablets is much different and will never *be* a postcard, but I wondered how the design of an application could capture the idea of a sender as someone in a unique location at a unique place in time who is doing work to create something specifically for a receiver. At the same time, I wondered how such communication could be uniquely positioned to leverage the potentials and existing practices with mobile tablets.

After much brainstorming with my advisor, Kimiko Ryokai, we saw correlations between our goals and a growing community of designers creating custom typography from everyday objects. For instance, designers have created fonts by arranging and photographing toy trains (Bureau Bruneau 2016) or strips of bacon in the shape of letters (Hargreaves 2016). We imagined that an application for creating custom typefaces form everyday objects could be a novel form of communication because it supported specificity (the sender would choose particular objects for a receiver) and labor (it would require effort to locate and create the typeface). Furthermore, we attempted to preserve site specificity by requiring that users create typefaces while physically situated in the environments, instead of creating them from images and videos that were previously captured.

Implementation

When a user launches the AnyType application on a mobile tablet, she is guided through a series of five steps. At each step, she sees the camera view on the screen of her device. AnyType places an overlay of one of five shapes (a long vertically oriented rectangle, a shorter horizontally oriented rectangle, a wide arch, a narrower arch, and a small square) that can be combined to create the letters of a typeface onto the camera view, like a keyhole on the screen (Figure 1a). A message on screen prompts the user to, "find something that fits into this shape." The user then looks through the device in order to fit an object into the

Figure 1: A) The user looks onto their environment through a shaped frame and captures (photographs) an object in this shaped frame. B&C) After capturing the shape, the user can edit by drawing a custom outline for the shape. D&E) After capturing all five shapes, the user is presented with their personal alphabet in the composition mode. The letters can be dragged, scaled and erased with fingers. F) In the history view, the user can see the original photographs that were used to compose each letterform

shaped frame shown on her screen. When she finds something that fits into the frame, she hits a capture button to save it and moves to the next step.

After capturing objects within the five shapes, AnyType automatically creates each letter of the alphabet by arranging the shapes and presents this alphabet to the user in a row on the top of the tablet screen (Figure 1d and 1e). This moment may come as a surprise, as it is the first time the user sees all of their shapes automatically transformed into different letterforms. The user can then drag letters from their personal alphabet onto a canvas, creating a composition. Their composition may take the form of a message or graphical artwork composed of the different letters. The user is given the ability to position, scale, and erase letters from their canvas. And at the press of a button, the user can email their creation to others.

In video mode, the user captures up to five seconds of video in addition to a photo for each shape. At the composition phase, the user can add letters to the canvas and press a letter to animate the video "within" the shape. Animations resemble stop-motion animations and replay in sequence within the letter. If the user captured a moving car within each of the shapes, that car could be animated in such a way that the car is driving along the letterform going from one shape to the next. For instance, in the letter "V," AnyType would animate the left side of the "V" (the car would be seen "driving" through the left side of the V) and then animate the right side of the "V" (the car drives through the right side).

When the user or recipient presses and holds one of their finished letters on the canvas, they is taken to the "history view" that shows how the different shapes were arranged to compose that letter (Figure 1f). Clicking on one of the letter's shapes reveals the original photo or video from the point of capture. This view is designed so that the user or recipient

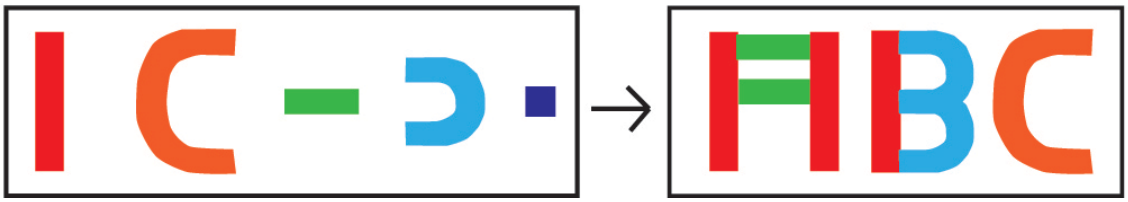


Figure 2: Each letter of the English alphabet can be created through a combination of the five shapes on the left. The AnyType application asks the user to identify those five shapes in their environment and algorithmically recombines the captured shape elements into the letters of the alphabet.

of the composition can access a history of how each letter was made. For instance, the user may capture a gear from a bicycle in one of the arched shapes. Without the added context of the entire image of the bicycle, someone other than the creator viewing the typeface might not be able to discern what it is. The history view allows the creator to reveal this context to others. This act of hiding and revealing where images or videos came from adds an additional level of storytelling and possible surprise between the creator and the receiver.

During the capture phase, each of the five shapes can be edited. Within the shape, the user can draw with their finger to outline the contours of her captured object. For instance, they might capture a tower with a pointed roof in the long rectangle shape. They can use their finger to outline the tower and its pointy roof in order to remove the background and emphasize the pointy roof. The resulting shape looks as though it was cut out with scissors. This editing can greatly alter the look and feel of the resulting typeface (Figure 1b, 1c).

Study Design

I recruited participants through university email lists and craigslist.com. In early studies, no restrictions were placed on who could participate. As studies continued, I made selections of participants to create a wider range of ages and experience in artistic disciplines. I conducted both a short-term study (1-2 hours) and a week-long study with AnyType. Each study provided distinct insights into different aspects of the system. In the short-term studies, I observed how people interacted with the system in order to gain insights about their initial reactions to the application. Through the week-long studies, I studied how AnyType was used in the daily lives of users. Participants used the same version of the AnyType in both studies and all study participants were provided with a tablet to use. All participants who participated in the week-long study also participated in the short-term study. At the beginning of the short-term study, I asked participants to describe any formal training or extensive experience they had in a visual arts field in order to tease out how people with particular training or propensities used the system.

In short-term studies, I collected data in the form of participant observation and semi-structured interviews as I outlined in chapter 2. The week-long study design was slightly modified from what I described earlier because I was not physically present with the participants during the week they used the application. Instead, I met with the participants at the end of the week and asked them to describe each typeface and composition to me in chronological order. I asked the participant to talk about their thoughts, feelings, and ideas

that gave rise to the composition and solicited elaborations as necessary. This method shares similarities with diary studies, where the AnyType composition logs served as the diary, and projective interview techniques (Collier 1957), where each composition acts as an elicitation method to prompt past memories of creation. Together, each method allowed me to gain insight into motivations for each creation and provoked discussions about participants' lives and state of mind at moments in which I could not be present. Professor Ryokai conducted and video recorded three of the post-long term study interviews. I reviewed those videos during my analysis.

Short Term Study

16 people with varying degrees of art experience participated in the short-term study only. 5 of these participants described themselves as artists (had formal training, degrees or significant job experience in visual art or design field), 2 as hobby artists (practice art for fun but no formal training), and 9 as non-artists (do not partake in any visual art activities). Their ages ranged from 23 to 52 with a median age of 28.

The short studies lasted approximately 90 minutes. I met each participant at a mutually convenient location (e.g., public parks, college campus, city streets). During the study, I video recorded each participant as they traveled around capturing shapes for their typefaces and made compositions from those typefaces. I asked participants to create 5 compositions using AnyType. Each time, they were asked to try a new feature (e.g., basic mode, video mode, using the history view). I also encouraged participants to "think aloud" while using the application and occasionally asked them to describe their reasoning ("I noticed you chose to use video for this typeface, why?") or how they catered the subject matter to the intended recipient ("Why did you capture X for Y?").

Week-Long Study

10 people participated in the short-term and week-long studies. Their ages ranged from 18 to 57 with a median age of 28. 7 female and 3 male. 3 described themselves as artists, 3 hobbyists, and 4 non-artists. After completing the short term study and expressing interest in participating in the long-term study, they received an Android tablet with AnyType installed and were told they could take the tablet wherever they went. They were asked to create at least two typefaces a day, one video mode and one photo mode. After the week passed, the participants were interviewed for about an hour to share their stories and experiences with AnyType and to describe each typeface and composition.

Findings

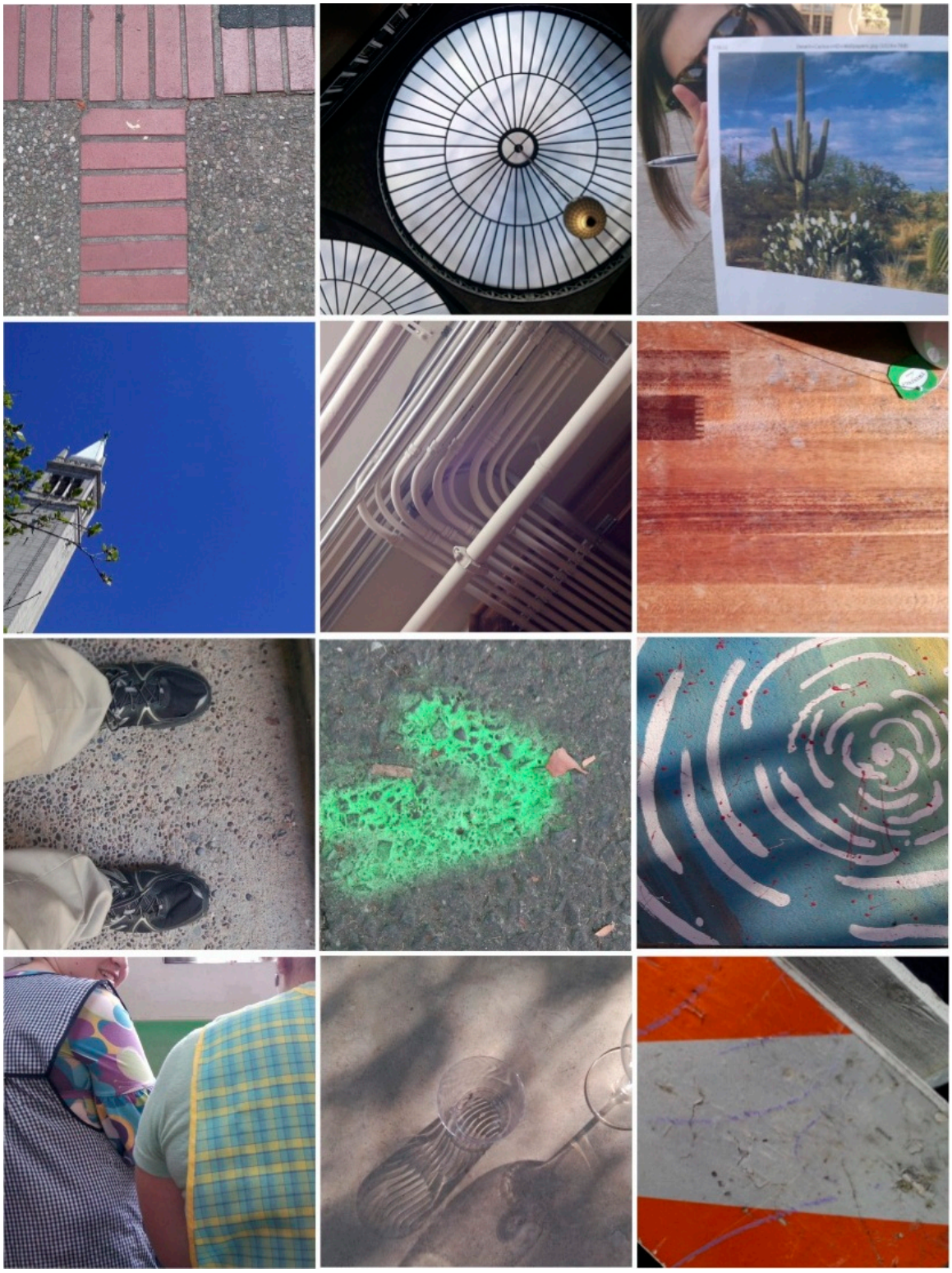
Some of the participants' approaches to AnyType began to reflect the processes of sensitizing and open-ended experimentation that characterize creative expansion. The effect the application had on a participant's attention towards noticing and responding to lively forces in their environment was emergent from the interplay between multiple design features. Specifically, the strangely shaped frames led these participants to explore their environments though a new lens. Rather than seeking rectangular scenes as they may have

with a camera, they began to seek what many referred to as "textures" within their environment. The strange fames, in combination with the lack of a zoom feature, led participants to physically move and at times, contort, their bodies into new nooks and crannies of familiar spaces. After capturing the five shapes and seeing the typeface that emerged, participants began to reflect on the gestalt of the messages they created and the symbolism that emerged by juxtaposing text and image. In each following section, I offer more detail to support these connections between the design and experience.

Noticing Nonhuman Agency in Familiar Spaces

The strange frames led some users to shift their strategies for composing photos and videos. After learning about the app at a high level and learning that it could transform images into typefaces, many participants proceeded to imagine the kind of typeface they would like to generate. They would capture elements in the frames in much the same way that they would capture images with a still camera, looking for complete rectangular "scenes" that were indicative of a particular thought or idea. Since many of the studies were conducted on the UC Berkeley campus, many of these first fonts were "Berkeley" fonts containing iconic images that would represent Berkeley—The Campanili, Sather gate, etc. The strange frames made this task particularly difficult as the heuristics for capturing good scenes shifted when the frame was not the usual rectangle they expected. They tended to be underwhelmed by the results since the font they created did not look like the font they imagined.

By their second attempt, most participants shifted to a more experimental approach for generating fonts. Many commented that they were shifting their approach to capture interesting "textures" as opposed to complete objects. Brian described how he imagined using AnyType on a trip to Paris, "...you could send somebody this sort of postcard of a place, where all these typeface captures are all the textures behind these iconic sites and places." Alex commented, "If our goal becomes, lets capture textures around here, then you realize…oh, there are all these textures that I walk right past." Textures were not complete compositions, but decontextualized visual elements in the environment, like brickwork, leaves on a lawn, cracks in the sidewalk, or individual LED pixels in a digital sign board. Where scenes and objects might be classified as macro perceptions of the world, textures represented an attention to the micro elements—parts that disappear when we see the whole. As we see in Brian's quote, textures fall "behind" more prominent objects. The shift in attention from whole to part, or macro to micro, led many users to find sources of inspiration in the details of things they typically overlooked. Brian commented, "This brick is boring and rectangular but it has new value in the context of this application." As Jane walked around her workplace creating fonts she remarked, "I work in this building everyday and I never realized that those railings were blue or that this building has those reliefs outside." Seen through the framework of making as material-semiotic inquiry the shift in attention from object to texture represents a thing-ing or activation of the environment through a shift in perspective. When a part is separated from the whole, it is able to take on a new life apart from the object that it previously served.



Physical Immersion in Vibrant Things

The lack of a zoom feature had the effect of physically propelling some users into parts of familiar spaces that, in most cases, they would have no reason to explore otherwise. As they struggled to fit shapes into frames and moved closer and closer to objects to make them fit just right, they found themselves in stranger spaces with more vibrant things and textures to notice. In combination with the video mode, responding to the lack of an automatic zoom feature turned some users towards more playful and performative engagements with AnyType. The zooming user, moving through their environment with a tablet in front of their face, doing things people do not normally do with a tablet, was an invitation for some participants to take on a particularly playful character or persona. This element of play led some to stage events to be captured in the application. Andrew, capturing a font in video mode, raced down Mission Street in San Francisco with the tablet in front of his face. Karen coordinated with her friends in a bar to record sound bites within each shape and composed a raucous happy birthday greeting for a friend. In these staged events, people performed alongside of things. In another examples, Kate animated the lights on her lab equipment to capture a performance of the equipment in her font. She also captured the howl of the BART train entering the station during her rush hour commute. The "C" shape presented Jeff with an idea to create a video font at a frozen yogurt shop. He purchased a yogurt, placed an Oreo in the center to create an arched shape and worked with a stranger next to him in line to capture video of the sprinkles as they fell onto the yogurt. The lack of zoom, in concert with other design features, resulted in the physical movement of the body in space, leading some users of AnyType to appear to their publics very differently than a person tucked behind the screen of their mobile device. Some embraced this difference to stage ad hoc performances, others hid behind the shelter of the typical mobile device to stealthy capture textures. In both cases, the unusual and public nature of the application infused the interaction with a sense of playfulness or self-consciousness.

Where strange frames targeted a change of perception in familiar environments, the lack of zoom targeted action. It provoked some to engage in their familiar environments along new trajectories, which crosscut the familiar or habitual, and, while traveling, to explore the textures offered in the topographies of concrete, bushes, or pipes. It pushed the body into unusual spaces where new inspirations could be discovered and captured. The physical movement of the body into the micro-topographies of the everyday can be seen as a complementary way of becoming physically caught up in everyday matter. As users crouched to capture one thing, they sometimes became caught up with another thing that they noticed along their journey. For example, a noticing of pipes in the ceiling led Anthony to notice other intricate shapes in plumbing systems, leading to a font composed of the winding pipes found in South Hall, a historic building on the Berkeley campus where Anthony worked.

Composing Messages with Lively Representations

The composition phase, where the typeface was presented to the user and the user was invited to create a composition, is when an attention to lively things and textures took a particular focus on the meanings of those lively things. Because AnyType was capturing representations of the world, and not actual pieces of sidewalk and grass, the imagery of

Figure 3: Some strange positions users adopted to capture textures

things was ultimately the material being crafted. The images juxtaposed within each letter were thought about in relationship to the message and the sender, prompting some users to ask questions about the multilayered meanings within their messages.

The juxtapositions that emerged when shapes were composed into letters and compositions presented different semiotic impressions. For some, the idea of crafting meaning was somewhat new. Jeff, a participant in the non-artist category, described his approach to the application as follows: "I guess I was trying to see this as how to capture some aspect of the experience or do something interesting with the texture and try to like evoke some emotion or feeling with the elements that I was looking at." I then asked if he felt like he was able to do that and he responded, "Yeah surprisingly, if someone told me that up front, I would have been pretty skeptical." Jeff felt the most confident in his ability to express emotional qualities of a place in the creation of a typeface he called *Flower Power* (Figure 5). In this typeface he captured textures from the plants in his garden, such as close ups of veins on leaves and the stalks of sunflowers. Jeff said, "I think Flower Power is when I kind of realized, I could imagine starting off a message about this with my garden like 'hey—here's my garden,' but also it's like this little weird mixture of the serenity you have when you're dealing with a garden in something that you're writing." AnyType, in Jeff's experience, can be understood as a sensitizing mechanism that helped him recognize and rework a world of lively meanings. He is not composing fonts purely based on their form, but how those forms

Figure 4: A typeface Jeff created in his garden

operate as indices to the way those plants become present in his life—the power of his garden to shape his experiences.

Because the application allowed fonts to be generated very quickly (about 5-10 minutes on average) participants were keen to quickly "sketch" typefaces, take chances, and reflect on the surprising meanings that may or may not have emerged. The iterative nature of the application and way it placed a premium on micro-textures led some users to create fonts that I judge to be more artistically sophisticated than their earlier fonts. Monica's experience is one example. Monica, a high school student, used AnyType to record two typefaces within her family's restaurant. The first typeface contains images one typically associates with a restaurant, from pots and pans to food on a table. In a later typeface, she captured a video from the aprons of all the women working in the restaurant. Each apron was made of a different checkered or plaid-patterned fabric (Figure 6). Monica captured short video clips of these fabrics moving around as the women worked in the kitchen. She also captured video from her own apron. In Monica's typefaces, we see how her experience with AnyType moved from capturing objects that generally characterize a restaurant (food and cookware) to a set of images that communicate the essence of her lived-experience working at the restaurant. The videos of the aprons moving within the word "Delilah" (her sister's name) resemble an Impressionist painting in the way that they capture the emotion and ephemerality of a fleeting moment.

Figure 5: Two fonts created by Monica in her family's restaurant. The top row is an early composition, featuring items that we traditionally associate with restaurants. The bottom row shows a later font, representing to a greater degree the lived experience of working in a restaurant

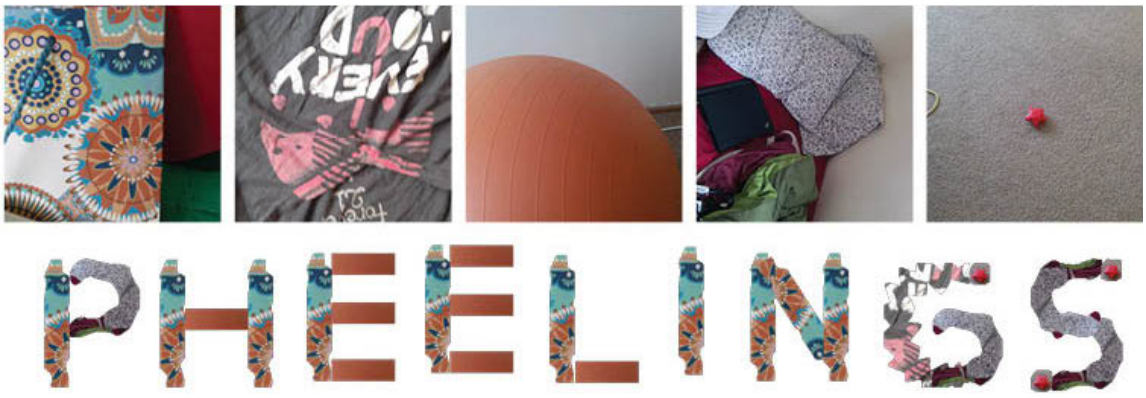


Figure 6: Melissa used AnyType like a diary and created this "Pheelings" composition from textures around her room to reflect on her life in college

Some users in our week-long studies approached the application as a diary for personal use while others saw it as a communication platform. For those interested in communication with others, the composition phase implicitly brought in the idea of a viewing public, or a set of interpreters to the meanings in the composition. This conceptual introduction of the "other" was a productive mechanism for participants to consider possible interpretations of their compositions and the way in which texts, images, and letters intermixed to produce a particular kind of meaningful gestalt. For those who saw the application as a personal diary, the symbolism of decontextualized textures fostered a reflexive conversation with their own emotions, a way to connect to and understand an "other" that is inside of themselves. Melissa created a composition using the word, "pheelings" and said, "It is about the way, I guess, life sort of changed now that I'm in college. More than the objects being important, [with AnyType] I looked for patterns. The text for it is feelings and I spelled with a 'ph' because I like that word a lot. I used the shapes to say—to give different feelings to it." Melissa used the editing function to customize the outlines of her shapes. She drew each shape in order to evocatively connect the shape and the image within the shape to a kind of feeling. She also found that she could use color as a way to represent feelings and emotions saying, "There was this bag I had that had this bright blue and orange pattern and that seemed like excitement and like new things and positive things but then I had a shirt that was black and red and it's kind of conflicted about things and not able to consider things as much as if it were going at a more glacial pace." For Melissa, the practice of capturing patterns created a prompt for her to engage her emotions during a life-change in a meditative way.

Perspectives on the Value of Noticing and Attending to Nonhuman Forces

While some participants use AnyType to become attuned the agency of others and engaged those agencies in radically open-ended ways, other did not. Some participants found the application to be frustrating. One stated that she would have preferred to create typefaces from images she already captured. Another participant, Andrew, was so frustrated by the

camera's resolution that he was unable to do anything he found particularly worthwhile. While finding a tablet with better resolution could have supported Andrew in a better experience with AnyType, changing the application or adding a mode that allowed users to work with previously captured photos would have undermined the ability of AnyType to create a unique experience.

The participants who found joy, pleasure, and personal value in AnyType had actively engaged methods of what I've been calling creative expansion to various degrees. For instance, Ann, a designer, described many experimental approaches that she engaged to "stretch her brain" and she saw AnyType as a tool that could be engaged to this end. She found herself using the application continually on walks and tinkering with compositions while talking on the phone. She noted that she was equally interested in the fonts produced as she was in the experiences and surprise connections that could come from the processes of production. Others, like Jeff who created the garden typeface, found themselves asking questions about things and meanings that they had never previously considered.

While AnyType was able to provoke and support practices of creative expansion for some, others were simply not interested in the work or outcomes of the processes. While it might be tempting to see an extra function as a way to reach more people or to be more "user-friendly," such an approach would offer a path of less resistance that could undermine what I see as the value of the application. To elaborate, the application is challenging and a bit deceptive. In the context of a user study, where users are committed to using it a particular amount of time, many were able to find value in the challenges. Yet, had this been a commercial application, it is unclear whether participants who eventually found value in the application would have given it the time of day. Offering an "easier" path towards composition, in my opinion, would have lessened the likelihood that someone would accept the challenges posed by AnyType.

What it means to Work Against Habit

In terms of creative expansion, the most valuable aspect of AnyType was its ability to shift a user's attention towards lively material-semiotic forces in the form of "textures" captured in their immediate environments. The strange frames, lack of zoom, and overarching task of message sending, created an experience where reflection on lively signs and symbols took precedence over physical sensations. While people were not corresponding with the textures themselves (they were not touching and manipulating the grass, leaves, or bricks), they were corresponding with *representations* of those textures. These representations acted as an intangible force or flow with which users worked. Through the gathering of textures and juxtapositions of textures in letters, the given meanings of everyday things became unsettled. Rather than thinking *about* what a texture symbolized, AnyType created a way to remix and recombine textures, allowing some users to see how meanings were always contingent on the associations and arrangements of the underlying representations. Some participants reflected on the reverberations of meaning that intra-acted between the meanings they assigned to textures, the way AnyType juxtaposed those meanings, and the way in which their recipient might assign meaning to the compositions they created. In these moments, active and unique

meanings materialized in the space between the user, the application, and the recipient. Thus, people were not thinking *about* what bricks or grass mean objectively, but what kinds of meanings bricks or grass could suggest within the context of this particular application. Examples from our study include Jeff's reflection on how representations of his garden could be suggestive of his own sensory experience within his garden, or how Monica shifted her restaurant composition from one that was formed of representations that typically describe restaurants towards one that captured her affective experience within her family's restaurant.

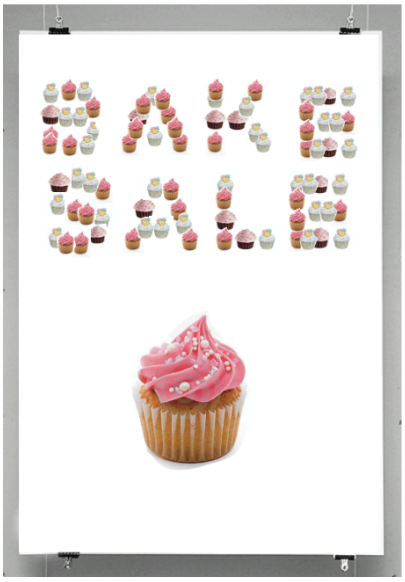


Figure 8: A typeface that could have been produced with an alternative design of AnyType

To strengthen the case that users were thinking *with* can corresponding with active material-semiotic forces in AnyType, it might be productive to consider the alternative—how AnyType would look differently if its design were focused on thinking *about* meanings? Imagine that AnyType's design used an algorithm to place objects cut out of photos within letters of an alphabet. I speculate that if this were the case, meanings would seem much more fixed because people would select the representative elements *after* they conceived of the idea. Users would be likely to engage familiar associations with their intended composition. Consider the "Bake Sale" composition (Figure 8). Here, we could imagine a user approaching the application with an idea for a Bake Sale poster in mind. They would then consider what kinds of things could be representative of baking and use that to reinforce their original message. In this example, the idea that a cupcake represents baking is unchallenged and alternative ways to represent baking remain at the periphery. By focusing attention on micro-textures and making it difficult to pre-plan a typeface or composition, AnyType prompted people to reconsider their own ideas, and search for alternative forms of representing familiar ideas.

Resonance with Pedagogical Art Exercises

In the practices of participants in the study, thinking with representation manifested in questions like "how do my clothes represent my emotional state?" or " how do I communicate the serenity I feel in my garden?" Such questions mirror established pedagogical questions within art and design education that are targeted towards teaching people how to see. For instance, in John Berger's *Ways of Seeing,* a foundational text in many art programs, he notes, "We only see what we look at. To look is an act of choice" (Berger 2009). Artist and educator Corita Kent writes,

> It takes practice for us to recover this ability to see, or before that, to gift of wanting to see. For so many years we have been learning to judge and

> dismiss—*I know what that thing is-I've seen it a hundred times*—and we've lost the complex realities, laws, and details that surround us (Kent and Steward 2008).

Both quotes challenge the given-ness of sight to highlight its subjectivity. They also present what Ingold might refer to as a "haptic" relation to sight, where one not only looks at things, but also actively looks with the visual phenomena of the world and treats visual imagery as a material with to manipulate. What makers choose to see allows them to become sensitive to varying phenomena and tune into particular histories or currents that made the artist take one particular expressive path over another. AnyType's particular effect of structuring sight towards micro-textures resonates with typographer Inge Druckery's pedagogical approach. In her words, "…you can't come up with ideas if you don't see first. What interested me was to teach students to see in an abstract matter. So, not to see an object, but to see it as something round or square, something textured or smooth" (Severny, 2012). Similarly, the design of AnyType mirrors a device described by Kent as a "finder:"

> [The finder] is a device, which does the same things as the camera lens or viewfinder. It helps us take things out of context, allows us to see for the sake of seeing, and enhances our quick-looking and decision-making skills.
> An instant finder is an empty 35mm slide holder. Or you can make your own by cutting a rectangular hole out of a heavy piece of paper …You can then view life without being distracted by content. You can make visual decisions—in fact, they are made for you. (Kent and Steward 2008)

In its design and effects in user experience, AnyType is surprisingly similar foundational lessons in creativity and art making which spans multiple domains of practice. This suggests on opportunity for designers interested in creative expansion to engage existing pedagogical lessons as a design resource. Descriptions of such assignments can be found in pedagogical texts from schools as diverse as the Bauhaus (Kandinsky 1979) to the Rhode Island School of Design (Maeda 2013) or draw from artists' own perspectives (Monument and n+1 2012) and reflections on practice (Stiny 2008). Further inspiration can be drawn from creative workbooks like the *Artist's Way* (Cameron 2002) or Corita Kent's *Learning by Heart* (Kent and Steward 2008). These foundational concepts of art, design, and visual literacy more broadly, that transcend any individual difference. They also highlight that process of making are not given or inborn, but grow from increasing sensitivity and perspectives on the everyday.

A common theme in the exercises listed above and the design of AnyType is the key role working against habit plays in fostering a fresh attention to the familiar. AnyType was able to prompt an attention to the textures and their associated meanings because it broke habits in relationship to how one captures photos, physically traverses everyday spaces, and composes text messages. Habit and routine render particular perceptions and actions automatic and when makers are working in automatic modes it becomes difficult to hear and connect with the lively forces in their surroundings. The particular combination of the design features in AnyType and the way participants responded to them in their own practice resulted in a strange and unusual activity that kept most users attentive to frequently overlooked aspects

of their daily environment and created a perceptual opening in the maker upon which the lively qualities of the everyday could strike.

Working Against Habit vs. Defamiliarization

The particular perspectival effect created by AnyType resonates with existing literature on defamiliarization. Literary theorist Viktor Shklovsky coined the term "defamiliarization" to describe phenomena where the familiar and habituated world can be encountered in unfamiliar ways. The function of art, or poetry in his case, was to defamiliarize language in order to reawaken a reader's sensations to the familiar; "Habitualization devours works, clothes, furniture, one's wife, and the fear of war … Art exists that one may recover the sensation of life; it exists to make one feel things, to make the stone *stony"* (Shklovsky 1917). To defamiliarize is to somehow make an object into a thing, shifting focus from how we know it towards how it affects us. It is a way to stripping away the automatism by which people describe what something is and, instead, allows the thing to strike them in ways that give rise to different understandings or uses of that thing. While AnyType resonates with this concept, the way it reawakened attention to the everyday was not so much oriented towards making something known seem unfamiliar, but by shifting attention to parts of the everyday that were simply overlooked because of habit. Thus, the everyday was not so much made to be unfamiliar, but enriched by an acknowledgement of many textures that appeared when one broke from their usual patterns of movement and habits of seeing. To clarify, where defamiliarization is a tactic for making something familiar seem strange, working against habit is a design tactic that can give rise to strange tools and workflows that enliven the familiar and highlight how there is more there than typically meets the eye. It is the strangeness of the tool that results in attention to the otherwise overlooked.

While there are subtle differences between the concepts of defamiliarization and working against habit, its worth noting that some of the design tactics that have historically been engaged to the effect of defamiliarization can also be seen as working against habit. Designer Anthony Dunne describes how defamiliarization can be achieved in interactive systems through "constructive user-unfriendliness," which he describes as "form of gentle provocation" capable of producing poeticized objects and aesthetic experiences with those objects: "The poetic can offer more than simply enriched involvement. It can provide a complex experience, critical and subversive" (Dunne 2008). A similar poetic effect emerging from a constructive user-unfriendly was on display with AnyType and attending to aspects of the everyday that one typically overlooks often results in an aesthetic experience. In this light, working against habit in the design of tools can be seen as a pathway towards engaging with the ineffable (Boehner, Sengers, and Warner 2008) and enchanting (McCarthy et al. 2006; Bennett 2001) within processes of production. In the context of creative expansion, these mystifying effects do not get in the way of making but are key portals through which sensitization, action, and reflection can coincide. Furthermore, both terms acknowledge qualities of experience that emerge when a user comes into contact something irreducible and beyond comprehension. In the framework of thing-power, such terms describe the "strange combination of delight and disturbance" (Bennett 2001) that characterizes encounters with nonhuman life that exceed human understanding.

Contextualizing AnyType among Broader Tools that Target Perception

Habits come in many forms and the particular habits that a tool or tactic breaks and the way it breaks them can enliven particular material-semiotic forces. In an effort to support designers who might be interested in pursing this design direction without being overly prescriptive, I draw AnyType in line with other examples of tools in HCI and tactics in art that have been engaged to similar effects. Within practices of experimental art, one can see elements of working against habit in Guy Debord's Theory of Dérive, which he describes as a practice for succumbing to the "psychogeographical flows" of urban spaces (Debord 2000). Dérive is a practice of moving through the city and tapping into a latent potential that the everyday tends to make invisible. In Debord's words, "…psychogeographical attractions discovered by dérivers may tend to fixate them around *new habitual axes*, to which they will constantly be drawn back" (Debord 2000 - Italics Added). For Debord, dérive was a practice for attending to life beyond spectacle—an attempt to connect with people and places in a fashion unmediated by representations. By moving along trajectories that crosscut the habitual the subject is situated in a position with a new attentiveness within familiar spaces. These alternative flows have the effect reconstructing how we encounter the everyday. In terms of intra-actions, strange prompts for engaging the familiar can give rise to different boundaries between things and reveal new potentials and connections that might not otherwise have been made apparent. Debord notes that constructions that reawaken attention to the familiar are not random or purely based on chance—strangeness is always positioned against the "usual" and it is crafted in order to tune into frequencies of everyday life that typically lie outside our habitual bandwidth.

Existing tools in HCI reveal patterns of crafted strangeness and working against habit towards particular effects. Placing AnyType in line with these other projects draws out deeper connections between the structure of a particular design, the habit it wishes to break, and the lively things that become active as a result of that breaking. Two such examples are *Context Cameras* and *I/O Brush*. Context cameras are digital cameras where photographs are augmented in real time with sensor data from the present context. Multiple variations of such cameras have been explored by Ljungblad (Ljungblad et al. 2004) and Håkansson (Håkansson and Gaye 2008; Håkansson, Ljungblad, et al. 2006; Håkansson, Gaye, et al. 2006). I/O brush, created by Ryokai et al., is a tangible paintbrush that allows children to paint with textures and colors captured in their immediate environments. Both applications report findings in line with those of AnyType whereby users began to attend to something in familiar spaces that they typically overlooked.

In studies of context cameras, Ljungblad et al. describe how participants using a camera that augmented photos based on movement and sound, "used different strategies to affect the sensor input, such as whistling or clapping" and "[found] sources of noise or movement in the environment" (Ljungblad et al. 2004). Another study includes findings with a user that, "plans and takes his context pictures differently than he does with a regular camera, as 'There is a whole new dimension, sound and movement to experiment with'. According to him, you 'sometimes experiment with different movements and settings to get the effects you want', even becoming more physical with the camera than usual: 'You move yourself or

the camera more. Spin it etc. just to try to get a fun effect'" (Håkansson, Gaye, et al. 2006). Within studies of context photography, the habit I see designers working against are practices of capturing photographs. All aspects of photography are held stable except for the change in the viewfinder created from manipulations from sound and movement. In seeking new manipulations, participants traversed their environments with a heightened sensitivity to the lively sounds and movements of everyday things.

Ryokai et al. study I/O Brush in a kindergarten classroom and describe how, after being introduced to the brush, "the children's eyes were everywhere—searching for things to try out and immediately reaching out to try them" (Ryokai, Marti, and Ishii 2004). They describe how children searched their classroom for colorful items and reacted to the interface's soft brush as a prompt to capture textures from their own and other children's bodies: "Children brushed over not only their own bodies, but also asked if they could sample their friend's face, skin, and hair. The softness of the brush tip seemed to allow children to play around with different shades and patterns they can find on their body." While I/O Brush was studied with children who may be more naturally inquisitive, it also revealed how children began to see their environment differently, in terms of painterly qualities like color and texture. I/O Brush broke habits around color selection for painting by the swapping paints for colors, textures, and movements in everyday spaces. Like context cameras, the overall process stayed as faithful to painting as possible. The thing-powers enlivened by I/O Brush took a variety of visual forms, leading children to attend to the color and texture of everyday things in ways they may not have before.

The Everyday as Material

A similarity in all of these designs as well as practices of dérive is that they frame the "everyday" as the media of inquiry. In this capacity, these tools or approaches become well suited to respond to a wide variety of "raw" material-semiotic entities in the sense that they have somehow become removed from their usual contexts of interpretation. Yet, a user cannot specifically choose the materials they engage, they must locate them. Thus, the tool becomes an orienting device creating what Debord described as a "new habitual axes" through the everyday. Along these trajectories chance happenings allow a maker to be struck by a material or phenomena they may not have previously noticed.

What is equally important to consider is that the user of the tool is also situated in everyday life and, thus, is subject to the attention of an audience. In AnyType, this led some users to engage in overtly performative behaviors that were likely to draw more attention. In context camera, the authors describe how photographers would work with other people to "stage" scenes to capture. In the classroom study of I/O Brush, the children responded to and pushed each other to search for new and interesting textures. In that particular case, the softness of the prototype was a prompt to explore colors on the body while offering the provider of those colors with a sensational experience. I use these points to illustrate that making does not take place in a vacuum or even the confined and focused space of a studio or workshop. While it is possible to be struck by lively things in confined spaces, having a tool that works in any setting radically broadens the kinds of materials that one can notice,

engage, and reflect upon. Furthermore, it broadens the performative roles makers can play in those spaces.

Incentives, Attention, and Perception

A unique quality of the aforementioned tools is the way that they incentivize attention to particular facets of the everyday by making the design responsive to those things. The aesthetic effects of sound in context cameras, colors in I/O Brush, or textures in AnyType created a prompt for seeking out such qualities, almost like a scavenger hunt. Whether such actions emerged from a desire to test the limits of the technology or an excuse to take different trajectories through familiar spaces, they placed the user in a state of attention to the mutual effects between the designed tool and the lively forces the tool itself was sensitive to. With AnyType, the strange frames and the common belief that the typefaces looked better when textures were captured prompted people to search for textures and shapes within those textures that they may have never noticed before. The activity of using those textures to produce written textual messages brought forth reflections on the meanings communicated by images and words in tandem. Focusing on what the design rewards in terms of perception and aesthetics, as opposed to what it affords in terms of use, could be an interesting strategy to provoke attention to the vibrant but overlooked aspects of the everyday in practices of creative expansion.

Expanding the Benefits of Working Against Habit to Fabrication Technologies

Projects like context camera, I/O brush, and AnyType resist classification as "maker" technologies. Each tool produces a particular kind of artistic digital outcomes that tends to be less visible in the present landscape of making. For instance, when attending Maker Faire or looking through the collection of projects on maker community websites like *instructables.com*, there are more examples of people building cameras or offering techniques for photography than showing the photographs they have captured. While photography or painting are certainly forms of making, they may have fallen outside of the purview of products associated with the maker movement for a number of possible reasons. It may be that the use of an existing technology is less valued than the development of a novel technology that specifically suits one's needs. Perhaps the need to have some external "product" to document an instance of making makes it difficult to showcase practices that are largely focused on expanding perception. It could also be that forums for painting and photography have always existed outside the maker movement, leading "making" to be seen as something distinct. For whatever reason, such technologies and the reflective and aesthetic engagements with the everyday they have been able to provoke have been largely overlooked in the design of "maker" technologies.

The unique benefits of working against habit, as it has been engaged in experimental art practice as well as in the design of tools in HCI, are certainly applicable to broader technologies for fabrication. The practices of seeing and thinking anew are not only

enjoyable for many people but cornerstones of art and design practice[4]. Within the ever-broadening landscape of novel fabrication systems for making there has yet to be work that frames a fabrication system as a means of exploring and rethinking the everyday. Instead, designers often attempt to create systems that leverage our familiarity and habit in order to foster more "accessible" engagements with new technological systems. In other systems, technology is seen as an enhancement to existing activities and attempts to blend into those activities without substantially changing them.

Applying the tactic of strange design in fabrication technologies could open up a new space for framing making as a dialog with the everyday and the material and cultural reflections everyday things, people, and spaces evoke. By asking makers to make differently, in strange, unpredictable or uncertain modes, a perceptual break can be created that allows them to attend to forces and ideas they may not have attended to otherwise. In this sense, we can imagine things like 3D printers leaving their stationary posts in laboratories to freely wander the world, succumbing to the unpredictable forces of everyday environments, things, and people. Questions about how tools shape our perception of materials, the way the materials feel in hand, or the forms they might take on, can motivate new sensory engagements with lively digital and physical things. I see these open-ended, vulnerable, reflective, and multi-sensory tools and the space they might create for the "bold creators of the world" to strike makers as important pathways towards broader diversity and creative development in maker

[4] Bell et al. (Bell, Blythe, and Sengers 2005) engage defamiliarization as a means of reflecting on the design of domestic technologies, arguing that it is a useful design tactic to open new perceptions in familiar spaces.

DESIGNING UNSTABLE TOOLS TO PROVOKE EXPERIMENTATION

> And what is the purpose of writing music? One is, of course, not dealing with purposes but dealing with sounds. Or the answer must take the form of paradox: a purposeful purposelessness or a purposeless play. This play, however, is an affirmation of life—not an attempt to bring order out of chaos nor to suggest improvements in creation, but simply a way of waking up to the very life we're living, which is so excellent once one gets one's mind and one's desires out of its way and lets it act of its own accord. (Cage 2011, 12)

Cage's approach to experimental practice took the form of an intentionally undirected task—an effort to work against a human desire to organize, structure, and impose order upon the world of chaotic and lively forces. By shifting his role in making from the sole author of the work to one that frames him as an orchestrator of chance events, he made room for lively forces to shape him and the works he produced in tandem. Herein lies the second motivation for tools for creative expansion—shifting the user's role from one of controller to collaborator with materials. As a collaborator, humans must be given space to shape materials and vice versa. The process and effects are analogous to collaboration between humans where growth is achieved from a mutual exchange of ideas and compromise. Within this framework, growth with nonhuman collaborators occurs when the maker is placed in a position to listen, respond to and compromise with nonhuman actors. In order to do so the maker must abandon firm goals, which inevitably silence nonhumans through the imposition of human will. This act of giving up is not easy or frivolous and it takes work to actively undo what we expect from the world in order to make room for material-semiotic forces give rise to new sensitivities and connections. With this in mind, this chapter asks how the design of a fabrication tool might make space for material-semiotic forces to strike upon and shape the maker and their products?

I reflect on this question through the design and study of Redeform, an alternative system for 3D printing that was able to make space for experimental engagements of nonhuman forces in making towards a variety of ends. While the design of Redeform takes up the call of designing against habit that I suggested in the previous chapter, the study revealed broader tactics that could be valuable in provoking and/or supporting makers in open-ended engagements with material-semiotic forces. Specifically, I suggest that Redeform's *instability*—the room it created for things to go wrong, the difficulty it presented to goal-based workflows, and the way it could be adapted to suit multiple modes of inquiry—allowed it to play a particularly valuable role in open-ended and reflective modes of making. Furthermore I reflect on how designing for instability makes space for the designer to take a more active position or subjective stance in the design, becoming yet another force within a nexus of forces in making.

Redeform

Redeform is a system that allows a human maker to receive, interpret, and execute the instructions typically provided to a 3D printer. The implementation of the system followed its own trajectory: A interest in exploring a 3D version of AnyType morphed into an idea for

a highly adaptable 3D printing system that could be used with everyday materials in everyday spaces. The project sought, from the start, to engage alternative sources of creativity (weather, nature, artificial materials) in the process of digital fabrication by resituating fabrication beyond controlled laboratory environments. Furthermore, it looked to broaden the kinds of materials that could be used in fabrication in recognition that each material, from sticks to cake batter, can be a source of material-semiotic diversity—each material brings makes a particular landscape of forms and meanings available for exploration.

Technically implementing this concept with the idea of a traditional CNC system in mind (where a computationally controlled tools adds or cuts away from materials to reveal a pre-specified form) was challenging since there is a trade off between tool-choice and material diversity. For instance, if you use a milling machine, you are restricted to materials like foam or wood that can be fastened down and cut away in a subtractive fashion. As I worked through ideas for several different tools that could maximize material choice, a spark for an idea ignited when I looked down at my hands and began to see them as tools. Hands are portable, capable of working with diverse materials (or working with multiple tools), and with the right interface, they could be controlled. Thus I began to explore the potential of a CNC system for controlling the human hand—a system that explicitly "programs" its user. I felt that such a system would be well suited to connect computational and generative design practices with the rich diversity of human production methods. Furthermore, it could work with particular materials, in contexts, and at scales that are largely to be unfeasible for 3D printers for years to come.

Aside from the functional capacities, I was personally compelled by the idea of the machine-controlled human hand because it resonates with evolving history of artworks that question human and machine boundaries. At the turn of the 20th century, Futurist mechanical performances featured actors physically performing the functions of machines like the steam engine as a method to provoke uproar and inspire rebellion in what they saw to be passive publics (Goldberg 2011). In the 1930's Jean Tinguely created mechanical sculptures, which functioned as "caricatures of the utilitarian, mechanical world, embodying Tinguely's critical posture towards technological optimism" (Tate Museum 2016). The fallible and ineffable, perhaps human, qualities of machinery have continued to be explored in and out of artistic contexts. More recently, in *Slumber*, artist Janine Antoni lives day and night in the gallery space (Antoni 1994). As she sleeps an EEG machine creates a graphical representation of her brainwaves. During the day she uses a loom to weave strips of fabric from her nightgown into a blanket by following the pattern created by the EEG. This particular work can be read as a statement about labor in the arts. It asks whether artists are geniuses by nature (as represented through brainwaves) or workers like anyone else (weaving). As a performance her labor takes a more prominent and visible role in the work. Additionally, the cyclical nature of her actions literally and figuratively weaves body and machine together, complicating perceived boundaries between those categories.

This partial history only scratches the surface of work in art that complicates human and machine boundaries by asking us to see the human in the machine or the machine in the human. In this sense, it is a concept that has persisted and become reinvented through time.

I had a hunch that taking up this theme in the context of 3D printing could offer a timely reflection on Western relationships with technology in making, as well as relationships with technology within an increasingly technology obsessed culture that would be of interest to many makers. While I saw doing 3D printing by hand as a particularly functional mode of production for particular tasks, I was equally interested in considering how the design of my tool might shape further reflection and ideation *about* fabrication technology and how it could be engaged in a critical capacity within an experimental art practice.

The design emerged from this shared interest in function and concept. In terms of function, I sought to develop the system with enough technical support so that a model could feasibly be realized but not so much support that the system worked to correct the maker or prevent errors. In terms of concept, I tried to keep the workflow as similar as possible to existing 3D printing such that "3D printing" could be engaged and represented in the work produced. Furthermore, drawing from my previous findings with AnyType I sought to create an experience that was somehow strange or uncanny, provoking questions of human and machine essence through embodied experience.

Implementation

Redeform (formerly "Being the Machine") is a system that asks humans to receive, interpret, and execute the G-Code instructions typically provided to a 3D printer in order to construct new objects, reversing the scenario of 3D printing, in which humans provide instructions to a printer that the machine must carry out[5]. In essence, Redeform makes the human user into a 3D printer. Technically, Redeform consists of a laser pointer that illuminates a single dot on a surface. The dot moves along the tool-paths generated from a digital model that the human has inputted, showing the human how a 3D printer would lay down material and inviting them to follow by hand. For the human, this feels like a game of connect- the-dots. Upon completion of the task "described" by the laser pointer, the human has sculpted a three-dimensional object more or less like the digital model they specified.

The dual consideration of function and concept gave rise to a different kind of system than what might have emerged had I considered function alone. Specifically, attending to the conceptual dimensions of following machine instructions shaped my choice to use a single dot as a guide, rather than an outline of an entire layer that a maker could fill in. An outline would have been as simple to implement and would have been more "useful" in a traditional sense. I chose to use the single dot for three related reasons. First, because a single moving point has no history and no future, the maker must focus deeply on the point while making. This focus on the point, rather than the pre-specified shape via outlines, was something that I felt would make the system more playful, open-ended, and subject to personal interpretation. Second, following the point of light can give the maker a bodily sense of the mechanics of 3D printers because guiding a maker along a path using a single point encourages the movements of the body to mimic those of the machine. Additionally, it prompts the user to work with their building materials in an uncommon way. By asking the

[5] Additional technical and operational details are offered in (Devendorf and Ryokai 2015a; Devendorf, De Kosnik, et al. 2016; Devendorf and Ryokai 2015b).

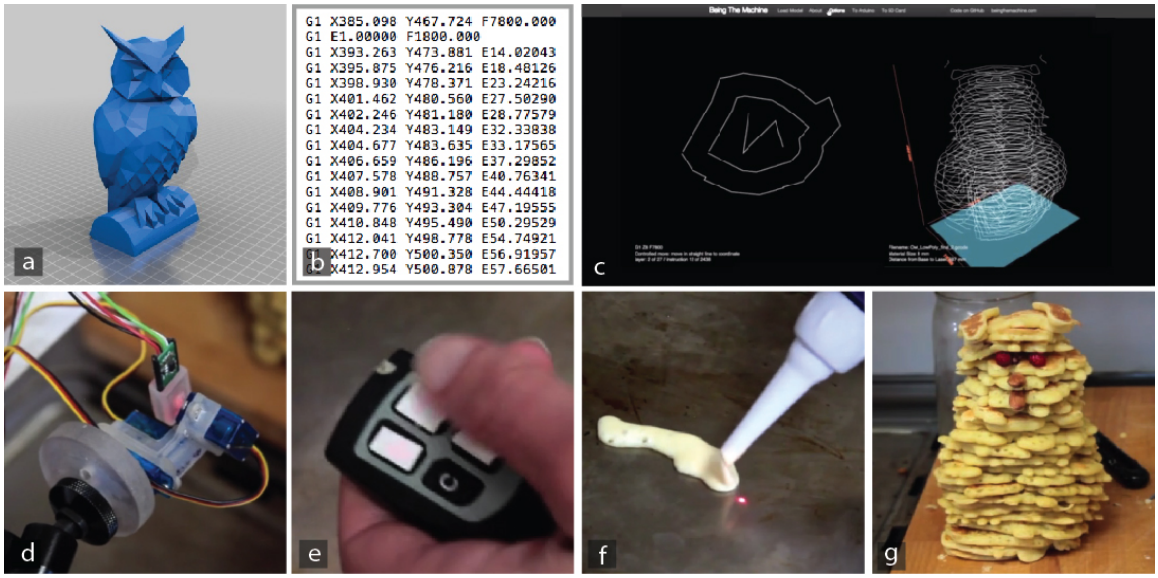


Figure 9: Working with Redeform. a. The maker selects a 3D model of an owl to build. b. The model is converted into G-Code. c. Visualization software allows the maker to view the G-Code paths generated. d. Once the maker finds the paths suitable, they can upload the G-Code to the Redeform machine, a laser pointer attached to 2 motors in a pan-tilt configuration. e. They press buttons on a key-fob to tell the machine to play or stop playing through machine instructions. f. They see instructions as a single laser point and follow the point with pancake batter on a hot skillet. g. After they follow all the paths described by the laser pointer, an object emerges.

maker to do something strange with their materials, I aimed to heighten their sensitivity to the ways materials conformed to or resisted the machine paths. Third, I felt it was important for the machine to have a unique persona and performance of its own. When the user presses "go" on the machine, the machine begins to animate the motors and laser pointer. The gears of the motors produce a low humming sound unique to mechanical parts. The sounds and motions of the machine may not play a primary role in interaction, but they become peripherally present as part of the environment of making.

Technical Specifications

Redeform consists of custom software and hardware components. The G-Code visualization software I developed allows the maker to see the paths specified by a G-Code file in two and three dimensions (Figure 9c). Using arrow keys on their computer, the maker can navigate through the instructions or layers in order to visualize the overall shape of the paths and the order in which they will be drawn. Reviewing the paths on a computer screen was intended to allow the maker to conceptualize and assess the feasibility of their structure with their given materials.

The hardware consists of an actuated laser guide, a laser pointer attached to two servo motors in a pan-tilt configuration (Figure 9d & 10). The guide can point to nearly any position on a 2D plane and I use an Arduino microcontroller to move the laser to point to the position indicated by a G-Code instruction. All of the building instructions are stored on the Arduino and the user is able to tell the system to move to the next or last instruction using buttons on a wireless key fob (Figure 9e). I used a magic arm tripod mount affixed to a

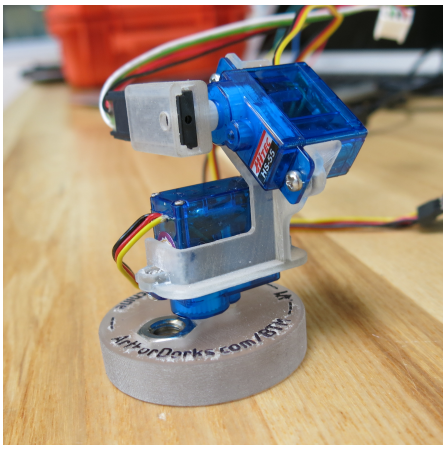


Figure 10: Redeform's Laser Pointing Mechanism

24" clamp to mount the laser guide above a building surface (table, floor, etc.). The software interface tells the maker how far they should position the laser from the building platform in order to generate a model with the specified dimensions. While a projector system could have performed many of the same functions as the laser guide, the low power usage and high light intensity of my guide offered increased portability.

To use Redeform, the maker locates a digital model and the materials with which they would like to print. Any standard digital model, like those found on *thingiverse.com*, can be used with our system. Next, the system converts the digital model into G-Code. This conversion typically takes place within 3D printer software, but freely available tools allow makers to generate G-Code files independently of owning a 3D printer. In my examples and studies, I used a software platform called *Slic3r*[6] to generate G-Code according to the specifications of RepRap 3D printers because it allowed me to customize building parameters like layer height and material width and generated simple files that used only straight-line moves (G1 instructions). The maker measures their building materials and enters those measurements to Slic3r in order to generate G-Code specific to their building materials.

Once the maker prepares a G-Code file, they import it into our G-Code visualizer, which parses and displays the paths that are described by the file. At this moment, the maker can make judgments about the structural integrity of their model. For example, if they are building a tree with branches that extend out from the base, they can look at the visualization to see if each layer will have enough support from the layer below to remain structurally sound. If not, they can go back to Slic3r and adjust the settings to add additional perimeters or scaffolding. Once the maker is satisfied by what they see in the visualization, they can upload the code generated by the G-Code visualization software to the laser guide for building.

To begin building, the maker positions the laser at the correct distance from the base (as indicated on the visualization) and pushes "next" on the key fob to queue the first instruction. The system beeps to acknowledge the command and moves the laser guide into the position specified by the first G-Code instruction. They place their material on the laser point and hit "next" to advance the laser point to the next spot specified by the G-Code instructions. They connect the current location of the laser pointer and the previous point by filling the space with their material. They follow this pattern until the laser turns off, indicating that they have reached the end of a path. The process of following the laser and building path by path and layer upon layer continues until the model is complete.

[6] http://slic3r.org/

Figure 11: Constructions I created with Redeform that were shown to participants prior to the study

Study Design

I sent recruitment calls with the subject line "Study of 3D Printing by Hand" via email to local arts groups, maker spaces, and university lists. When I received responses from participants expressing interest in participation, I responded with a short video that explained how a 3D printer works and how it related to Redeform. The video included time-lapse videos of my own process building three example models: a hand made of pipe cleaners, a vase made of live flowers (with additional images of the vase decaying over time), and a gun made of "Good & Plenty" candies (Figure 11). I chose this particular set of examples to invite curiosity and demonstrate the variety of materials the system could accommodate. In early studies, I did not restrict participation based on background or experience but as studies progressed I began to make choices about participants based on the prospective participant's background in the arts (i.e. if they self-identified as crafters, artists, or makers) and the unique perspective I felt they could bring to the study. Prior to meeting, I asked prospective participants to watch the video and send a list of materials and models that they would like to use with our system. Participants were not screened based on their responses; I simply wanted to prepare a selection of materials that might be of interest to the participants. I also invited participants to bring materials of their own to the study.

I conducted 14 one-on-one study sessions in various locations including participants' homes, studios, and indoor and outdoor spaces on a university campus. When participants arrived to the study, I asked them to complete a 15-minute introductory activity (following the laser with a pencil to draw paths on paper) to become familiarized with the process before they embarked on their own project. After they felt comfortable following the laser with a pencil, I asked them to select materials and a 3D model to build. The participants were free to choose the order in which these items were selected. In some cases, participants took short walks to survey the local environment for interesting materials. The participants selected a 3D model using *thingiverse.com*. I used the 3D model, information about the user's desires (e.g., hollow, bigger, less complex), and information about the materials to generate a G-Code file. I helped with scaling the chosen models and identifying specific G-Code options to allow the model to be completed in a relatively short amount of time (about 90 minutes in most sessions). Before building their 3D model, I told participants that there was no "right" way to use the system and that they were free to follow (or not follow) the laser point however they pleased. I also made a laptop with the visualization of the paths available for the participants to reference as they wished. I asked participants some questions about their

approach, ideas, feelings, and thoughts while they built their models. When their model was completed, I asked participants about their experience with the system.

The age of participants ranged from 22 to 43. The study call was successful at piquing the interest of a variety of makers, including 5 participants who had formal art or design training and were actively exhibiting in galleries. This class of participants had not responded as strongly in the AnyType study and I felt that this was a sign that the concept engaged in the design was, in fact, one of interest to a variety of artists. One participant who responded to the call ultimately decided not to participate, stating that she could not understand how 3D printing would help her since she was already skilled with her building materials. Another participant arrived at the study expecting to craft custom parts from metals and made the best of the situation when he realized that he was responsible for working with the materials and the quality of the resulting construction. In this sense, the call may have leveraged the technical appeal of "3D printing by hand" (as opposed to "computer guided construction" or "human-assisted fabrication") towards somewhat deceptive ends. Participants seemed to expect the system to be more controlled and accurate (for better or worse) like traditional 3D printing system. The study results reflect how some participants grappled between their expectations and the reality of the system—some found value in the difference between Redeform and traditional 3D printing and others faced difficultly in pointing to the benefits of such a system.

Classifying participants based on their artistic approach is difficult since participants identified with multiple categories of makers. While some participants identified themselves as a single kind of maker (e.g., "I'm a knitter"), others felt they took on multiple roles and sought different experiences in each role. As Matt put it, "as a maker I strive for efficiency, then as an artist I see that efficiency sometimes gets in the way of really great things." This highlights the messiness of individual practice and the ability for a single maker to take different positions as they see fit. One of the criteria that I felt could impact the participant's approach was the degree to which they might be inclined to attend to the semiotic dimensions of making. This approach to making often grows out of a formal art or design education. 5 of the participants had such training and were actively producing work for broad public audiences in the form of art exhibitions or mass-produced products. Other participants had varying levels of experience making but were less inclined to showcase the work in public venues. The study did not include any makers who were actively selling work on sites like Etsy.com or sharing work in craft communities like Ravelry.com. To this degree one might say that the sample had an artistic (as opposed to craft) bias. I was also interested in exploring what participants with advanced knowledge of 3D printing might bring to this system. Five participants had previous experience creating prototypes, custom parts, artworks, and/or figurines with 3D printers. Two of the participants were actively involved in research developing new fabrication techniques and technologies. The other nine participants knew something about 3D printers but had never used one.

The sessions varied in length between 2 to 4 hours. Most participants created one model during the study. 2 participants created two models and both had created a model that failed and were eager to try again with different materials and/or models.

Patterns of Engaging Material-Semiotic Forces in Making

In studying Redeform, I began to think of the actors enrolled in making and the relationships between actors as a kind of mobile, with some fixed parts, and others that fell into balanced arrangements around the fixed entities. While design of Redeform fixed a particular connection between a human maker and G-Code, participants were able to orient their choice of materials and models in order to arrange the activity "mobile" in a way that suited their ideal experience of making. In this way, no two "configurations" of making with Redeform were identical, and each configuration offered different possibilities, in terms of objects and experiences, to the maker.

For two participants, no suitable configuration was found and Redeform was ultimately frustrating in a non-productive way. They felt that building like a 3D printer was inappropriate for many materials and were not interested in exploring the symbolism of the technology itself. Both of these participants had extensive experience with 3D printers and felt that the system should have shown them the "right" way to work with their materials to get the form that they pre-specified.

Most other makers saw potential in the system, either as a way to work with computational models in their practice or to engage the symbolism of doing something like a machine in the work itself. The way that these makers engaged nonhuman forces also resonated with the idea of experimental practice. As I analyzed the findings and traced the way Redeform functioned within each practice, I saw it operating in two simultaneous capacities: as a "guide" that bridged computational design with diverse practices and as a choreographer of a particular kind of human-machine performance. Both practices engaged material-semiotic forces towards different effects. When Redeform was treated as a guide, participants often reflected on the role that the life of materials, in terms of their physical properties, could play in their practice. When treated as a choreographer, participants tended to focus on both the material experience as well as the meanings of such material experiences within the present cultural landscape. Thus, where guides tended to be engaged to think about particular kinds of products, choreography tended to focus on reflection of "the machine" as a culturally significant symbol. These capacities were fluid, simultaneous, and richly connected but each maker attended to these capacities in different degrees—some only referencing the potentials of Redeform as a guide and others reflecting more broadly on the meaning of making as a machine makes.

Guidance, Focus, Interpretation, and Risk

Many participants described Redeform as a "guide" that would allow them to realize computationally specified models without relying on a machine that removed them from the building process. For each maker, doing the work of building afforded particular benefits in relation to their practice. Arlo, an industrial designer, imagined using Redeform as a guide to create models that would be too difficult to track without a computer, like a large computationally faceted bear's head made from spot-welded wire or sticks, or an intricate and delicate faceted vase made from pine-needles. He felt that the translation of complex and precise computational models through more error-prone and imperfect materials could give rise to a compelling aesthetic in the objects we produced. Josh, a composer,


a
b
c
d
e
f
g

experimented with Redeform as a means of translating digitally specified models into soundscapes by placing a note at every point where the laser point stopped, creating a musical score from the model of an object. Josh saw this as a way to push his composition into new territories, and to perhaps, explore how form might give rise to particular sonic profiles that would be distinct from other composition methods. For Nina and Clare, both hobbyist artists and crafters, Redeform was a way to leverage the 3D forms stored on websites like *thingiverse.com* in processes of making by hand that they found more personally rewarding than printing on a machine.

The particular method of guiding makers with a single moving dot created space for participants to engage forces beyond themselves in the production of forms. Some described how the dot was able to focus and heighten their attention to the materials (both G-code and the selected building materials) by making it difficult to conceptualize or keep track of the larger object in formation. For some, the focus needed to attend to the materials in relation to the paths was so intense that they were unable to talk with me while building. Many valued the ability to interpret the dot, to follow it more closely or loosely, because it allowed them to engage materials with particular shapes and physical properties that they could not use in more rigid or precise systems. Finally, participants appreciated the ability for the models to be imperfect or even to break completely. The ability of Redeform's dot to promote focus and interpretation in the wake of eminent "failure," was taken by many as an invitation to work with building materials in indeterminate and experimental capacities.

Arlo, the industrial designer, came to the study with an interest in doing something outside what he might normally do, describing routine as something that worked against novel ideas. As he worked with Redeform to build a computationally faceted vase made of sticks that were "straight but not too straight" he reflected on the role of "happy accidents" in his practice and offered the following definition: "its this idea that if you pay attention to what's going on with the materials and you let yourself listen, than you will come up with ideas that are novel…because you're paying attention to what the thing wants you to do and how the material is telling you how to act…The opportunities for something surprising often come from paying attention to the unintended." Because Redeform made room for the life of materials by allowing room for breakage, he saw it as a system for capable of creating generative accidents. Furthermore, in reference to the ability to interpret the dot, Arlo noted that, "…[Redeform is] giving me freedom to make judgments, which is an important part of art and design." He went on to describe artistic judgments as the locus of unique style, a quality that is removed when making becomes overly instructed or protected from errors. Arlo provides a case of a maker who already finds values the experimental practices that have shaped this dissertation. His accounts of practice reify how such approaches matter in making and his interest in and enjoyment of the system suggests that the specific design of Redeform was productive in this capacity.

Josh's descriptions of his practice also resonated with the tenants of experimental practice that inform this dissertation. Working with Redeform prompted him to reflect on the experimental compositions of John Cage as well as medieval scoring techniques that sought visual and musical harmony by writing music upon circular scores. He used the dot to

constrain his practice in a way that he felt could be productive. Specifically, he followed the laser point and placed a note at every position where the laser stopped. In this process, he began to form deeper understandings about the structure of G-Code, specifically the idea that all models were composed of straight-line segments and thus, curves contain more points (or notes) than long straight lines. He reflected on how he would choose forms differently with this understanding, suggesting a bowl could be an interesting way to create fairly regular patterns of notes that varied in radius layer by layer. After creating his composition from a 3D model of a gun, he came up with more ideas about how 3D printing process could be interesting in the context of composition: "The idea of layers is extremely rich...I could decide that the points from the first layer are going to be pitches, the second layer is going to be rhythms, the third level is going to be dynamics, the fourth level is going to be articulation, the fifth is going to be...something else. It could start very basic and get very specific as the gun, or other object, comes into focus." While Josh had an idea of what the general patterns of the models, the specific movements the laser pointer were largely outside of his perception—creating kind of a semi-intentional constraint. In the moment of composition, Josh would enter into a dialog with G-code, making judgments about the duration of the note or pause to place at the position dictated by the machine. In this sense, G-code became the lively force upon which Josh reflected in his use of Redeform.

Clare, a hobbyist maker and DIY enthusiast, built a model of a goat's head from ivy that she had weeded out of her back yard. As she build her model she intentionally avoided cutting the ivy with scissors and instead, bent the ivy along the paths and glued them into place. This required great effort but she felt that it would help her reveal an interesting or surprising form, saying, "I did not want it to conform to the shape exactly because then I would just use a 3D printer, I wanted the materials to influence what the shape would be." Similarly, Nina, a student and hobbyist artist, created a pair of eyeglasses from magnolia leaves. When she was searching for building materials, she was attracted the visual texture of the leaves and noticed that dead leaves take on a suede like color and texture. She found the idea that her glasses would eventually decay and transition into a new texture to be interesting. As she prepared her materials for building, she took care to cut her leaves along the veins to preserve their natural curves and "poetry." She also used the strong spine of the leaves as something that could add structural integrity to her model. Nina's interest in decay and preservation of the curvature of the leaves attend to the unique life of magnolia leaves to shape the form of her glasses. While both Nina and Clare were less inclined to describe making as a "practice" of discovering novel ideas they found pleasure in "relinquishing control" and having deep sensorial engagements with materials towards meditative and playful effects.

In each case, forces beyond the maker were engaged to spur new ideas or simply push back upon makers in ways that they found personally valuable or enjoyable. While some of these experiences could have been equally supported through alternative designs, like one that projected an outline of all the paths instead of a point, there were features of experience that were specific to the choice of a single dot. The dot had the ability to focus attention on the movements and connections between the materials at any given point in the construction process. It also resisted a human's desire to see the "whole" model, thus allowing makers to

focus on the connections between parts. Similarly, as a procedural instruction, it structured an order between the steps. This promoted particular interpretations and responses that may not have emerged from building from a projected and complete layer.

Reflecting on Symbolism to Making like a Machine

Where Redeform's "guide-like" qualities allowed for different possibilities in terms of function and material experience, there were also ways that the symbolism of a human following a machine's instructions was taken up within the practices of some makers. In some cases, the strangeness of the activity gave rise to brief reflection's on everyday experiences with technology. Clare remarked, "I like that the machine is the expert on the abstract shape and I'm the expert on the material. I feel like we have a nice division of roles and the machine isn't *making me feel stupid*. The machine is only making the suggestion, I'm the one realizing it." Such comments suggest a novelty in collaborating with a machine in a way that ultimately gives a user space to make their own decisions. Others dove deeper into the kinds of symbols that emerge when someone does something in the manner of a machine.

Matt, an exhibiting artist and ceramics instructor had a personal interest in questioning the relationship between automatic and manual building processes. He was interested in participating in my study because it connected to questions about the role of automated processes in creative practice that he had been thinking about prior to the study. He described how students at his institution were leaving ceramics to work with more cutting edge technologies like milling machines and 3D printers. In response, he was currently in the process of developing a course that explored the crossings between ceramics and fabrication by broadly exploring themes of "extrusion." In our conversations, Matt talked less about new potential objects that could be created, and more about the machine and its particular way of constructing objects. While building, he let the machine dictate his actions to a high degree. For instance, the tool-paths of Matt's model (a spiral staircase) had some unusual features. Each stair has a bit of internal scaffolding, which looked like a "squiggle" in the center of the outlined stair. Matt remarked, "I want to represent that squiggle" and when I asked him why, he said, "the red dot (laser) is telling me to, I want to follow the red dot no matter what." Following the dot "no matter what" was a way of learning the system while at the same time, representing the idiosyncratic "hand" of the machine in the work produced. The concept of a 3D printer represented by G-Code was an "outsider" in Matt's practice that Redeform allowed him to question and interrogate.

Ellen was also an exhibiting artist and graduate student in fine art who had worked extensively with discarded plastics. The idea that plastics were, "made to be thrown away" was interesting to Ellen and she was interested in engaging plastics towards new aesthetic ends. She frequently collected discarded plastics, photographed them, and then traced the patterns created by light as captured in the photograph. In this sense, her work already explored a hand-translation of a machine process of photography. She arrived at the study with a collection of plastic bags and after learning about the system, cut the bags into long strips. She was interested in transforming one plastic container, a bag, into a different kind of container and after searching the models, she chose a model of a "to go cup" and began

building. Her model was quite simple and consisted of layered concentric circles. While she could have easily just ad-libbed the cup without the use of the guide, she took great care to follow the laser as exactly as possible. For Ellen, the doing by hand was symbolically significant, as she remarked, "I was interested in using my own labor…it would allow someone to see [the object I'm making] and experience it as a translation by a person…" Her process was not intended to be a commentary on fabrication but a more general statement on labor and consumption. In this sense, the aspect of doing the work of the machine was a way to bring human labor into conversation with the symbolism evoked from discarded plastics.

Brynn was a public programs manager at a technology company. She had a background in game design and art curating and was working in a space where her co-workers were frequently using fabrication machines, thus, 3D printing was a prominent topic in her daily life. She wanted to build a grandiose model like the Titanic or the Eiffel tower with Easy Cheese (a spreadable cheese that squirts out of a can) because, "I knew that it would be impossible to do something perfect with Easy Cheese, so I felt more comfortable being more up front and candid about the fact that this is not going to be a beautiful object. Also, the absurdity. I really appreciate how 3D printing is a very formal, mechanized, precise process and we're kind of breaking that – we're using very sophisticated tools to do something very unsophisticated, which I appreciate a lot." She loosely followed the dot with her Easy Cheese without much care. At one point, her model was bumped out of alignment and she carried on without a worry, as though she wanted the model to be imprecise. As she reflected on her construction she revealed more personal insights about her feelings and fears of failure: "I feel that failure and messiness is a really important component if you want to be good at anything." Brynn wanted to become more comfortable with the idea of failing and saw Redeform as an opportunity to work through some of her anxieties. She said, "I'm definitely a recovering over-achiever and I work really hard to not be super hard on myself, so this [points to her cheese pepper model] is an achievement." In this case, Redeform and the "machine" it represented stood in for broader ideas of perfection and control. Actively poking fun of that concept was a way to produce something both comical and meaningful at the same time.

In each case, the maker can be seen tapping into some symbolic meaning that is amplified by complicating human and machine roles, whether it be questions of labor, exercises in imperfection, or contrasts between new and old. While these accounts focus less of explicit discussions of generative capacity of materials that do unexpected things, the materials remain an important part of this interaction because their histories and behaviors in interaction suggest new conceptual possibilities. Juxtapositions between clay, Easy Cheese, or plastics as they are engaged by a human doing 3D printing produced particularly resonant themes. The role of the "dot" in these studies was important in the sense that it allowed participants to reflect on the very specific processes of a 3D printer and bring "3D printing" into the symbolic gestalt of the interaction in a more powerful way than a building in a process that did not specifically mimic the machine's movements.

Connecting Instability and Experimentation

Different makers, from different disciplinary or professional backgrounds, with different values in making, and different material preferences and skills, were able to engage Redeform in ways that they found personally valuable. In each pattern of use, nonhuman forces played a key role. In some cases, engaging forces beyond the self created a therapeutic exercise in failing, in others, non-human forces pushed familiar practices into new terrains. While these processes took place with particular goals, the goals were focused on experience and discovery as opposed to determining a specific object. The space that Redeform created for nonhuman forces to come into making and the relationship it structured between humans and those forces is linked to the way in which Redeform functioned as an unstable tool.

Stability and Diversity

Tools provide templates for particular experiences and outcomes. In designing the form and functions of a tool, a designer creates the overarching structure of the template. This template can be more or less specific about the types of actors that can be involved in making and also sets up a space for particular kinds of relationships between those actors. While the designer fixes some actors and relationships, others are left "blank" or mobile for the maker to fill in to suit their particular values or needs. For instance, in Redeform the relationship between the human maker and the 3D printer was fixed but the choice of materials and the context in which making could take place was left open or mobile. The distinction between a stable and an unstable tool lies in the degree to which the user-supplied content or actions are able to shape the experience and outcomes. If the range of possible experiences and outcomes is narrow, then the tool is more or less stable. If a diversity of experiences and outcomes can emerge from the tool, then the tool may be said to be unstable.

Consider the hammer as an example of a stable tool. It sets up the "hit" relationship between a human and a thing. The diversity of experiences and outcomes that a hammer suggests is related to a number of sociotechnical factors: the diversity of things that can be hit by a hammer; the social practices around the tool; the broader eco-system of tools that exist; and what the hammer allows its user to feel in response to the hit. While a hammer can hit just about anything, people typically use it only to hit nails because, socially and historically, they may have learned that that's what hammers are for. Since there are other tools for hitting other kinds of things, like a kitchen mallet for tenderizing meat, or a fist for knocking on a door, the hammer may not be employed towards these ends. In using the hammer, the maker is able to sense the force of the material upon which they strike; thus, it makes a material's toughness or density present in the experience. In consideration of all these factors, the diversity of outcomes with the "hammer template" could be considered quite narrow.

Yet, the relative of stability or instability of a tool is fluid, changing across cultures and time, as the broader set of sociotechnical forces change around the hammer. Thus, the quality of stability is relative to broader sociotechnical forces. Furthermore, describing the hammer as

"stable" doesn't mean that people can't use a hammer to, say, create a chair[7] or pet their cat, but such actions tend to be marginal or labeled as "misuse" in relation to broader norms around hammers. In this sense, the concept of instability I suggest falls in line with descriptions of stabilization as described in theories of the social construction of technology (Bijker 2009). Specifically in describing the social construction of a bicycle, Bijker and Pinch describe how the present form of the bicycle has emerged from tensions between "relevant social groups" who each sought to determine the design in a different direction. While many years ago, a bicycle was subject to interpretive flexibility, or the ability for different groups to see it as different things, a process of one group winning out, or a compromise between groups, has given rise to the present "stable" form of a bicycle.

It is precisely this stability, given-ness, or normalcy in human-thing relationships that an experimental practice looks to disrupt. Cage's compositions created from pouring water between household appliances or Kaprow's conversion of a gallery into a junk yard can be seen as attempts to destabilize human-thing relationships in the hopes that it will create fissures where the "life" beyond what we think we know, can shine through. As Bennett writes, "if we think we already know what's out there, we'll surely miss much of it" (Bennett 2010). In this line of thought, a tool for experimental practice is one that should actively work against stabilization, habit, and norms. It should take a stable moment as a starting point and actively work towards destabilization. Reflecting on the design of Redeform, the interpretive flexibility it offered, and the way it provoked or supported makers in engaging nonhuman forces in open-ended ways, allows me to see it as an unstable or destabilizing tool. The instability of design came from multiple factors, each of which I outline below.

Destabilizing Goal-Based Workflows with the Single Dot

In practice, the requirement to build by following the single dot had the effect of shifting a maker's attention from ideas of what the completed form would look like to the responses of the materials in the moment-to-moment processes of construction. This shift in focus can be seen as working against approaches that are driven by the desire to create a particular kind of object and, instead, force makers to attend to their materials as they bend, push, and fold in their hands. This attention opened a space for physical sensations as well as conceptual reflections on what the experience of, say labor, within the broader task could symbolize, reflect or comment upon. Thus, the single dot made space for material-semiotic life through increased attention to the materials (both the building materials and G-code). Since it would be difficult to accurately "get what you want" with Redeform, material-semiotic responses to human actions were able to be treated as insights or inspirations as opposed to "errors." While makers with Redeform did describe their engagements as having some goals in relation to the objects they were producing, the makers who found value in the system were those who treated this goal as a prompt to get started as opposed to the specifically desired end point—the imposition of a "goal" became a way to start a nomadic trajectory that was free to wander in multiple directions.

[7] Droog design's "Do hit chair" offers an example of "misuse" of a hammer for this purpose (Droog 2016)

The single dot also offered interpretive flexibility. It simply told the user where the machine would have been in this part of building and allowed the human to do what they wanted with that information. Following the dot in particular ways had particular effects. For instance, following the dot closely was a way to attend to understandings about 3D printers and following it loosely was a way to add flexibility for materials that may not perform in the same manner as the materials typically used in 3D printers. In tandem with the breaking of goal-based practice, the dot allowed the life of materials to come through by removing any and all conceptualizations of "error." Thus, the technology functioned as a collaborator that simply brought its own particular way of doing things to the table and invited makers to do what they pleased with that knowledge.

Destabilizing Common Use with Unlikely Human-Machine Relationship

Tools, specifically tools for digital fabrication, are often framed as things that serve a maker and in many cases, they look to enhance an existing practice by offering some new computational feedback. By asking users to build like 3D printers, instead of the other way around, Redeform broke from this normal, expected, and common use. Since there was no precedent for this particular way of working makers had to "stabilize" the tool into their practice. Makers stabilized Redeform by bringing in a broader set of material-semiotic forces in the form of 3D models, materials, and processes for joining those materials into forms.

As seen though the framework of an experience template, Redeform created an experience that consisted of the material-semiotic actors of human maker, the Redeform machine, building materials, and a digital 3D model. It specified a relationship between the human and the Redeform machine as one where the human follows the machine. Makers were free to select the material-semiotic actors that would fill the role of building material and 3D model. Each material-semiotic actor a user selected brought particular physical properties as well as histories and associations to the experience. As Massumi might say, it created an envelope of forces to be developed into an object/interpretation (Massumi 1992). The unique combinations and juxtapositions formed between each of these actors allowed for particular reflections on material and culture. For example, a maker bringing clay into the activity ushers in broader notions of ceramics, hands, studios, musty smells, locality, and so on. In juxtaposition with 3D printer workflows, which may represent the new, technical, or inhuman, particular aspects of clay's "clay-ness" come forth, like the way it preserves fingerprints or its long history as a building material. Each additional material-semiotic actor adds to the harmony of symbolism and allows particular concepts to become particularly resonant.

In my study, the material-semiotic actors brought to Redeform allowed the tool to become stabilized around aesthetic explorations, meditation, therapy, learning, and reflection. Each of these stable tool-states was seen by makers to, in some way, enhance their creativity. In this capacity, unstable tools are well suited to adapt to the messy and "wicked" (Rittel and Webber 1969) landscape that is personal creativity while honoring the idea that creativity means different things for different people. Furthermore, by breaking the expected relationship between people and tools, Redeform prompted reflection on human-technology relationships more broadly. For makers who were inclined to approach making as inquiry

into cultures, the particularly strange workflow acted as a hook to reflect on relationships between humans and machines that is already a theme in many makers' practices.

Designer Subjectivity in Tool Design

While Winner addresses that all artifacts, and thus tools, have politics (Winner 1980), the idea of an unstable tool makes space for the designer to take a more explicit role in shaping those politics. While many designs of fabrication technologies attempt to "neutralize" the design by appealing to common practices, norms, or user feedback about the role tools in making ought to play, Redeform took an intentionally politicized stance in the form of the intentional decision I made to require the user build like a machine. I was motivated to do this as a means of hooking into existing lineages of art that have questioned human/machine boundaries. For those knowledgeable of such histories, Redeform became a way to conceptualize their practice within such a frame. For those unaware, the design simply offered the machine as a category to be questioned in the context of their lives and values.

Because of the intentional non-neutral stance of the design, and the way I wanted user to actively think *about* the concepts that motivated the design, Redeform played a dual part as an interactive art piece as well as a tool. Its like an art piece in the sense that I wanted to provoke reflection on particular relationships with machines but like a tool in the sense that it seeks a more modest role in everyday practice. Such crossings between artist and designer have also emerged from studies of improvisation whose tools could also be conceptualized as unstable in varying capacities. I see the crossing between artist and designer in unstable tools as creating a potentially interesting crossing between critical design (as it is understood in Dunne 2008; Pierce et al. 2015) and more functionalist programs in HCI. Rather than assessing tools for their functionalist capabilities alone, designers might begin to attend to how entanglements between tools, materials, places, and people that produce particular lines of materials-semiotic inquiry.

The very framing of the technology as a "tool" as opposed to an "art piece" allows the project to work into the vernacular of the everyday. The consideration of tools a means of aesthetically engaging with the everyday brings this project full circle to the experimental practices from which it was inspired. Namely, experimental approaches sought to frame art as inseparable from everyday life (characterized by artists like Kaprow, the Situationists (Debord 2000), and a broader Fluxus "rear-guard" (Harren 2015)), thus, blurring the distinction between tools and art objects moves art into the realm of instrumentality, suggesting a way of doing differently.

REFLECTIONS AND ASPIRATIONS FOR TOOLS FOR CREATIVE EXPANSION

While all making is a process of material-semiotic correspondence, fabrication systems create spaces to attend to material-semiotic forces in different degrees and through different sensory modalities. Supporting a variety of practices in making is not a question of building better tools or findings the "killer" tool that subsumes all the others, but creating multiple pathways that honor the complexity, nonlinearity and individuality of creative practice. While programs of research on making within HCI have done well in supporting common values held by engineers, and are working towards broader support for "traditional craft" values that make space for nonhuman life, there is a promising role for a framing of making as creative expansion to play in inspiring designs and supporting an ever-wider set of relationships between tools, humans, and environments.

In this dissertation, I have augmented existing new materialist theories of making to address how material-semiotic forces can be enrolled towards personal and productive effects. Where material force describes physical, haptic experience between humans and things, semiotic forces push and pull against a maker's mental image of what to make and how now the thing may be enrolled in particular contexts. Considering material-semiotic forces in tandem foregrounds making as inquiry into physical stuff as well as culture. Furthermore, it focuses a designer's attention to a wider space of materials that are capable of sensitizing makers within processes of creative expansion. Moving from theory to practice, I reflected on the design of two tools for making to describe how a vision of making as creative expansion through correspondence with material-semiotic forces gives rise to different design features than those that may have emerged out of an idea of making as creative expression. Namely, I argue that strange tools that work against a maker's habit are well suited to provoke attention to material-semiotic forces in the environment. Unstable tools create spaces for those forces to be folded into making, allowing the maker and the products made to take on forms that harness the active "voice" of materials, tools, humans and environments.

To conclude my provocation that designers or tools for fabrication should consider the value of creative expansion through unstable and strange design tactics, I reflect on the relationship between these design features; the nature of such tools and how they might be evaluated in an HCI context; and speculate on the impact such tools might have on the ever growing "maker movement." Together, I hope to propel a research program that turns towards complex and messy meaning making practices and, more broadly, embraces the inherent instability of everyday life.

Crossing Strangeness and Instability

While this dissertation has drawn from AnyType to describe how strange tools help makers notice active material-semiotic forces and Redeform to describe how unstable tools create space for nonhuman forces affect makers and their products, both tools can be seen as both strange and unstable.

AnyType as an Unstable Tool

Instability in Redeform was linked to its ability to block goal based workflows, make room for "risk" in making, and to underspecify the design in a way that allowed makers to adapt it

to their own preferences and values in making. AnyType attended to each of these qualities in different degrees. Many people in the study found it difficult to preconceive what their typeface was going to look like and thus, actively turned to chance as a compositional strategy. As they began to use the tool more often, they developed deeper intuitions of what might turn out and strategies that could result in pleasant surprises. While there was some risk associated with this workflow, in the sense that one couldn't fully predict what might happen, the risk was lessened by the relative ease of composition. Where most users of Redeform required at least an hour to build, AnyType's quick production process may have contributed to the positive attitude participants had towards the unknown. Specifically, discussions of "trust" did not characterize the studies of AnyType as they did with Redeform.

Participants in the study of AnyType also adapted the system to fit their ideal experience of making by selecting particular kinds of material-semiotic actors to engage. For instance, Melissa used AnyType like a diary and used her own belongings as subject matter to reflect on her feelings. Kate staged performances with the system to commemorate an event. Others framed the messages as "gifts" for others, created evocative messages for friends, treated the system as a kind of sketchbook for design ideas, and used it just to pass the time. Each domain for the system brought in a different set of opportunities for users to think about themselves, the people they loved, or reflect on their everyday environments. But unlike Redeform, the system itself was not the subject of reflection. Specifically, while some people approached Redeform to reflect on 3D printing because of the link between the tool's constraints and the functions of 3D printers, the lack of connection between AnyType's constraints and a particular process prompted little reflection on the tool itself.

Redeform as a Strange Tool

Since the design of Redeform followed the study of AnyType, I made conscious decisions to include strange constraints that could work against habit. The choice to use the dot moving along G-Code paths was particularly appealing in its capacity to defamiliarize processes of construction. Considered holistically, Redeform broke habits in relationship to what might normally be considered building material and how makers approached arranging their materials into a form. While some users found themselves noticing overlooked things in their environment, the physical exploration and amount of things noticed with Redeform were far fewer than AnyType. Where users of AnyType were dealing with digital representations of things in the world, users of Redeform had to deal with the physical things. This narrowed the kind of materials that could be considered to those things that could be conveniently gathered in some ample quantity and arranged along layered paths. As such, the materials for the studies often included discarded and nonprecious things like weeds, food, or sticks. Additionally, because of the relatively long amount of time needed to construct a model, there were fewer opportunities for study how participants searched for new materials and how their perceptions of their environments changed over time. Thus, where AnyType had a wide scope on noticing everyday things, Redeform's scope was more narrow and deep.

Exploring the Nature of Tools for Creative Expansion

While I advocate for further design research efforts for informing the design of tools through the lens of creative expansion, making this case is difficult because *any* tool can be used as a tool for creative expansion if a maker approaches it as such. The household items used in Cage's *Water Walk* (Cage 1960) were not *designed* for the task he envisioned, instead, he can be seen as folding those items into his practice to question the sonic profiles of everyday objects. Such is the case with almost all examples of experimental practice, which suggests that tools designed explicitly for experimental practices miss the point or are not fulfilling any hole or need within the landscape of tools for making. So what, then, does designing from the perspective of creative expansion do differently?

Tools for Creative Expansion are Subversive

Designing from the framework of creative expansion can give rise to tools with different characteristics of form and experience. For some, these tools will be useless (as a pottery wheel may be to a silversmith), to others the tools will fit precisely within their practice of making. In the middle, there are makers who may not be inclined to approach making as creative expansion but for whom the tool provokes new perspectives and actions in making. In AnyType and Redeform, "middle" users participated in the studies because of the subversive framing of the tools. With Redeform, the framing of the laser guide as a "tool for 3D printing" as opposed to a "tool for nonlinear practice" was instrumental in attracting a group of makers who may not have personally identified their practice with the latter description. In this regard, the design of tools for creative expansion have subversive aims to lure makers into an activity of production only to disrupt or resist those processes in order to let other experiences occur. For some, as we saw in Redeform, the singular focus on the goals made the system seem dysfunctional. For those already exhibiting aspects of creative expansion in their practice, the tools were interesting and provocative. But others in the middle, who did not explicitly describe their creative process as experimentation, found themselves having pleasurable moments of experimentation with materials. While I suggest that this reveals a hole in the landscape of existing fabrication design, a question for future research is the degree to which participants would continue to engage this tool or would have engaged it in the first place if not in the setting of a user study.

Tools for Creative Expansion Tend to Margins

Within the strand of HCI focusing on technology and creative production there are broad norms around what making is and the role technology ought to play in making. Most of this work attempts to place the machine or technology in service to the human user, by providing error checking, predictive modeling, or ways of streamlining existing processes. Such motivations allow the technological prowess of the design shine through at the risk of creating thin user experiences. Drawing from experimental practice has reinforced the idea that these norms are not the *only* roles for technology to play in making. Alternatively, this project joins broader calls to consider benefits of designs that actively force the user to contend with the resistance (D. K. Rosner, Ikemiya, and Regan 2015) or "counter-functionality" (Pierce and Paulos 2014) of a machine and/or materials engaged in building.

As I have written about and presented Redeform at various events, I am continually questioned about the design choices. Reviewers have called the project "absurd," it has been

described as "art project" whose contribution is "controversial" in the domain of interaction research, and others are perplexed at the "usefulness" of a technology that does not explicitly aid the maker in getting what they want. I take each of these responses as evidence that Redeform does something quite different with technology in the domain of making that has yet to be explored. The experiences of the majority of participants using Redeform and AnyType attest to the fact that, while unusual, the practices were valued by many users towards a variety of ends. Specifically, Redeform was able to support qualities of making, like risk and chance, that may be difficult to evaluate but are ultimately important parts of creative practice. These practices may not be the most popular or common, but they are also by no means rare and bringing them to the surface can reveal viewpoints that have been marginalized by present design norms.

Tools for Creative Expansion Support Craft

As I have suggested throughout this dissertation, tools for experimental practice seek a more radical role for nonhuman forces in making than those that have drawn from traditional craft. Particularly, I frame making as a process of actively getting "out" of ones ideas and beyond the self as a way to see and feel the world anew. Nonetheless, the studies of Redeform showed how some makers approached the system to address traditionally associated with "craft" values, like becoming fluent in materials (whether that was oriented towards G-Code or their building materials) while also welcoming unpredictable moments of resistance or complete breakdown. Most of the makers in the study did not expect, and even appreciated, the fact that the tool did not make their objects automatically aesthetically interesting. This feedback suggests that Redeform's preservation of "risk" allowed it to support characteristic craft experiences that crossed different domains of craft labor. Such insights align with David Pye's idea that craft is distinguished from manufacturing because it is a "workmanship of risk" as opposed to "workmanship of certainty" (Pye 2007). In this sense, designing for creative expansion is not anti-craft, in fact, it may support a broader set of "craft values" than projects that actively reduce risk through technological safeguards.

Contemporary craft, as opposed to "traditional craft" which is typically referenced in HCI, can be characterized by a diverse set of practices, goals, and orientations. Several projects leverage the semiotic weight and associations of amateurism represented by craft towards critical social effects (Adamson 2008). Other practices are increasingly engaged with "the digital" as a material alongside physical stuff. Examples include projects like Stephanie Syjuco's *Empire/Other* in which Syjuco scans ceramic objects from disparate cultures and attempts to computationally join them to create hybrid forms (Stephanie Syjuco 2016). The process has resulted in forms that are impossible to produce, which Syjuco describes as "ghosts or phantoms of traumatic histories…" Their inability to be produced strengthens the incompatibility of the original objects, highlighting diversity and struggle as opposed to unification and compromise. Another example is a project entitled *Stratigraphic Manufactury,* which consists of multiple locally produced objects that were created from a single computer model. Each instantiation, or ceramic object, varies because of the qualities of the local clay engaged as well as the particular machine used to produce the work (Unfold 2012). As such, the project demonstrates a "style" that is located in machines and materials as opposed to the craftsperson's hand.

Contemporary craft presents a complicated and messy terrain that resists characterization by core set of universal values. A strange and unstable tool like Redeform, which embraces multiple orientations towards making and material experience, may be better suited to address the contemporary landscape of craft than tools that narrow in on "traditional," and perhaps less complicated, conceptualizations of craft. Furthermore, drawing from creative expansion creates a space where the digital is not in opposition to the physical, but simply exists as a material of a different kind. Thus, concerns in design and evaluation can shift from focusing on the authenticity of the experience, or tensions between pre- and post-digital practices, towards the critical capacity of the forms produced and the methods used to produce them[8].

Tools for Creative Expansion are Meta-Tools

I have come to think of tools for experimental practice as meta-tools in the sense that the tools set up an activity that targets key aspects of creative thinking, independent of a specific material domain. Meta-tool can be thought of as tools for "stretching" ones mind creatively or nurturing one's creative spirit. As such, tools for creative expansion can serve as a complement to tools for expression in the sense that one might approach tools for creative expansion to generate new ideas and inspiration, and tools for expression to realize those ideas. Tools for creative expansion may not be the implement one picks when they decide to produce something specific, but they might be the implement one picks as a prompt to "get the juices" flowing so to speak. These tools offer techniques and strategies that allow one's mind to expand creatively, to see the everyday anew, and to bring those thoughts and ideas to more traditional arenas of production, say, the studio or fabrication lab.

Evaluating Tools for Creative Expansion

Because experimental practices work against goals, evaluating how well a tool for creative expansion performed in any given task is a key challenge. Often, researchers evaluate fabrication systems by imposing some goal in order to make a claim that the technology worked. Often, this is accomplished through a maker's relationship to the object they produced and addresses questions like: were you able to create something you like? Were you able to realize an idea? Were you able to create something that you'd be proud to put your name on? Goal-based workflows circumscribe needs that are worthy of technical assistance and construct technology to address those needs. In many cases, this can create fun and interesting technical problems to "solve" in code and hardware. But, at times, a tradeoff is made between an interesting piece of technology and an interesting user experience with a piece of technology. Where cutting edge technology can offer "solutions" or simplifications to commonly encountered problems in making, interesting experiences often emerge from a maker's response to "problems" with no real solution. If one cannot measure the success of a tool based on its technical innovation or the way it fits into a predefined goal or task, new metrics and evaluation techniques are needed.

[8] A similar call for fine art to consider the means of production as central to the meaning of the work has recently been advocated in (Adamson and Bryan-Wilson 2016). Such calls reflect the increasing similarities of art, craft, and design in contemporary discourse.

Assessing how a Tool Balances Chance and Control

A key criterion for evaluation in tools for creative expansion is the degree to which tools balance chance with control. The maker should feel invested in the process and know that their actions make a difference in the outcome, but that knowledge should be balanced with a lack of certainty about what might ultimately emerge. Both Redeform and AnyType struck a balance between chance and control. In AnyType, users felt that continued use of the application could lead to more interesting typefaces. The choice to find "textures" in the environment was developed as a strategy to increase the likelihood that they would appreciate the font they created. If the system were purely random, participants would have no need to develop strategies for use. On the other end, if the application provided more information on what might emerge throughout the capture phase, then participants may have lost the ability to be pleasantly surprised and enchanted by the experience of application. In Redeform, participants continually used the term "trust" in relationship to their experiences, signaling that the function of the system was beyond their predictive abilities. Some of the feedback in response to Redeform suggests that the design may have erred too heavily on the side of supporting chance, suggesting that most makers in my study found themselves seeking more purposeful actions than Cage may have found to be desirable.

The ability for a maker to have some control in the making process was meaningful in two capacities. First, deviations are not meaningful if there is no chance at "getting it right," so to speak. For instance, doing something imperfect with Redeform is not meaningful if there is no real connection between the system and the ability to achieve a more perfect form. In relation to the user study of Redeform, the proof that the tool *could* work was documented in videos that I sent to participants showing successful constructions. Second, makers seemed to need a hook to work through the struggles presented by the system. As such, the system needed to express authority and make its ability to work non-randomly clear in order to motivate makers to put in the required effort to discover how it will work for them. This hook, in the case of Redeform, tended to be its ability to function as a guide for doing a particular kind of work that makers found to be interesting or attractive.

Evaluating the Quality of Ideas above Objects

Since the goal of creative expansion focuses on ideas ahead of objects, and is oriented toward becoming sensitized to new phenomena, the objects produced along the way may not be representative of the overall quality of the experience. Such was the case in Redeform. Aside from Nina's magnolia leaf glasses, which were quite visually interesting, most of the objects participants produced were not particularly inspiring or useful in and of themselves: Arlo's vase made of sticks was not something he was eager to keep; Josh commented that the composition he created would be impossible to play; Clare's goat head made of ivy became an ad-hoc house plant; and so on. Nevertheless, most participants found value in the experience and found it to be in support of broader efforts to expand their creativity. The valuable outcomes of using Redeform were new ideas and sensitivities it fostered in the maker as opposed to the material products makers created. For instance, Arlo enjoyed the experience and it sparked several other ideas for combining computational design and

handcraft. Josh also generated ideas about digital forms, G-code, and composition. For participants like Nina and Clare, the value in the experience came from simply clearing ones mind by devoting focus to materials. Nina spoke specifically of Redeform as a way to "undo" screen time. Clare valued the opportunity to "relinquish control" by succumbing to material.

Where adding more technical support might have allowed more compelling models to emerge with less effort, giving materials the space to "do wrong" was regarded by many participants as one of the primary strengths of the system, since these "unintentional" happenings are often rich sources of inspiration. Instances of "breaking" revealed key moments in which the maker is able to become affected and thus, expand beyond their own ideas. With this in mind, evaluations of strange and unstable tools may focus on the insights the tool brought forth and the degree to which makers found those insights valuable in their particular practice. I think such an evaluation approach would be better suited to address the multiplicity of values in creative practice by asking questions about the personal relevance of making as opposed to focusing on specific quality of presumed importance and assessing whether or not it happened.

Long-Term Studies and Self-Use

A second strategy for evaluating tools for creative expansion could focus on use over time and the degree to which the tool structures experiences in an ongoing process of making. But since the relationship between tool-use and individual maker is highly personal, it might be difficult to find a maker who is deeply interested in using such a tool in their practice in a meaningful way over time. One approach towards long-term studies of tools in experimental practice could be exercises of co-design in the style of (Saegusa, Tran, and Rosner 2016; D. K. Rosner, Ikemiya, and Regan 2015) where a designer and maker work together to cater the tool to the maker's practice. The particular directions the tools take, as a material outcome of the collaboration between the artist and designer, could materialize concerns and design options that highlight alternative values in making.

A strategy that has been useful in my own work has been rigorous self-use alongside of user studies. In their description of autobiographical design, Neustaedter and Sengers argue for a deeper examination of processes of self-use that are often engaged but understudied within HCI (Neustaedter and Sengers 2012). They advocate that a *rigorous* autobiographical design approach, characterized by "extensive period of genuine, intensive use, measured in months or years; surprises in usage that lead researchers to rethink or further develop initial design conceptions; improvements to design driven by specific, documented incidents of use; and careful articulation of the impact of design decisions on experiential qualities of the system in use" can offer complementary contributions to those found in traditional user studies.

While I firmly believe that Redeform has something to offer makers of different backgrounds and values, as the sole designer of the system, it also uniquely addresses concerns that I value in making. Over the past two years, I have been using Redeform, updating the design, and reusing it within my own art practice to reflect on its potential as a tool in my practice as well as a prompt for thinking about agency of nonhumans in making

Figure 13: The outcome of my attempt to build a large-scale bunny from balloons.

more broadly. Much of this has taken place in collaboration with the Autodesk Artists-in-Residence program and I have keep a detailed journal of each "performance" with Redeform in an online journal at *beingthemachine.com.*

My self-use of Redeform has been particularly helpful for holding myself accountable to theoretical positions I advocate. It also helped me realize the contentious nature between my theoretical position and what HCI more broadly considers to be "innovation." This particular insight emerged from a performance with Redeform at the annual conference of Tangible and Embodied interaction (Devendorf and Ryokai 2015b). I wanted to demonstrate the unique ability of my system to create large-scale models by building a life-size model of the Stanford Bunny, a common test bench model for 3D printers, from balloons. Because the audience of the performance would be largely composed of HCI researchers, my goal was to bring forth reflections on heuristics for 3D printing through a spectacular construction that would be impossible with other 3D printing technology. But after a total of 15 hours of construction and a few breezes, the project ultimately failed in the sense that the balloons never quite made it into the form of the bunny. It failed because I mistakenly believed the use of my technology would help me overcome the properties of the materials I was working with. Even though my motivation for the system was collaboration with nonhuman forces, I found that I was not collaborating with the materials, I was

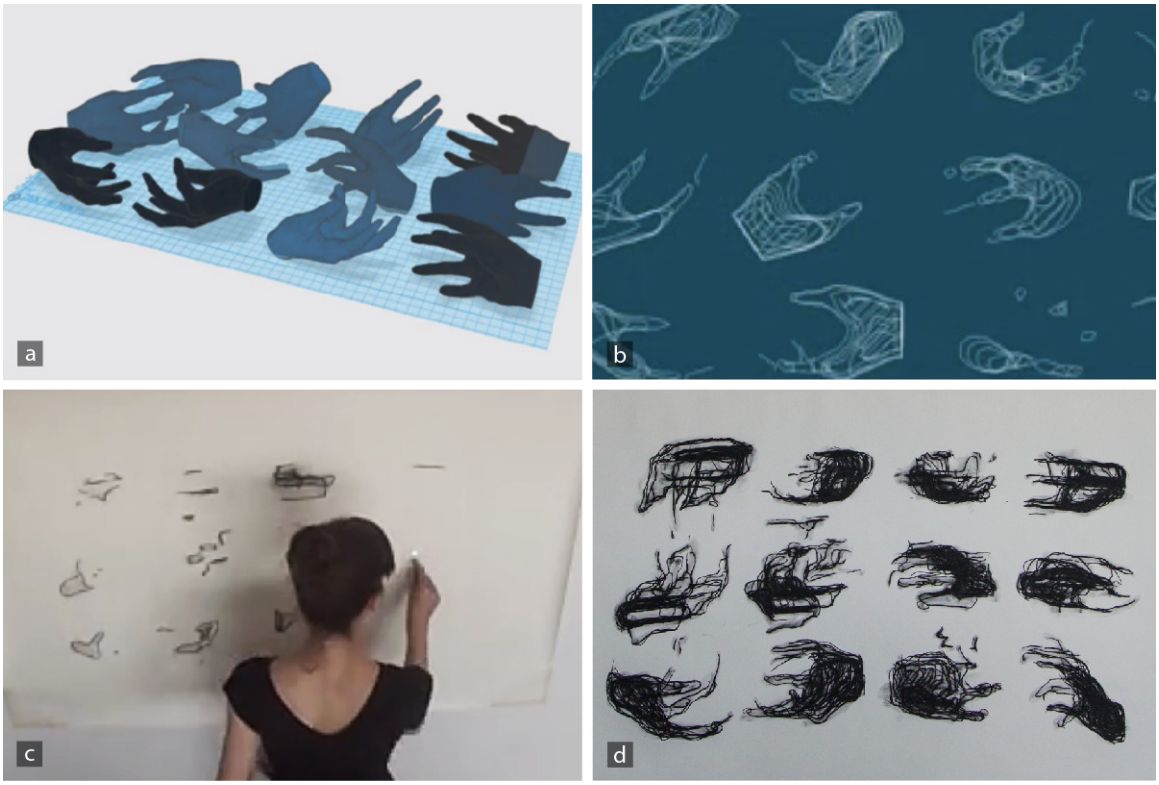


Figure 14: Following Redeform with Charcoal. a. 3D model of several hands in different orientations is used as input to Redeform b. A visualization shows the tool-paths generated from the 3D model. c The laser pointer moves along the tool-paths and I follow it with charcoal. d. The drawing that emerged is an abstract derivation of the original 3D model.

attempting to control them and fit them into a shape they were not suited to fit. I did not listen to the balloons enough to realize that balloons do not intend to be tied into static shapes; they want to be with the wind.

The entire situation (spending 15 hours laboring over the performance; feeling physically sore and exhausted; exhibiting a shapeless pile of balloons alongside well polished tech demos; offers from fellow kind students to help me "fake" the shape of a bunny in order to save face) made me realize the value of humility and the way in which humility does not quite fit within existing narratives of technology's role in making. Materials often resist their makers and the way in which they resist can challenge makers to develop new methods and ideas that could not have emerged without that resistance. This observation, which emerged through the performance, became something I talked about with attendees and it opened a space for them to share their own thoughts about materials, resistance, failure and craft.

Other performances with the system have provided additional insights into the nature of nonhuman engagement in creative practice. In (Devendorf, De Kosnik, et al. 2016), I outline how a subsequent performance of drawing the tool paths gave rise to attention to new kinds of materials as well as what it meant to make space for those materials in practice. Reflections on the user studies and my own practices inspired an additional iteration of the

Figure 15: My current explorations with Redeform have embedded the system within an augmented portable plein air easel in order to explore ideas of site specificity in making.

project that sought to engage broader materials (specifically environmental factors) in a more meaningful way by wrapping the original Redeform system in a portable form factor of a "plein air" painting easel. Though the project was documented and exhibited in the 2016 Autodesk Artists in Residence show, I am currently working through ways to make the objects produced with the system resonate with their contexts to a greater degree.

The insights from my ongoing self-use or performances with my design complement traditional user studies in several ways. First, in the case of the TEI demo, the personal bodily experience of failure, like feeling physically sore, let down, exhausted is something I had to experience to know and may never have understood through extended user studies. Second, each performance became a probe, surfacing opinions from others in a way that was more voluntary and perhaps more frank than those solicited in traditional user studies. Viewers were commenting on my actions, not their own, and (while some may have been trying to make me feel better) they were able to relate my experience to their own and articulate the ways in which it was similar or different. Thus, the performances became a way to fold in other perspectives to the design and my topic of inquiry without specifically soliciting them. Third, performing made me practice what I preach and while some of the forms did not turn out as I expected, it was a success in the sense of personal enrichment. Not getting what I wanted was a valuable experience. Unique experiences emerge through struggle and I began to see that technology does not have to remove struggle, but can produce new kinds of productive struggling.

Speculating on Futures for Creative Expansion in Design

At its core, fabrication technology represents an opportunity to transform digital information into physical forms. The operation offered by fabrication systems creates a space for lively engagements with machines that have historically been separated from the rest of the world in factories, labs, and workshops. Framing making as material-semiotic inquiry and formulating machines around the concept of creative expansion is an attempt to bring fabrication into dialog with a broader set of cultural and material forces. Fabrication machines may no longer sit idle, waiting for a creative human to put their plastics into motion, but they may unhook from their power sources and become animate within different spheres of the everyday. Maybe it takes the form of a system for creating dramatic costumes from everyday materials (a la Nick Cave's sound suits (Cave 2006)), machines that harness wind gusts to produce kits, or a knitting machine that creates unique patterns from various data streams, the possibilities are multiple. The user of these systems might find themselves diving deeper into the everyday, searching for costume materials among discarded junk, seeking expressive wind gusts along urban corridors or mountains, or harnessing streams of data from solar storms or smart thermostats to encode into garments. In each case, the machines and users interweave "making" into the fabric of daily life. The machines do not only make room for lively materials but become lively in and of themselves. Collaborations between lively humans, machines, and building materials may be characterized by simultaneous acts of noticing, questioning, and reflecting on the digital and physical intersections that increasingly color lived experience. The future I anticipate for fabrication and that I hope for notions of creative expansion to manifest extends beyond learning engineering concepts and designing custom objects, to include a broader set of subjects for inquiry into culture and technology. While this may involve programming, designing, and tinkering with electronic hardware, it ultimately seeks to frame these activities within larger programs of critical inquiry, or perhaps critical making (Ratto 2011; Hertz 2012), shifting ideas of what *can* be made with what making particular kinds of things can question.

While digital fabrication represents a new and exciting field of technical and creative production, the way these systems are designed carries political weight. There is a strong link between the maker movement and digital fabrication technologies and many compare the rise of digital fabrication with the rise of the personal computer (Gershenfeld 2007). Educators and policy makers alike have looked to digital fabrication and the momentum of the maker movement to reinvigorate a dwindling American science, technology, engineering and math (STEM) workforce, hosing a Maker Faire at the White House and investing millions of dollars to create maker spaces in schools (Dougherty 2014). The values and modes of making baked into fabrication systems, especially those used in schools and educational settings, will play an important role in shaping who participates within STEM fields in future generations.

Currently, I see the maker movement repeating some of the patterns demonstrated in the rise of the personal computer that marginalized groups like women and people of color. Specifically, the design of commercial fabrication systems which function in terms of planning, command and control, seem to suggest that "makers" prefer to work in abstract,

hard, and controlled ways that have historically been seen as more technically valid (Turkle 1997; Lave and Wenger 1991). While the rhetoric of the movement promotes inclusivity and takes a notable non-critical attitude toward the objects produced, Toombs and others have pointed to "sociological barriers" that prevent some makers from participating in maker communities (Toombs, Bardzell, and Bardzell 2015). These sociological barriers include bias in the content presented by *Make* magazine, the public face of the "maker" movement, and a lack of shared values among members in community maker or hacker spaces. As the public face of the maker movement and organizer of Maker Faires, the image *Make* magazine constructs of a maker has deep implications on who identifies and participates in the maker movement and thus whose viewpoints becomes reflected in the technologies for making. Leah Buechley's keynote at a 2013 conference on the role of fabrication in education challenged *Make* magazine to reconsider its outward facing image of makers and making (Buechley 2013). She presented a content analysis of the magazine to show that 85% of the *Make* magazine covers depicted men and boys engaged in projects focused primarily in the domain of robotics and electronics. Similar statistics were reflected in articles within *Make* magazine. While Maker media has many programs targeted at diversity, the outward facing image of the magazine reproduces existing stereotypes about who participates in STEM subjects through making. Her presentation included several examples of culturally specific making practices that are mathematically challenging, such as the decoration of a vase with non-Euclidean geometry, and asked why these forms of making tend not to appear in *Make* magazine. While it could be argued that other public facing maker communities like *etsy.com* or *ravelry.com* could counter the image of a upper middle-class boy-hacker, they do not hold the same title to the term "maker" as *Make* magazine and media.

The rise of feminist maker spaces also highlights cultural assumptions about makers and making. Maker spaces offer shared access to sophisticated machinery (including digital fabrication machines like CNC mills, laser cutters, and 3D printers) and serve as central meeting point for communities to unite through making. The kinds of individuals that join maker spaces play a large part in defining the "maker" identity. Feminist maker spaces, from Mothership HackerMoms in Oakland to Double Union in San Francisco, emerged to accommodate different modes of participation in these spaces. HackerMoms offers childcare and family focused making events, which are not currently offered by prominent San Francisco maker spaces like Noisebridge and TechShop. Liz Henry, the founder of Double Union, a feminist maker space in San Francisco, describes the way many women who are part of Double Union felt uncomfortable or marginalized in male dominated maker spaces. As she explains, "You might be there coding, and you want to stop for a while and draw in your notebook and think, but if you're not staring at a black and green screen or, like, melding your brain with an Arduino every second, some dude is going to come up to you and act like you need his expert lessons in how to hack" (Henry 2014). For Henry, the formation of Double Union was seen as a productive way to support alternative communities of makers, which is reflected in events like identity workshops that are offered along side of technical workshops.

While I acknowledge that designing for creative expansion will not fix the problems with diversity in the maker movement, there are strong resonances between the values of making

as creative expansion and the values that have tended to be marginalized within the broader maker movement. Thus, in a move inspired by (Lindtner, Bardzell, and Bardzell 2016), I see the call to design fabrication systems through the lens of creative expansion as a productive critique that attempts to hone in on positive happenings in the present and imagine spaces where those could be developed in the future. For example, Fox et al.'s studies of feminist hackerspaces reveal an interest in "hacking culture not devices" signaling making as a mode of social inquiry and activism (Fox, Ulgado, and Rosner 2015). My framing of making as material-semiotic inquiry, and the way it foregrounds cultural inquiry alongside material inquiry makes it easier for such practices to be recognized and taken up in the design of technologies for making. Furthermore, Rosner and Fox's finding that "failure" plays a central role in mother-oriented hacker spaces aligns with my own findings that risk and failure to be highly valuable within creative expansion (D. K. Rosner and Fox 2016).

To date, projects targeting diversity tend to focus on domains of making that have been traditionally seen as feminine, such as e-textiles, and have had success at supporting girls and women in making (Buechley and Perner-Wilson 2012). As such, this approach has inspired many others that seek to support diversity by modeling practices that have been traditional seen a "women's work." I see a focus on creative expansion in design as a move that takes a step back from individual domains (cooking or sewing) in order to think about the way those particular modes of work structure relationships between makers, materials, and environments—practices that I have come to see as characterized by humility, care and inevitable compromise. This includes an attention to what happens during making, where making takes place, as well as the life the objects produced can take on. When tools are designed to work in everyday life, they can engage everyday life to a more meaningful degree. For instance, computational design and fabrication can take on the role of family craft as opposed to prototyping strictly construed. Furthermore, the objects produced can perform different work—you can eat a computational model made of pancakes or watch as your glasses made of leaves decay and take on new textures. These projects engage important computational and engineering concepts but do so in a way that creates a space for a different set of outcomes and experiences and thus, may appeal to a different class of makers.

On a broader level, designing from the perspective of creative expansion seeks new roles for technology in everyday life that shift from operating as a mechanism of increased human prediction and control, to a position that provokes increased attention to the world around humans. While I see this shift potentially impacting the maker movement, it is a relationship that I think has broader impacts in how designers think about and design technologies. I see creative expansion as one of many possible approaches that seek reflective, thoughtful, and meditative engagements with people, spaces, and selves. These technologies embrace the uncertainty and instability that characterizes lived experience as a resource as opposed to a problem for technology to solve. We can participate in fantasies that see technology bringing the world into predictable control, but I prefer to work through an alternative vision that sees technology embracing the messiness and uncertainty of the world to cultivate experiences of wonder, curiosity, enchantment, and surprise that come from seeing oneself as small part of a great number of wonders that surround us in everyday life.

REFERENCES

Adamson, Glenn. 2008. "When Craft Gets Sloppy." *Crafts* 211 (Mr/Ap)

Adamson, Glenn, and Julia Bryan-Wilson. 2016. *Art in the Making: Artists and Their Materials from the Studio to Crowdsourcing*. 1 edition. New York, NY: Thames & Hudson.

Agrawal, Harshit, Udayan Umapathi, Robert Kovacs, Johannes Frohnhofen, Hsiang-Ting Chen, Stefanie Mueller, and Patrick Baudisch. 2015. "Protopiper: Physically Sketching Room-Sized Objects at Actual Scale." In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*, 427–436. UIST '15. New York, NY, USA: ACM.

Antoni, Janine. 1994. *Slumber*.

———. 2000. *2038*. C-Print.

———. 2014. "SEGMENT: Janine Antoni in 'Loss & Desire' | Art21 | PBS." Accessed November 2. http://www.pbs.org/art21/watch-now/segment-janine-antoni-in-loss-desire.

Balsamo, Anne. 2011. *Designing Culture: The Technological Imagination at Work*. Durham NC: Duke University Press Books.

Barad, Karen. 2006. "Posthumanist Performativity : Toward an Understanding of How Matter Comes to Matter." In *Belief, Bodies, and Being: Feminist Reflections on Embodiment*, edited by Deborah Orr. Rowman & Littlefield Publishers.

———. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Duke University Press Books.

Bell, Genevieve, Mark Blythe, and Phoebe Sengers. 2005. "Making by Making Strange: Defamiliarization and the Design of Domestic Technologies." *ACM Trans. Comput.-Hum. Interact.* 12 (2): 149–173.

Bennett, Jane. 2001. *The Enchantment of Modern Life: Attachments, Crossings, and Ethics*. Princeton, N.J: Princeton University Press.

———. 2010. *Vibrant Matter: A Political Ecology of Things*. Durham: Duke University Press Books.

Berger, John. 2009. *Ways of Seeing*. Penguin Group(CA).

Bijker, Wiebe E. 2009. "Social Construction of Technology." In *A Companion to the Philosophy of Technology*, edited by Jan Kyrre Berg Olsen, Stig Andur Pedersen, and Vincent F. Hendricks, 88–94. Wiley-Blackwell.

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

———. 2015. "Third-Wave HCI, 10 Years Later—participation and Sharing." *Interactions* 22 (5): 24–31.

Boehner, Kirsten, Phoebe Sengers, and Simeon Warner. 2008. "Interfaces with the Ineffable: Meeting Aesthetic Experience on Its Own Terms." *ACM Trans. Comput.-Hum. Interact.* 15 (3): 12:1–12:29.

Boehner, Kirsten, Janet Vertesi, Phoebe Sengers, and Paul Dourish. 2007. "How HCI Interprets the Probes." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1077–1086. CHI '07. New York, NY, USA: ACM.

Bogost, Ian. 2012. *Alien Phenomenology, or What It's Like to Be a Thing*. Minneapolis: Univ Of Minnesota Press.

Bolt, Barbara. 2007. "Material Thinking and the Agency of Matter." *Studies in Material Thinking* 1 (1). https://www.materialthinking.org/papers/37.

Bowers, John, Simon Bowen, and Tim Shaw. 2016. "Many Makings: Entangling Publics, Participation and Things in a Complex Collaborative Context." In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 1246–1257. DIS '16. New York, NY, USA: ACM.

Bowers, John, Robyn Taylor, Jonathan Hook, Dustin Freeman, Charlie Bramley, and Christopher Newell. 2014. "HCI: Human-Computer Improvisation." In *Proceedings of the 2014 Companion Publication on Designing Interactive Systems*, 203–206. DIS Companion '14. New York, NY, USA: ACM.

Buechley, Leah. 2013. "Thinking about Making." presented at the FabLearn 2013, October 28. http://edstream.stanford.edu/Video/Play/883b61dd951d4d3f90abeec65eead2911d.

Buechley, Leah, and Hannah Perner-Wilson. 2012. "Crafting Technology: Reimagining the Processes, Materials, and Cultures of Electronics." *ACM Trans. Comput.-Hum. Interact.* 19 (3): 21:1–21:21.

"Bureau Bruneau - Train Set Typography." 2016. Accessed December 13. http://www.bureaubruneau.com/pro-train.html.

Cage, John. 1951. *Music of Changes*. http://johncage.org/pp/John-Cage-Work-Detail.cfm?work_ID=134.

———. 1960. *Water Walk*. https://www.youtube.com/watch?v=-koTMW95NZs.

———. 2011. *Silence: Lectures and Writings, 50th Anniversary Edition*. 2 edition. Middletown, Conn: Wesleyan.

Cameron, Julia. 2002. *The Artist's Way: A Spiritual Path to Higher Creativity*. 10th ed. edition. New York: Jeremy P. Tarcher/Putnam.

Carl DiSalvo, and Jonathan Lukens. 2011. "Non-Anthropocentrism and the Non-Human in Design: Possibilities for Designing New Forms of Engagement With and Through Technology." In *From Social Butterfly to Engaged Citizen Urban Informatics, Social Media, Ubiquitous Computing, and Mobile Technology to Support Citizen Engagement*. MIT Press.

Cave, Nick. 2006. "Soundsuits." http://www.jackshainman.com/exhibitions/past/2006/nick-cave/.

Cheatle, Amy, and Steven J. Jackson. 2015. "Digital Entanglements: Craft, Computation and Collaboration in Fine Art Furniture Production." In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 958–968. CSCW '15. New York, NY, USA: ACM.

Collier, John. 1957. "Photography in Anthropology: A Report on Two Experiments." *American Anthropologist* 59 (5): 843–859.

Dawkins, Nicole. 2011. "Do-It-Yourself: The Precarious Work and Postfeminist Politics of Handmaking (in) Detroit." *Utopian Studies* 22 (2): 261–84.

Debord, Guy. 2000. *Society Of The Spectacle*. Detroit: Black & Red.

DeLanda, Manuel. 2004. "Material Complexity." *Digital Tectonics*, 14–21.

Devendorf, Laura, Abigail De Kosnik, Kate Mattingly, and Kimiko Ryokai. 2016. "Probing the Potential of Post-Anthropocentric 3D Printing." In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 170–181. DIS '16. New York, NY, USA: ACM.

Devendorf, Laura, Joanne Lo, Noura Howell, Jung Lin Lee, Nan-Wei Gong, M. Emre Karagozler, Shiho Fukuhara, Ivan Poupyrev, Eric Paulos, and Kimiko Ryokai. 2016. "'I Don'T Want to Wear a Screen': Probing Perceptions of and Possibilities for Dynamic Displays on Clothing." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 6028–6039. CHI '16. New York, NY, USA: ACM.

Devendorf, Laura, and Daniela Rosner. 2016. "Beyond Hybrids: Metaphors and Margins in Design." Under Review.

Devendorf, Laura, and Daniela K. Rosner. 2015. "Reimagining Digital Fabrication As Performance Art." In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, 555–566. CHI EA '15. New York, NY, USA: ACM.

Devendorf, Laura, and Kimiko Ryokai. 2013. "AnyType: Provoking Reflection and Exploration with Aesthetic Interaction." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1041–1050. CHI '13. New York, NY, USA: ACM.

———. 2015a. "Being the Machine: Reconfiguring Agency and Control in Hybrid Fabrication." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '15. New York, NY, USA: ACM.

———. 2015b. "Redeform: Participatory 3D Printing in Public Spaces." In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*, 423–424. TEI '15. New York, NY, USA: ACM.

Droog. 2016. "Do Hit Chair." Accessed December 14. https://www.droog.com/webshop/product/do-hit-chair-non-hitnew.

Dunne, Anthony. 2008. *Hertzian Tales: Electronic Products, Aesthetic Experience, and Critical Design*. Cambridge, Mass.; London: The MIT Press.

Dunne, Anthony, and Fiona Raby. 2013. *Speculative Everything: Design, Fiction, and Social Dreaming*. The MIT Press.

Efrat, Tamara Anna, Moran Mizrahi, and Amit Zoran. 2016. "The Hybrid Bricolage: Bridging Parametric Design with Craft Through Algorithmic Modularity." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 5984–5995. CHI '16. New York, NY, USA: ACM.

Forlizzi, Jodi, Carl DiSalvo, Jeffrey Bardzell, Ilpo Koskinen, and Stephan Wensveen. 2011. "Quality Control: A Panel on the Critique and Criticism of Design Research." In *CHI '11 Extended Abstracts on Human Factors in Computing Systems*, 823–826. CHI EA '11. New York, NY, USA: ACM.

Fox, Sarah, Rachel Rose Ulgado, and Daniela Rosner. 2015. "Hacking Culture, Not Devices: Access and Recognition in Feminist Hackerspaces." In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 56–68. CSCW '15. New York, NY, USA: ACM.

Frayling, Christopher. 1993. "Research in Art and Design." *Royal College of Art Research Papers 1*, no. 1: 1–5.

Gaver, Bill, Tony Dunne, and Elena Pacenti. 1999. "Design: Cultural Probes." *Interactions* 6 (1): 21–29.

Gaver, William. 2012. "What Should We Expect from Research Through Design?" In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 937–946. CHI '12. New York, NY, USA: ACM.

Gershenfeld, Neil. 2007. *Fab: The Coming Revolution on Your Desktop--from Personal Computers to Personal Fabrication*. New York: Basic Books.

Giaccardi, Elisa, Nazli Cila, Chris Speed, and Melissa Caldwell. 2016. "Thing Ethnography: Doing Design Research with Non-Humans." In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 377–387. DIS '16. New York, NY, USA: ACM.

Goldberg, RoseLee. 2011. *Performance Art: From Futurism to the Present*. Third Edition edition. London ; New York: Thames & Hudson.

Håkansson, Maria, and Lalya Gaye. 2008. "Bringing Context to the Foreground: Designing for Creative Engagement in a Novel Still Camera Application." In *Proceedings of the 7th ACM Conference on Designing Interactive Systems*, 164–173. DIS '08. New York, NY, USA: ACM.

Håkansson, Maria, Lalya Gaye, Sara Ljungblad, and Lars Erik Holmquist. 2006. "More Than Meets the Eye: An Exploratory Study of Context Photography." In *Proceedings of the 4th Nordic Conference on Human-Computer Interaction: Changing Roles*, 262–271. NordiCHI '06. New York, NY, USA: ACM.

Håkansson, Maria, Sara Ljungblad, Lalya Gaye, and Lars Erik Holmquist. 2006. "Snapshots from a Study of Context Photography." In *CHI '06 Extended Abstracts on Human Factors in Computing Systems*, 333–338. CHI EA '06. New York, NY, USA: ACM.

Hallnäs, Lars, and Johan Redström. 2001. "Slow Technology – Designing for Reflection." *Personal Ubiquitous Comput.* 5 (3): 201–212.

———. 2002. "From Use to Presence: On the Expressions and Aesthetics of Everyday Computational Things." *ACM Trans. Comput.-Hum. Interact.* 9 (2): 106–124.

Harman, Graham. 2011. *The Quadruple Object*. Reprint edition. Winchester, U.K.; Washington D.C.: Zero Books.

Harren, N. 2015. "The Crux of Fluxus: Intermedia, Rear-Guard." *Living Collections Catalogue* 2 (1). http://www.walkerart.org/collections/publications/art-expanded/crux-of-fluxus/.

Hebdige, Dick. 1979. *Subculture: The Meaning of Style*. New Ed edition. London ; New York: Routledge.

Heidegger, Martin. 2008. *Being and Time*. Reprint edition. New York: Harper Perennial Modern Classics.

"Henry Hargreaves | Photographer." 2016. http://henryhargreaves.com/.

"Henry Moore - Works in Public - Warrior with Shield 1953-54 (LH 360)." 2016. Accessed July 7. http://www.henry-moore.org/works-in-public/world/uk/birmingham/birmingham-museum-and-art-gallery/warrior-with-shield-1953-54-lh-360.

Hertz, Garnet. 2012. "Crtical Making." http://conceptlab.com/criticalmaking/.

Hudson, Scott E. 2014. "Printing Teddy Bears: A Technique for 3D Printing of Soft Interactive Objects." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 459–468. CHI '14. New York, NY, USA: ACM.

Hutchinson, Hilary, Wendy Mackay, Bo Westerlund, Benjamin B. Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, et al. 2003. "Technology Probes: Inspiring Design for and with Families." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 17–24. CHI '03. New York, NY, USA: ACM.

Igarashi, Yuki, Takeo Igarashi, and Jun Mitani. 2012. "Beady: Interactive Beadwork Design and Construction." *ACM Trans. Graph.* 31 (4): 49:1–49:9.

Igarashi, Yuki, Takeo Igarashi, and Hiromasa Suzuki. 2008. "Knitty: 3D Modeling of Knitted Animals with a Production Assistant Interface." *ResearchGate* 26 (1).

Ikemiya, Miwa, and Daniela K. Rosner. 2014. "Broken Probes: Toward the Design of Worn Media." *Personal Ubiquitous Comput.* 18 (3): 671–683.

Ingold, Tim. 2013. *Making: Anthropology, Archaeology, Art and Architecture*. 1 edition. London ; New York: Routledge.

Jackson, Steven J., and Laewoo Kang. 2014. "Breakdown, Obsolescence and Reuse: HCI and the Art of Repair." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 449–458. CHI '14. New York, NY, USA: ACM.

Jacobs, Jennifer, and Amit Zoran. 2015. "Hybrid Practice in the Kalahari: Design Collaboration Through Digital Tools and Hunter-Gatherer Craft." In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 619–628. CHI '15. New York, NY, USA: ACM.

Kandinsky, Wassily. 1979. *Point and Line to Plane*. New York: Dover Publications.

Kaprow, Allan. 1958. "The Legacy of Jackson Pollock." In *Essays of the Blurring of Art and Life*.

Kent, Corita, and Jan Steward. 2008. *Learning by Heart: Teachings to Free the Creative Spirit*. 2nd edition. New York, NY: Allworth Press.

Kohn, Eduardo. 2013. *How Forests Think: Toward an Anthropology Beyond the Human*. 1 edition. Berkeley: University of California Press.

Lave, Jean, and Etienne Wenger. 1991. *Situated Learning: Legitimate Peripheral Participation*. 1st edition. Cambridge England ; New York: Cambridge University Press.

Law, John. 2008. "Actor Network Theory and Material Semiotics." In *The New Blackwell Companion to Social Theory*, edited by essor Bryan S. Turneressor, 141–58.

Leahu, Lucian. 2016. "Ontological Surprises: A Relational Perspective on Machine Learning." In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 182–186. DIS '16. New York, NY, USA: ACM.

Leahu, Lucian, and Phoebe Sengers. 2014. "Freaky: Performing Hybrid Human-Machine Emotion." In *Proceedings of the 2014 Conference on Designing Interactive Systems*, 607–616. DIS '14. New York, NY, USA: ACM.

Leong, Tuck W., Lalya Gaye, Atau Tanaka, Robyn Taylor, and Peter C. Wright. 2011. "The User in Flux: Bringing HCI and Digital Arts Together to Interrogate Shifting Roles in Interactive Media." In *CHI '11 Extended Abstracts on Human Factors in Computing Systems*, 45–48. CHI EA '11. New York, NY, USA: ACM.

Lindtner, Silvia, Shaowen Bardzell, and Jeffrey Bardzell. 2016. "Reconstituting the Utopian Vision of Making: HCI After Technosolutionism." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 1390–1402. CHI '16. New York, NY, USA: ACM.

Ljungblad, Sara, Maria Hakansson, Lalya Gaye, and Lars Erik Holmquist. 2004. "Context Photography: Modifying the Digital Camera into a New Creative Tool." In *CHI '04 Extended Abstracts on Human Factors in Computing Systems*, 1191–1194. CHI EA '04. New York, NY, USA: ACM.

Maeda, John. 2013. *The Art of Critical Making: Rhode Island School of Design on Creative Practice*. Edited by Rosanne Somerson and Mara Hermano. 1 edition. Hoboken, New Jersey: Wiley.

Maestri, Leah, and Ron Wakkary. 2011. "Understanding Repair As a Creative Process of Everyday Design." In *Proceedings of the 8th ACM Conference on Creativity and Cognition*, 81–90. C&C '11. New York, NY, USA: ACM.

Massumi, Brian. 1992. *A User's Guide to Capitalism and Schizophrenia: Deviations from Deleuze and Guattari*. A Swerve Ed edition. Cambridge, Mass: The MIT Press.

McCarthy, John, Peter Wright, Jayne Wallace, and Andy Dearden. 2006. "The Experience of Enchantment in human-computer Interaction." *Personal Ubiquitous Comput.* 10 (6): 369–378.

McCullough, Malcolm. 1998. *Abstracting Craft: The Practiced Digital Hand*. Cambridge, Mass.: The MIT Press.

Miller, Daniel, ed. 2005. *Materiality*. Durham, N.C: Duke University Press Books.

Monument, Paper, and n+1. 2012. *Draw It with Your Eyes Closed: The Art of the Art Assignment*. 1st edition. Brooklyn, NY: n+1 Foundation.

Mori, Yuki, and Takeo Igarashi. 2007. "Plushie: An Interactive Design System for Plush Toys." In *ACM SIGGRAPH 2007 Papers*. SIGGRAPH '07. New York, NY, USA: ACM.

Morris, William. 2010. "The Revival of Handicraft." In *The Craft Reader*.

Mueller, Stefanie, Pedro Lopes, and Patrick Baudisch. 2012. "Interactive Construction: Interactive Fabrication of Functional Mechanical Devices." In *Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology*, 599–606. UIST '12. New York, NY, USA: ACM.

Mueller, Stefanie, Pedro Lopes, Konstantin Kaefer, Bastian Kruck, and Patrick Baudisch. 2013. "Constructable: Interactive Construction of Functional Mechanical Devices." In *ACM SIGGRAPH 2013 Talks*, 39:1–39:1. SIGGRAPH '13. New York, NY, USA: ACM.

Mueller, Stefanie, Tobias Mohr, Kerstin Guenther, Johannes Frohnhofen, and Patrick Baudisch. 2014. "faBrickation: Fast 3D Printing of Functional Objects by Integrating Construction Kit Building Blocks." In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems*, 3827–3834. CHI '14. New York, NY, USA: ACM.

Neustaedter, Carman, and Phoebe Sengers. 2012. "Autobiographical Design in HCI Research: Designing and Learning Through Use-It-Yourself." In *Proceedings of the Designing Interactive Systems Conference*, 514–523. DIS '12. New York, NY, USA: ACM.

Piekut, Benjamin. 2013. "Chance and Certainty: John Cage's Politics of Nature." *Cultural Critique* 84 (1): 134–63.

Pierce, James, and Eric Paulos. 2014. "Counterfunctional Things: Exploring Possibilities in Designing Digital Limitations." In *Proceedings of the 2014 Conference on Designing Interactive Systems*, 375–384. DIS '14. New York, NY, USA: ACM.

Pierce, James, Phoebe Sengers, Tad Hirsch, Tom Jenkins, William Gaver, and Carl DiSalvo. 2015. "Expanding and Refining Design and Criticality in HCI." In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2083–2092. CHI '15. New York, NY, USA: ACM.

Pye, David. 2007. *The Nature and Art of Workmanship*. London: A&C Black.

Rand, Ayn. 1963. *For the New Intellectual: The Philosophy of Ayn Rand*. New York: Signet.

Ratto, Matt. 2011. "Critical Making: Conceptual and Material Studies in Technology and Social Life." *The Information Society* 27 (4): 252–260.

Rittel, Horst W. J., and Melvin M. Webber. 1969. "Dilemmas in a General Theory of Planning." *Policy Sciences* 4 (2): 155–69.

Rivers, Alec, Andrew Adams, and Frédo Durand. 2012. "Sculpting by Numbers." *ACM Trans. Graph.* 31 (6): 157:1–157:7.

Rivers, Alec, Ilan E. Moyer, and Frédo Durand. 2012. "Position-Correcting Tools for 2D Digital Fabrication." *ACM Trans. Graph.* 31 (4): 88:1–88:7.

Rosner, Daniela, and Jonathan Bean. 2009. "Learning from IKEA Hacking: I'M Not One to Decoupage a Tabletop and Call It a Day." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 419–422. CHI '09. New York, NY, USA: ACM.

Rosner, Daniela K. 2010. "Mediated Crafts: Digital Practices Around Creative Handwork." In *CHI '10 Extended Abstracts on Human Factors in Computing Systems*, 2955–2958. CHI EA '10. New York, NY, USA: ACM.

Rosner, Daniela K., and Sarah E. Fox. 2016. "Legacies of Craft and the Centrality of Failure in a Mother-Operated Hackerspace." *New Media & Society*

Rosner, Daniela K., Miwa Ikemiya, and Tim Regan. 2015. "Resisting Alignment: Code and Clay." In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*, 181–188. TEI '15. New York, NY, USA: ACM.

Rosner, Daniela K., Margaret E. Morris, Ariel Duncan, Sarah E. Fox, Kathi R. Kitner, Ankur Agrawal, and Mei J. Chen. 2016. "Designing for Movement in Public Life with Itinerant Probes." In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 1072–1082. DIS '16. New York, NY, USA: ACM.

Rosner, Daniela K., and Fred Turner. 2015. "Theaters of Alternative Industry: Hobbyist Repair Collectives and the Legacy of the 1960s American Counterculture." In *Design Thinking Research*, edited by Hasso Plattner, Christoph Meinel, and Larry Leifer, 59–69. Understanding Innovation. Springer International Publishing.

Roumen, Thijs, Bastian Kruck, Tobias Dürschmid, Tobias Nack, and Patrick Baudisch. 2016. "Mobile Fabrication." In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, 3–14. UIST '16. New York, NY, USA: ACM.

Ryokai, Kimiko, Stefan Marti, and Hiroshi Ishii. 2004. "I/O Brush: Drawing with Everyday Objects As Ink." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 303–310. CHI '04. New York, NY, USA: ACM.

Saegusa, Hidekazu, Thomas Tran, and Daniela K. Rosner. 2016. "Mimetic Machines: Collaborative Interventions in Digital Fabrication with Arc." In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 6008–6013. CHI '16. New York, NY, USA: ACM.

Schön, Donald A. 1983. *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books.

Sengers, Phoebe, Kirsten Boehner, Shay David, and Joseph "Jofish" Kaye. 2005. "Reflective Design." In *Proceedings of the 4th Decennial Conference on Critical Computing: Between Sense and Sensibility*, 49–58. CC '05. New York, NY, USA: ACM.

Sengers, Phoebe, and Bill Gaver. 2006. "Staying Open to Interpretation: Engaging Multiple Meanings in Design and Evaluation." In *Proceedings of the 6th Conference on Designing Interactive Systems*, 99–108. DIS '06. New York, NY, USA: ACM.

Sennett, Richard. 2008. *The Craftsman*. 1 edition. Yale University Press.

Severny, Andrei. *Inge Druckrey: Teaching to See*. https://vimeo.com/45232468.

Shklovsky, Victor. 1917. "Art as Technique." In *Russian Formalist Criticism: Four Essays*, edited by Lee T. Lemon and Marion J. Reis. University of Nebraska Press.

Smith, Rachel Charlotte, Kasper Tang Vangkilde, Mette Gislev Kjaersgaard, Ton Otto, Joachim Halse, and Thomas Binder, eds. 2016. *Design Anthropological Futures*. Reprint edition. London ; New York: Bloomsbury Academic.

Stephanie Syjuco. 2016. "Empire/Other." Accessed September 2. http://www.stephaniesyjuco.com/p_empireother.html.

Stiny, George. 2008. *Shape: Talking about Seeing and Doing*. Cambridge, Mass.; London: The MIT Press.

Stolterman, Erik. 2008. "The Nature of Design Practice and Implications for Interaction Design Research." *International Journal of Design* 2 (1): 55–65.

Suzuki, Shunryu, Huston Smith, Richard Baker, and David Chadwick. 2011. *Zen Mind, Beginner's Mind*. Edited by Trudy Dixon. Boston: Shambhala.

Tate Museum. 2016. "Jean Tinguely, 'Metamechanical Sculpture with Tripod' 1954." *Tate*. http://www.tate.org.uk/art/artists/jean-tinguely-2046.

Taylor, Robyn, Guy Schofield, Jonathan Hook, Karim Ladha, John Bowers, and Peter Wright. 2013. "Crafting Interactive Systems: Learning from Digital Art Practice." In *CHI '13 Extended Abstracts on Human Factors in Computing Systems*, 3223–3226. CHI EA '13. New York, NY, USA: ACM.

Toombs, Austin L., Shaowen Bardzell, and Jeffrey Bardzell. 2015. "The Proper Care and Feeding of Hackerspaces: Care Ethics and Cultures of Making." In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 629–638. CHI '15. New York, NY, USA: ACM.

Torres, Cesar, Wilmot Li, and Eric Paulos. 2016. "ProxyPrint: Supporting Crafting Practice Through Physical Computational Proxies." In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, 158–169. DIS '16. New York, NY, USA: ACM.

Turkle, Sherry. 1997. *Life on the Screen: Identity in the Age of the Internet*. Reprint edition. New York: Simon & Schuster.

Turner, Fred. 2013. *The Democratic Surround: Multimedia and American Liberalism from World War II to the Psychedelic Sixties*. Chicago ; London: University Of Chicago Press.

Unfold. 2012. *Stratigraphic Porcelain*. http://unfold.be/pages/stratigraphic-porcelain.

Verbeek, Peter-Paul. 2006. "Materializing Morality Design Ethics and Technological Mediation." *Science, Technology & Human Values* 31 (3): 361–80.

Wald, Matthew L. 2001. "Rescuing a World-Famous but Fragile House." *The New York Times*, September 2, sec. U.S. http://www.nytimes.com/2001/09/02/us/rescuing-a-world-famous-but-fragile-house.html.

Weiss, Robert S. 1995. *Learning From Strangers: The Art and Method of Qualitative Interview Studies*. 1 edition. New York: Free Press.

Wilcox, Ella Wheeler. 2012. *Poems of Progress ; and New Thought Pastels*. HardPress Publishing.

Willis, Karl D.D., Cheng Xu, Kuan-Ju Wu, Golan Levin, and Mark D. Gross. 2011. "Interactive Fabrication: New Interfaces for Digital Fabrication." In *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction*, 69–72. TEI '11. New York, NY, USA: ACM.

Winner, Langdon. 1980. "Do Artifacts Have Politics?" *Daedalus* 109 (1): 121–36.

Wright, Peter, Jayne Wallace, and John McCarthy. 2008. "Aesthetics and Experience-Centered Design." *ACM Trans. Comput.-Hum. Interact.* 15 (4): 18:1–18:21.

Yoshida, Hironori, Takeo Igarashi, Yusuke Obuchi, Yosuke Takami, Jun Sato, Mika Araki, Masaaki Miki, Kosuke Nagata, Kazuhide Sakai, and Syunsuke Igarashi. 2015. "Architecture-Scale Human-Assisted Additive Manufacturing." *ACM Trans. Graph.* 34 (4): 88:1–88:8.

Zimmerman, John, Jodi Forlizzi, and Shelley Evenson. 2007. "Research Through Design As a Method for Interaction Design Research in HCI." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 493–502. CHI '07. New York, NY, USA: ACM.

Zimmerman, John, Erik Stolterman, and Jodi Forlizzi. 2010. "An Analysis and Critique of Research Through Design: Towards a Formalization of a Research Approach." In *Proceedings of the 8th ACM Conference on Designing Interactive Systems*, 310–319. DIS '10. New York, NY, USA: ACM.

Zoran, Amit. 2013. "Hybrid Basketry: Interweaving Digital Practice Within Contemporary Craft." In *ACM SIGGRAPH 2013 Art Gallery*, 324–331. SIGGRAPH '13. New York, NY, USA: ACM.

Zoran, Amit, Roy Shilkrot, Suranga Nanyakkara, and Joseph Paradiso. 2014. "The Hybrid Artisans: A Case Study in Smart Tools." *ACM Trans. Comput.-Hum. Interact.* 21 (3): 15:1–15:29.