MAKING AS A LEARNING PROCESS:
IDENTIFYING AND SUPPORTING FAMILY LEARNING IN INFORMAL SETTINGS

by

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Making is characterized by engagement in creative production at the crossroads and fringes of disciplines such as science, technology, engineering, art, and math, and has developed into a recognized social, technological and economic movement. As a creative activity at the intersection of the physical and digital, making integrates current trends in do-it-yourself culture, traditional craft, and emerging technologies, such as physical computing and fabrication. Making is currently being positioned as directly tied to children's participation in science, technology, engineering and math, and to their orientation towards related workforce pathways. There is a growing demand from educators and policymakers for definitions, measures, and guidelines of design that capture the qualities of making as a learning process. The articles that comprise this dissertation respond to this demand, mapping the practices and perspectives of the maker community to foundational theories of the learning sciences. Theoretically, the work is based in the communities of practice framework. In adopting this approach, I am able to distinguish what making is as a learning process, through the identification of the core learning practices of the making community, and to explore how such learning can be evidenced in the context of a designed informal learning environment. First, I present a textual analysis of *Make Magazine*, the most popular textual source of maker community participation, wherein I identify seven core learning practices of the maker community, as well as notable attributes of featured makers, such as gender and disciplinary affiliation. Second, I extend this analysis to family participation in the designed informal learning environment of a children's museum, where I locate and trace evidence of learning through two case studies of young children's contextualized participation in a family maker space. Findings show how young children meaningfully participate in making as a learning process by coordinating contextual resources to participate with intent and sophistication in maker community practices. I discuss key factors that influence children's participation in making as a learning process, as well as implications for leveraging making as a learning process for all.

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1.0 INTRODUCTION

The goal of this collected body of research is to make progress on the notion of *making* as a learning process. Since the articles that comprise this dissertation are among the first empirical research studies to consider the learning potential of this current social phenomenon, they work to lay a foundation for further research and design through an exploratory investigation of *what* making is as a learning process, and *how* such learning can be evidenced in the context of a designed informal learning environment. The analyses presented have direct implications for educators, designers and policymakers who seek to leverage making as a learning process and pathway.

> MAKE unites, inspires, informs, and entertains a growing community of resourceful people who undertake amazing projects in their backyards, basements, and garages. MAKE celebrates your right to tweak, hack, and bend any technology to your will. The MAKE audience continues to be a growing culture and community that believes in bettering ourselves, our environment, our educational system—our entire world. This is much more than an audience, it's a worldwide movement that Make is leading—we call it the Maker Movement (http://makezine.com/about/index.html).

The MAKE brand, which hosts a collection of platforms and programs that support, centralize and give representative voice to their readers and users, characterize makers and their emergence as a community. Making integrates current trends in DIY (do-it-yourself) culture, traditional craft, and emerging technologies, such as physical computing and fabrication. The making community has evolved through forms of social meeting and exchange, through widely distributed publications and online affinity spaces, through regional Maker Faires, or large convenings where makers meet and share their projects and perspectives, and through the increasingly widespread development of maker spaces, places where people blend digital and physical technologies to explore ideas, learn technical skills, and create new products (Sheridan et al, in submission; Dougherty, 2012).

Thought to be both a means to and a mode of participation in disciplines such as science, technology, engineering and math (STEM), making is being positioned by educators and policymakers as a new and promising program of national education reform and the pathway towards our nation's future economic success. Classroom teachers, school administrators, and designers of informal learning tools and environments are seeking funding, building facilities and sharing strategies for integrating making into formal and informal learning contexts. The White House has participated in and hosted numerous public meetings and private conversations to consider the ways in which making can be leveraged to motivate and engage our nation's youth to participate in STEM disciplines and look towards a future which translates the creative spirit associated with makers into jobs and national pride. Just recently, President Obama announced with anticipation the intention to host the first Maker Faire at the White House:

> We cannot wait to see more of that innovative spirit later this year when we host our first ever White House Maker Faire…This new event is going to highlight how Americans, young and old, are tinkerers and inventors, are imagining and designing and building tools and machines that will open our minds and propel our economy. We want to bring this spirit, including more technology, into the classroom (Remarks by President Obama, February 28, 2014).

Across the country, informal learning institutions such as children's museums, science centers and libraries are rapidly working to integrate making into their associated exhibits and programs (Honey & Kanter, 2013), as making has been recognized as a way for these institutions to engage new and existing audiences in their quest to provide disciplinary learning opportunities in science, technology, engineering, art and math. In January 2012 the New York Hall of Science hosted *Design, Make, Play – Growing the Next Generation of Science Innovators.* This was among the first major meetings of practitioners, researchers and policymakers, national foundations and leaders of the Maker Movement to discuss making as a learning process, and highlighted the expanding range of learning experiences through making being developed across the country. A major thrust of the meeting, introduced in an address by Tom Kalil, Deputy Director for Policy in the White House's Office of Science and Technology Policy, was towards the establishment of field-wide definitions and measurable learning outcomes for making. The collection of articles presented in this dissertation represents an empirically based response to this appeal, as I work to map the practices and perspectives of the making community to foundational theories of the learning sciences.

This research has three complementary aims: 1) to characterize making as a learning process through the identification and qualification of the making community and its learning practices 2) to provide an empirical lens through which educators, designers, policy makers and the making community may locate and trace children's contextualized learning through participation in making by extending the notion of making to family learning experiences in designed environments, and 3) to highlight some of the key factors that influence, support and limit learners' participation in making as a learning process.

1.1 MAKING IN MUSEUMS

Typically, maker spaces target and attract adult and youth members, who use these spaces as sites to gather with other individuals who are pursuing individually- or collectively-determined projects (Sheridan et al, in press) and thus provide making resources appropriate for these particular interests and age groups. When maker spaces are incorporated into designed informal learning environments such as children's museums, they must be adapted to the expectations and learning needs of the populations served by these institutions. The majority of visitors to children's museums and science centers in America are families (Museum Audience Insight, 2010), while most children's museums orient their offerings to families with young children, age birth to ten years (Association of Children's Museums, 2012). Families use these institutions as resources for shared leisure and learning (Falk & Dierking, 2000). As a distinctive learning group and unit of analysis, families have become a research focus for museum studies and scholars of informal learning (Ellenbogen et al, 2004). The field of museum research and evaluation has identified typical learning practices of families in conventional museums (e.g., Crowley & Callanan, 1998; Crowley et al., 2001; Ellenbogen, 2002), established principles for effectively designing conventional exhibits for these visiting groups (e.g. Borun & Dristas, 1997), as well as methods for measuring associated discipline-based and behavioral learning outcomes (e.g., Serrell, 1998). Although these principles, outcomes and measures have and continue to guide quality exhibit design for families, they are insufficient for a full understanding of family learning in this new arena of museum-based participation. An extensive literature considers the learning and disciplinary practices that result from families' consumptive engagement with conventional museum exhibits (e.g. NRC, 2009), but little is known how families learn through making as multidisciplinary, technical and creative activity situated within designed informal learning environments. This dissertation works to fill this gap.

Today's maker spaces are unlike most conventional family-centered museum exhibits that are often designed to encourage imaginative play or provide defined outcome-based experiences that are designed to enrich content knowledge. Designed for creative production, maker spaces encompass open-ended, personally-enriching creative opportunities with shop tools and equipment, raw materials such as wood, textiles, and solder, and often require the active presence and participation of skilled and knowledgeable facilitators (Brahms & Werner, 2013). Nascent studies and evaluations of family conversations and behaviors that can be heard and seen as families sew, solder, and build together are distinctly different from those observed through past museum learning research, as children and adults positions with regard to expertise, methods of engagement, and time-scales of participation shift (UPCLOSE, unpublished evaluation). Groups are working to distinguish best practices, authentic indicators and learning outcomes of making as it relates to these designed spaces and the audiences they serve (Bevan et al, in press). And yet, evaluations have shown that many museums and science centers do not have a clear understanding of what distinguishes making, as an informal learning process, from the designed experiences they traditionally have offered (Children's Museum of Pittsburgh, Unpublished Evaluation, 2013). Furthermore, one must question what differentiates making from other recent tried and tested movements in education reform such as gaming, which has and continues to spark heated debate about its legitimacy as a gateway to STEM learning and its effective fit within the structure of formal schooling. As making becomes integrated into the fabric of learning practice, the tandem fields of learning research, design and practice, must work to develop shared lenses and language with which to define, measure and design towards, as they consider the discriminating qualities of making as a learning process.

The data and analyses presented here are part of one of the first federally funded large-scale research projects to study making as an informal learning process, granted by the Institute of Museum and Library Services through the National Leadership Grant program (award number LG-25-12-0577-12) to Children's Museum of Pittsburgh. The goal of this larger study, led by Children's Museum of Pittsburgh and in partnership with the New York Hall of Science, the University of Pittsburgh Center for Learning in Out of School Environments and Carnegie Mellon University's Entertainment Technology Center, is to explore and identify patterns of family participation in making within and across designed informal learning environments, such as children's museums and science centers, in order to more reliably design for families' contextualized learning through making.

Children's Museum of Pittsburgh's *MAKESHOP* is among the first maker spaces to be designed and developed for family learning, and is the main site of data collection and design-based research for the grant. *MAKESHOP* is a rich and supportive informal learning environment for children and families to engage in authentic making experiences with the authentic materials, tools and processes of making. A partnership of the Children's Museum, the University of Pittsburgh Center for Learning in Out of School Environments (UPCLOSE), and Carnegie Mellon's Entertainment Technology Center (ETC), *MAKESHOP* embodies the Museum's dedication to nurturing and furthering informal learning opportunities and research-based understanding. *MAKESHOP* provides Museum visitors open-access to digital media resources and physical materials to produce a robust place for curiosity, exploration, creativity and innovation. A dedicated facilitation team, comprised of skilled makers, artists and educators with specialties in the areas of digital media, sewing and flexible materials, electronics, woodworking and informal learning introduce visitors to the diverse materials and processes of making, as they help visitors translate their visions into tangible products.

1.2 THEORETICAL FRAMEWORK: COMMUNITIES OF PRACTICE

This body of work follows the current understanding of learning as a participatory process that is fundamentally tied to the social contexts in which it occurs—that what people learn is inextricably linked to how and where they learn; learning is considered to be change in participation—knowing through doing—in the socially-determined practices, situated within a given activity setting (Brown, Collins, & Daguid, 1989; Lave & Wenger 1991; Gutierrez and Rogoff 2003; Greeno, 1991, 1997; Hutchins, 1995, 2002, Wenger, 1998; Gresalfi, 2009).

The theoretical framework that grounds this work is that of communities of practice (Lave & Wenger, 1991; Wenger 1998). Lave and Wenger's ethnographic accounts of apprenticeship across geographic location and cultural milieu provide a framework for exploring, identifying, and analyzing learning as social practice. Together, their detailed descriptions generalize and distinguish a process of social learning whereby learners participate legitimately in the practices of the community, and move from peripheral participation as novices, to more central participation as they develop knowledgeable skill in the learning practices of the community, and assume an identity as a member of the community. Over time, members establish trajectories of participation with respect to the practices of the community. Wenger (1998) discusses the ways in which a community's learning practices evolve through the recognition and negotiation of relationships, norms of participation and accountability among members, the pursuit of shared purpose, and the development of shared resources used in the production of new meaning. Qualitative accounts of the collaborative activity and practice development of youth and adults (e.g. Nasir & Cooks, 2004; Cobb, McClain, Lamberg & Dean, 2003) strengthen an understanding of how learning through social participation happens within and across contexts and over time, as they provide methodological insight to the study of family learning in designed informal learning environments.

As alluded to above, makers have begun to distinguish themselves as a learning community, and to delineate aspects of legitimate participation that are more or less definitional to one's association and identity as a maker. In order to inform and advance the nascent but growing national conversation about making as a learning process and pathway for children, I use the communities of practice framework as a theoretical touchstone in two ways: First, as theory to empirically characterize makers as a learning community, through the identification and description of the core learning practices and attributes of the making community. Second, I situate this understanding within the extant literature on family learning in and with designed environments and tools, to locate and trace evidence of learning through young children's participation in making as a learning process through their contextualized activity in an informal learning environment designed for family engagement in making. In so doing, I aim to better understand how opportunities and environments can be designed to support participation in making as a learning process for children and families, and to prove that young children can meaningfully participate in making.

1.3 OVERVIEW OF DISSERTATION

In the first article, presented as Chapter 2 of this dissertation, I investigate the ways in which the making community works to define participation through shared practice and forms of experience. Through a textual analysis of one year of publication of *Make Magazine*, the most popular and ubiquitous textual source of maker community participation, I sought to investigate the extent to which makers associate as a community of practice (Lave & Wenger, 1991; Wenger, 1998), and to characterize their participation as a learning community through the identification and illustration of the community's core learning practices. Analyses focus on two questions: Who are the makers who contribute to *Make Magazine*, and for analytic purposes, represent central participation in making community practice? And what are the learning practices of the making community, as represented in *Make Magazine*? Through an empirical textual analysis of volumes 30-33, I found that makers strongly identify as a community and exemplify many of the core tenants of the communities of practices framework (Lave & Wenger, 1991). Fundamental, to this interpretation is the identification and quantification seven inter-related learning practices which, I argue, are definitional to participation in the making community—*explore & question; tinker, test, & iterate; seek out resources; hack & repurpose;*

combine & complexify; customize; and share—as well as attributes of the makers featured in each article, such as gender and disciplinary affiliation. Analyses also show that there exist current boundaries to participation, such as gender, which must be taken into consideration, as making is positioned as a solution to the recent challenges of STEM education. I discuss the implications of our findings for leveraging making as a learning process by widening the boundaries of participation.

In the second article, presented as Chapter 3 of this dissertation, I extend this notion of making as a community learning practice, through an exploration of how making takes shape in the context of a museum-based maker space, designed for family participation. Through a fine-grained qualitative analysis of two comparative case studies of family participation, I locate and trace young children's contextualized participation in the learning practices of the maker community through an afternoon visit, and identify key factors that influence and support children and families in making as a learning process. Analyses show how learners' evolve their participation by coordinating contextual resources to participate with intent and sophistication in the learning practices of the making community, and prove that young children may establish a meaningful trajectory of participation in making. I discuss the implications of these findings for the design of learning environments and experiences that support family participation in making as a learning process.

Finally, Chapter 4 presents a summary of our major findings, discussion points, limitations, and possible implications, and concludes this body of work by outlining a agenda of future research, design and practice development that grows directly out of the analyses presented herein.

2.0 TEXTUAL ANALYSIS OF MAKE MAGAZINE: CORE PRACTICES OF AN EMERGING LEARNING COMMUNITY

The creative process of *making,* characterized by a practice of messing around at the crossroads and fringes of disciplines such as science, technology, engineering, art and math, has recently developed into a recognized cultural, social, technological and economic movement (Brahms & Werner, 2013). Motivated by a resurgence of interest in DIY (do-it-yourself) culture and prompted by the introduction of new technologies, physical computing and fabrication, the movement has grown to embrace the potential for creativity and innovation made possible at the intersection of the physical and digital.

Born from individual basement tinkerers and garage-mechanic hobbyists, the Maker Movement has evolved to support a strong community among makers, formed through three primary means of social meeting and exchange. First, the remote exchange of the widely distributed publication *Make Magazine* and the online communities such as etsy.com, ravelry.com, DIY.org and many others. Second, the growth of the international Maker Faires' annual showcases of makers' inventions and investigations which have become celebrated meccas of maker culture, attracting hundreds of thousands of makers of all ages and interests. Third, the localized development of maker spaces, hackerspaces, tech shops, and fab labs, where groups composed of diverse ages, genders and backgrounds are motivated to learn with and from one another how to use and combine materials, tools, processes, and disciplinary practices in novel ways.

The opportunity for learning through making has sparked tremendous national recognition and financial support. Making has been hailed for its potential to encourage students to get interested and engaged in STEM (science, technology, engineering and math) education, a potential pathway to providing specific jobs skills to youth for the STEM workforce (e.g. Kalil, 2010), and the well-spring of potential political and economic rebirth (The Economist, 2011). It has been positioned as key to (re)engaging new and traditional users of informal learning spaces such as museums science centers (Honey & Kanter, 2013), as well as the retooling of libraries (Torrone, 2011). Educational platforms have been created to strengthen and associate the many individuals and organizations that seek to integrate and study making as a means of learning, while national funding from sources such as the National Science Foundation, the Institute of Museum and Library Services, the John D. & Catherine T. MacArthur Foundation, and Cognizant, has been provided for the creation, maintenance and study of the learning opportunities manifest through making in various informal and formal educational experiences and environments for children and youth. These include museum- and library-based exhibits and programs, high school tech labs, community maker spaces, national symposia, and exploratory and design-based research studies.

While the Maker Movement has been well documented through popular publications such as *Make Magazine*, and as spaces dedicated to making are becoming widely recognized for the learning potential they afford (Honey & Kanter, 2013; Martinez & Stager, 2013), the learning sciences do not yet have empirical evidence of the current phenomenon of making as a learning process. As the Maker Movement gains momentum, the field demands a better understanding of making as a learning activity that is designed with intention, and reflective of its learning context, be it schools, museums, libraries or living rooms.

In this paper we take up the question of making as a learning process. Similar to recent popular movements of education reform, such as gaming and digital literacies, where initial efforts to determine the educational potential of these emergent learning modalities focused on distinguishing the learning practices of expert gamers (e.g. Squire, 2005; Steinkuehler & Duncan, 2009) or digital natives (e.g. Jenkins, 2006), we seek to identify the learning practices of makers. Like gaming, making is a fundamentally informal learning phenomenon that makes use of high levels of technological fluency and social connectedness, both physical and virtual (e.g. Stevens et al, 2008). Like gaming, while making has been recognized as a gateway to STEM learning pathways and workforce development, it may not fit naturally into a primarily school-based educational pipeline logic model (e.g. Squire, 2005, Gee, 2003). Similarly, where there continue to be debates about the extent to which educational content could and should be "gameified" to accommodate curricular or content-driven educational goals (e.g. Nicholson, 2012), there is tremendous effort to engineer formal and informal learning environments to accommodate the innovative thinking and creativity associated with making.

Our goal in this paper is to explore and identify the core learning practices of making, as they are understood and enacted by the community of makers, themselves. This is a primarily adult community that has emerged and been strengthened through its modes of social communication and exchange. Do these making practices align neatly with those of STEM disciplines, or are there practices that are unique to making and its community? Is making the on-ramp to STEM careers that the educational policy world hopes it to be? Are there discernible and actionable steps the learning community can take to reliably capitalize on making as a learning phenomenon? The answers to these questions begin with an exploration that aims to characterize the making community, and to define its core learning practices.

2.1 MAKING AS A COMMUNITY PRACTICE

Over the past few decades, an important theoretical shift has taken place, whereby learning theorists have increasingly considered and demonstrated learning as fundamentally tied to the social and cultural contexts in which it occurs—that *what* people learn cannot be separated from *how* they learn it—and learning as an interaction among the social, physical, and temporal aspects of shared activity (Brown, Collins, & Daguid, 1989; Lave & Wenger 1991; Gutierrez and Rogoff 2003; Greeno, 1991, 1997; Hutchins, 1995, 2002). This body of work focuses on the "cultural practices" in which people, and the communities of which they are a part, engage through their lived experiences with the world. Here, learning is considered a to be a change in participation—knowing *through* doing—in a given practice as it is situated within a given activity setting (Lave & Wenger, 1991; Wenger, 1998; Gresalfi, 2009). As others have simply stated, learning is thought to be a characteristic of practice (Wenger, 1998; Nasir & Cooks, 2009).

Lave and Wenger (1991) codified the notion of learning emerging from the individual's participation in the cultural practices of a community, with the framework "Communities of Practice." Using examples of the apprenticeship practices of midwives, tailors, quartermasters, butchers, and recovering alcoholics, they generalized and distinguished a process of social learning whereby learners (apprentices) participate in communities of practitioners and move from peripheral participation as a "newcomer," towards mastery as an "oldtimer." For Lave and Wenger, community does not "imply necessarily co-presence, a well-defined identifiable group, or socially visible boundaries. It does imply participation in an activity system about which participants share understandings concerning what they are doing and what that means in their lives and for their communities" (p. 98).

Lave and Wenger describe the movement of newcomers becoming core participants in the community as *legitimate peripheral participation,* which depends on newcomers' legitimate participation in the sustained practices of the community, and results in the development of knowledgeable skill and identity as a member of the community, or as Lave (1996) qualifies, "the production of persons" through participation in the community. Yet, equally as important is the cyclical development and transformation of the community, as newcomers eventually become oldtimers. Learning through practice is a dynamic process of being engaged, and participating in the ongoing and changing practices of the community. Wenger discusses three interrelated and evolving forms of participation that characterize a community of practice: *Mutual engagement,* or the recognition and negotiation of relationships and norms of participation; *joint enterprise,* or the pursuit of shared purpose, which lends to accountability among members; and developing a *shared repertoire,* or a set of shared resources used in the production of new meaning, which includes participatory and reified aspects of practice through the generational renegotiation of meaning and reinvented practice (Wenger, 1998). As community members participate in authentic social practices and forms of participation over time, their engagement in these aspects of community participation gain structure and meaning.

A learner's negotiation of meaning involves the interaction of two integral processes, which Wenger calls *participation* and *reification* (Wenger, 1998). For Wenger, *participation* is the social process of being active participants in the practices of social communities and constructing identities, or the development of self in relation to these communities through practice. Participation in social communities shapes members' experiences, as it also shapes the communities in which they practice. *Reification* is the process of giving form to our experience, in process and product. Wenger explains, "any community of practice produces abstractions, tools, symbols, stories, terms and concepts that reify something of that practice in a congealed form" (p. 59). Such reifications of community practice create points around which the negotiation of meaning may become organized and practice realized.

Through participation and reification learners establish trajectories of participation with respect to the practices of communities. The Communities of Practice framework has been applied to a range of educational contexts to understand such things as students' practiced tasks (e.g. Roth & Bowen, 1995) and positionality (Bielaczyc & Collins, 1999) within classroom communities, the contextualized instructional practices of teachers (Cobb et al, 2003), the informational and interpersonal learning trajectories of students (Greeno & Greslafi, 2008), and athletes' trajectories of identity formation through community resource activation on the track field (Nasir & Cooks, 2009).

In this paper, we take up the question of making as a community learning practice—the ways in which the making community works to define participation, and therefore itself, through shared practice and forms of experience. To do so, we looked to the most popular and nationally recognized textual source of maker community participation: *Make Magazine*. With a reported readership of 300,000 (http://makermedia.com/press/fact-sheet/), this platform is a logical place to turn to identify and verify the community's core practices and definitional perspectives. To approach this analytical task, we take a learning sciences approach and draw on the Communities of Practice framework as a theoretical touchstone. Our analyses of one year of the magazine's publication (vol. 30-33) focus on two questions: Who are the makers who contribute to *Make Magazine*, and for analytic purposes, represent central participation in making community practice? And what are the learning practices of the making community, as represented in *Make Magazine*? To answer these questions, we will begin by describing the attributes of the makers who authored each article, and therefore comprise the community, followed by an introduction to the learning practices of the community that were identified across the articles. To illustrate these practices, we will take a close look at how they are exemplified through an analysis of a single feature article.

2.2 DATA SOURCE: MAKE MAGAZINE

We chose *Make Magazine* as our data source because it is the oldest and most visible textual marker of a branded movement gaining a strong foothold in a broad conversation about learning. It is a curated and edited collection of individual, self-identified, primarily adult makers, describing and discussing their own and others' making processes and projects through text, images and photos.

The MAKE brand, founded by Dale Dougherty, has become the most visible reference point for the Maker Movement. Make describes itself as follows,

> MAKE unites, inspires, informs, and entertains a growing community of resourceful people who undertake amazing projects in their backyards, basements, and garages. Make celebrates your right to tweak, hack, and bend any technology to your will. The Make audience continues to be a growing culture and community that believes in bettering ourselves, our environment, our educational system—our entire world. This is much more than an audience, it's a worldwide movement that Make is leading—we call it the Maker Movement (http://makezine.com/about/index.html).

The MAKE brand's most centralized platform for communication among the community of makers is its magazine, *MAKE Magazine*. Originally published by O'Reilly Media, MAKE and its affiliate brands—*Make Magazine*, Maker Faire, Maker Shed and Makezine.com—spun out as its own company, Maker Media, Inc. in January 2013. *Make Magazine* has been in quarterly publication since February 2005, as a hybrid magazine/book. Each 200-page volume contains approximately 40 articles, written and edited by makers, including profiles of makers and projects, how-two guides, product reviews, and thematic features:

> MAKE: Magazine brings the do-it-yourself mindset to all the exciting projects in your life and helps you make the most of technology at home and away from home. Projects in the magazine range from old-school balsa wood and tissue-paper airplanes to what to do to keep aging high-tech gadgets alive to building autonomous robots from junk (http://makezine.com/about/index.html).

Make Magazine was created with the intention of sparking a community; a movement of makers originating with a shared past and vision for the future. As a June 2005 op-ed piece describes, "Make…is a throwback to an earlier time, before personal computers, to the prehistory of geekiness - the age of how-to manuals for clever boys, from the 1920's to the 50's.…The technology has changed, but not the creative impulse" (NYT, June 12, 2005). The piece goes onto to clarify Make's agenda for participation,

> Make is not just a clubhouse for guys with Skittle breath and abbreviated social skills. Beneath all the home-brewed gadgets and cool software tricks lies a sly and subversive agenda. Make, its makers will tell you, is part of a grass-roots rebellion against consumer technology that they say stifles ingenuity by discouraging end-user modification…In this world, to tinker - to open the case, to fiddle with wires and see what happens - is to rebel (NYT, June 12, 2005).

As an introduction to the inaugural volume, the editors welcomed readers through a declaration of community identification and an invitation to join the bourgeoning movement. "More than mere consumers of technology, we are *makers*, adapting technology to our needs and integrating it into our lives. Make is a new magazine dedicated to showing how to make technology work for you" (Dougherty, Make: Vol. 1, p. 7, 2005).

Maker Faires and Mini Maker Faires have now spread across the world, and today the Make brand has grown to include derivative projects and programs for youth and educators such as the Maker Education Initiative, a non-profit educational arm of the brand which seeks to be the networked support of the bourgeoning make-related learning landscape. *Make Magazine*, through its longevity and visibility could be considered the archival journal of the maker community; establishing, shaping and reinforcing practices, beliefs and values of the community by way of its contributors, editors and readership.

As a data source, *Make Magazine* is not a direct observational record of the making process, nor is it the only publication associated with the Maker Movement. Therefore, our findings should be interpreted as representing the sample from which they were derived—a primarily adult, male, well-educated and affluent population of makers[1] who, through wide distribution and esteem, have come to represent a broad movement of individuals whose ages, genders, educational aspirations and financial situations vary far more than those selected for representation in the pages of this publication. Despite these limitations to generalizability, we consider *Make Magazine* a useful benchmark for identifying and characterizing the qualities and behaviors of this emerging community.

2.3 WHO ARE THE MAKERS WHO CONTRIBUTE TO MAKE MAGAZINE?

In turning to *Make Magazine* as a data source, where makers openly display and share their making processes, products and personalities, we first seek to develop an understanding of the makers themselves as representatives of the community of practice. Specifically, we are interested in makers' orientation of their own participation. Making is currently being positioned as a direct pathway to participation in STEM careers. In what ways do the makers featured in *Make Magazine*, and their making endeavors identify and align with these disciplinary orientations?

The Makers who contribute to *Make Magazine* are mostly men. The gender of authors or featured makers of each article tallied. Reflecting and surpassing the readership of the magazine, 89% of the authors or featured makers across the sampled articles of *Make Magazine* were men and only 11% were women. Most (64%) of the time when women appear as authors or featured makers, they were part of a team that included at least one man.

[1] Make reports that among readers, 81% are male, 19% female, with a median age of 44 and median household income of $106,000. 97% graduated from and/or attend college, 80% have a post-graduate degree and 83% are employed. (http://makermedia.com/press/fact-sheet/).

Makers are multidisciplinary. Figure 2.1 reveals the frequency of disciplinary attribution across the articles. Each article was coded as being framed, or not, by one or more of the disciplines of science, engineering, technology, math, and art. STEM disciplinary affiliation was determined based on the core learning practices of each discipline as they have been described in the most recent consensus reports published by the National Research Council (NRC, 1999, 2001, 2007, 2009, 2010, 2012a, 2012b). In the case of art, where authoritative consensus documents are unavailable or inconclusive, foundational learning research studies supplement these identified practices (e.g. Eisner, 2002; Hetland et al, 2007). If the authors' description of their process or featured product clearly encompassed discernable aspects of disciplinary practice, the entire article was coded as being framed by that discipline. Each article could be framed by one, two or three representative disciplines. In cases where more than three disciplines may have been present, researchers discussed the representation and agreed on which disciplines were dominant.

The majority of articles were multidisciplinary. The figure shows that these disciplines are present in the activities of makers, yet rarely does each discipline occur independently of others. Science, technology, and engineering were the most common disciplinary framings for the articles, although art was also common. This analysis begs the question of what disciplinary communities makers are most connected to or aligned with. This analysis supports the idea that that the activity of making may well lead to participation in the STEM disciplines, or at least the disciplines of science, technology and engineering, but disciplinary affiliations were not comprehensive, either within or among disciplines.

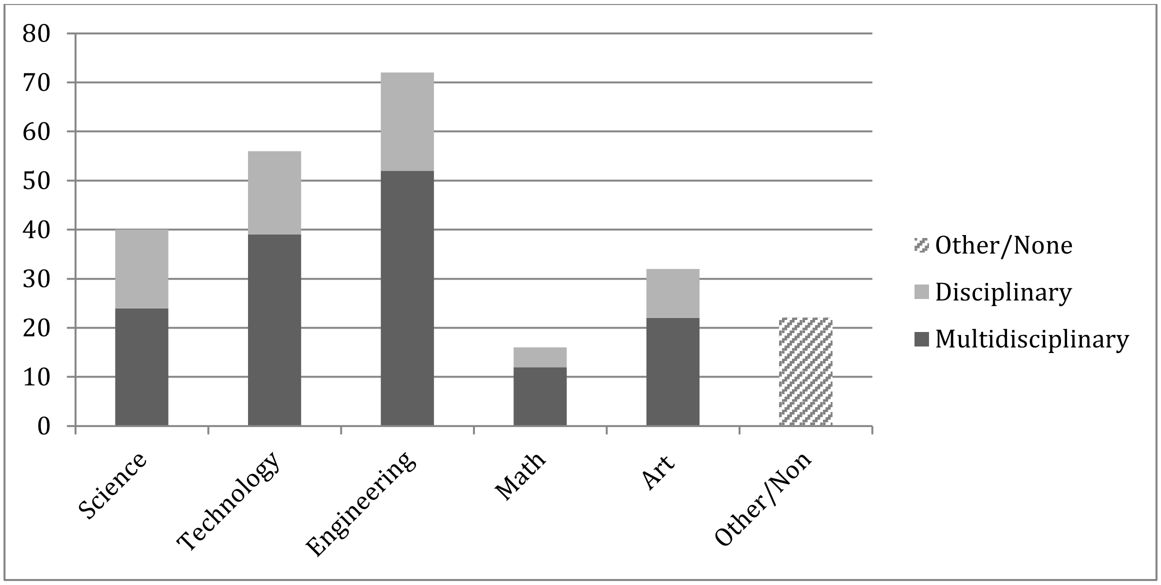

Figure 2.1. Disciplinary Framing and Co-Occurrence

Figure 2.2 shows the disciplinary-based professional affiliations of each article's author(s) and featured makers. These professional affiliations were determined based on authors' own explicit identification with a disciplinary profession either within the body of the text or within the byline of the article. The majority of authors did not identify as working in the disciplines. Rather, within the context of *Make Magazine*, many makers' self-identification was with their diverse and often playful interests outside of their professional affiliations. For example, one author who shows readers how to grow and use bhut jolokia chili peppers in Volume 33, describes himself as "a web geek living in Portland, OR, who loves building tall bikes, brewing beer, and growing unusual edibles" (pp. 88-91, vol. 33), while another author, the maker of The Electronic Nag from Volume 30, describes himself as "a forgetful, loving husband and the proud father of three beautiful little girls. He has always had to learn how everything works" (pp. 50-53, vol. 30). Those authors and makers who were identified as "other" describe themselves as a polyglot of professions and interests, ranging from students (as young as 8) to teachers (Vol. 30), lawyers (Vol. 30), community organizers (Vol. 31), and even includes a naval officer (Vol. 32), physical therapist (Vol. 31), and "fireworks master" (Vol. 33).

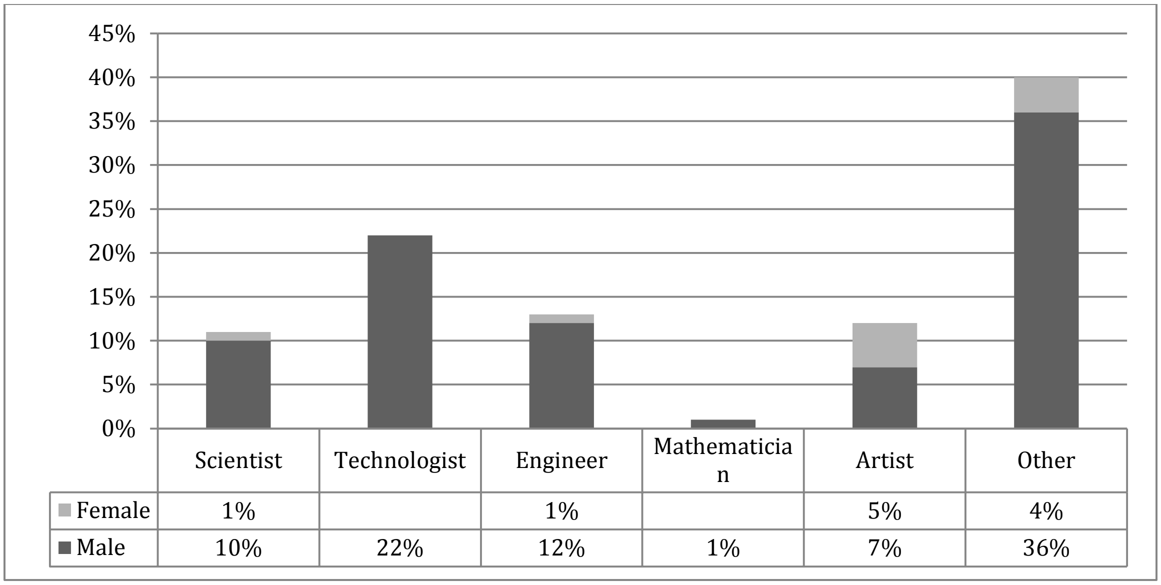

Figure 2.2. Author's Professional Disciplinary Affiliation

Even when authors identify as working in a discipline, it did not necessarily mean that their making activity was aligned to their professional affiliation. When we compared the disciplinary framing of the articles with the disciplinary self-identification of the authors, 61% of authors wrote an article that was framed by a discipline other than their stated professional discipline.

2.4 WHAT ARE THE LEARNING PRACTICES OF THE MAKING COMMUNITY, AS REPRESENTED IN MAKE MAGAZINE?

In a community of practice, learning is a dynamic process of being engaged, and participating in the ongoing and changing practices of the community. To identify the core learning practices of the making community, we read all selected volumes of *Make Magazine*, volumes 30-33, to gain a comprehensive sense of the data (Tesch, 1990), collecting lists and memos of key characteristics, qualities and emergent patterns of maker practice that surfaced through this initial reading. We then engaged in several cycles of inductive and iterative coding of two volumes of *Make Magazine* (Vol. 30 & 31) until the identification of defining patterns of the maker community's practices emerged. From these, we iteratively developed a set of codes reflective of these identified patterns of practice. This included extensive discussion, examination, re-examination and definition of categories. A coding scheme and manual was created to establish and identify the qualities and quantities of these specific practices, as well as other attributes of the makers featured throughout the volumes, such as gender and disciplinary affiliation. We then re-coded all textual data (n=162 articles) using an analysis software. Texts were segmented by main idea being conveyed. Since our goal was to identify and characterize maker community practices, codes were not exclusively assigned to specific text segments, as some segments described multiple practices. Inter-rater agreement, performed on roughly 60% of the data, was 92%. Using the coded text conceptually ordered matrixes (Miles & Huberman, 1994) were created to reduce the data, and to more clearly see, compare and contrast examples and dominant factors related to the broad themes of maker community practices.

Our analysis revealed a set of seven core learning practices that associated with recognizable participation in the maker community: *explore and question; tinker, test, & iterate; seek out resources; hack and repurpose; combine & complexify; customize; and share.* Table 2.1 summarizes these community practices.

The analyses that follow quantitatively describe the representativeness of the practices across the articles, and qualitatively describe the practices through an illustrative example.

Table 2.1
Maker Community Learning Practices

Maker Community Practice	**Definition**
Explore & Question	Interrogation of the material properties of the context in order to find inspiration or to determine intention for a process or project.
Tinker, Test & Iterate	Purposeful play, experimentation, evaluation and refinement of the context.
Hack & Repurpose	Harnessing and salvaging component parts of the made world to modify, enhance, or create a product or process.
Combine & Complexify	Developing skilled fluency with diverse tools and materials in order to reconfigure existing pieces and processes and make new meaning.
Seek out Resources	Identifying and pursuing the distributed expertise of others, includes a recognition of one’s own not-knowing and desire to learn.
Customize	Tailoring the features and functions of a technology to better suit one’s personal interests and express identity.

Share	Making information, methods and modes of participation accessible and usable by members of the community.

Figure 2.3 shows the percentage of articles that evidenced each of the practices. It is clear that each of the seven practices are relatively common across articles, with percentages of identified practices ranging from 51% of articles containing the practice *Seek out Resources*, to 28% of articles containing the practice *Combine & Complexify*.

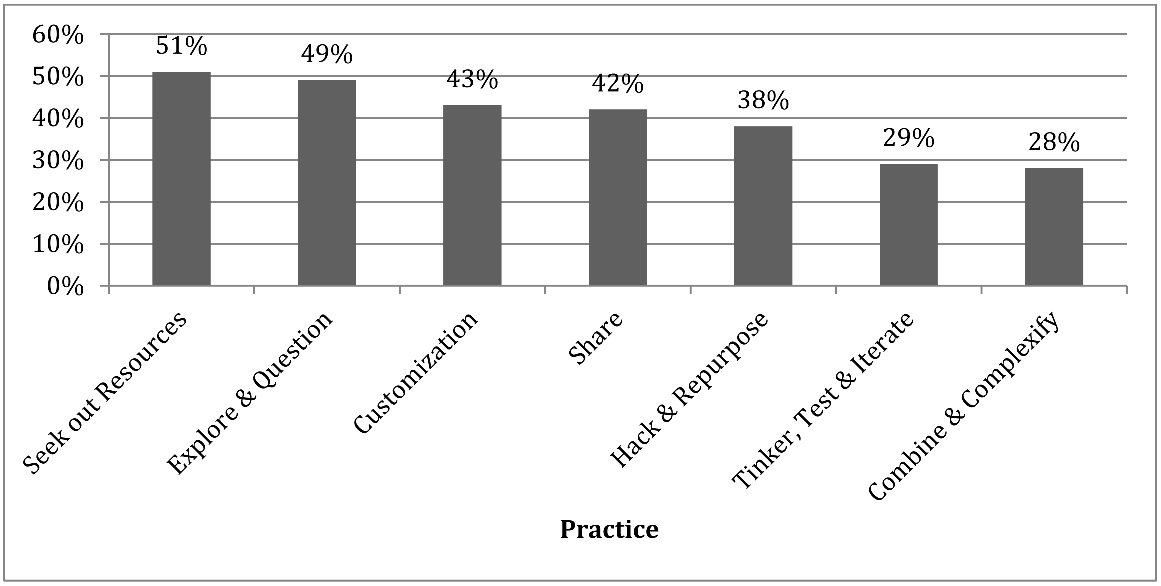

Figure 2.3. Evidence of Practice per Article

Making practices tend to co-occur within an article. Figure 2.4 shows that 75% of articles contained two or more practices and more than a third of the articles contained four or more practices. This finding suggests that the practices may be commonly part of a repertoire that characterizes making, or participation in the community of makers, as opposed to specialized practices that some makers use and others do not.

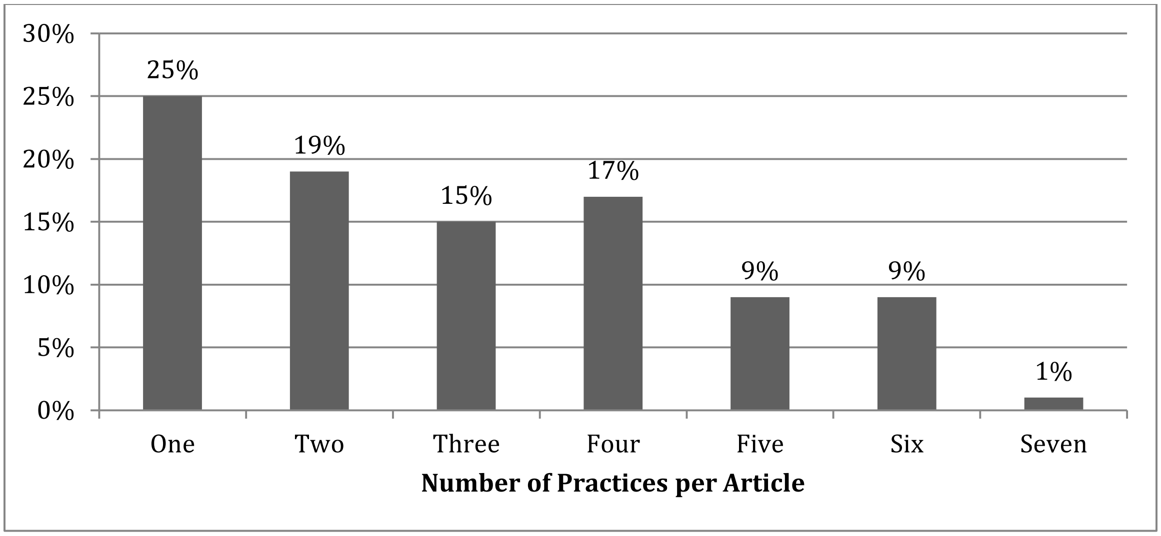

Figure 2.4: Number of Practices per Article

To illustrate the influence of these practices in detail, we will describe one example of making: Rocket-Ship Tree house, a feature article in Make, Volume 31 (pp. 144-151).Rocket-Ship Tree house is the story of a dad, Jon, his friend and colleague, Jeremy and their process of building a backyard play structure for Jon's six-year old son Eliot. What began with the simple idea of beautifying a small backyard space, developed into an elaborate project that spanned two years, evolved to include a host of neighborhood friends, exponentially expanded Jon, Jeremy and Eliot's knowledge base and skill set, harnessed their imagination and creative spirit, and above all, solidified their identities as makers. Through the authors' description of their process and project, we may come to qualitatively understand the identified practices of the maker community.

The rocket ship was conceived of when Jon's wife suggested that Jon install a tree house for their son Eliot under the trees in the backyard. Jon, a researcher at Mircosoft, took the request as a challenge, and through an elaborate and imaginative process, decided to, instead build a stationary rocket ship as a play structure for his son. As the vision for the project became more elaborate, Jon recruited his colleague, Jeremy to collaborate on the electrical aspects of the rocket ship.

The rocket ship, or RULAV (Ravenna Ultra-Low Altitude Vehicle, named after the makers' Seattle, Washington neighborhood) is a hexagonal capsule, rising 15 feet off the ground, atop a tripod structure. The capsule is 6.5 feet wide, and is framed in welded steel with a riveted aluminum skin. Inside, the rocket contains nearly 800 LEDs forming flashing lights and numeric display panels. The “pilot” controls the rocket using a joystick, switches, knobs and buttons. The rocket “takes off,” “rumbles” and “docks,” by way of “thrusters” that shoot compressed air and water, accompanied by vibration and sound effects (http://rocket.jonh.net/intro.html).

Explore & Question: Makers generally approach a project or making process through the practice of questioning and exploring the context of activity and/or problem space. Makers are curious people, whose interest in and wonder about a particular topic leads to inquiry and exploration. Makers interrogate the past, researching and referencing former projects and ideas related to their future intentions. Contributing authors of articles to *Make Magazine* often introduce the reader to their motivation for engagement in the particular project, medium or process of making to be considered, through an explanation of their process of investigating personal and/or collaborative inquiries.

For Jon and Jeremy, the question came as a suggestion posed by Jon’s wife to build a simple tree house for their son, yet taken up as an exploratory challenge by Jon, Eliot and eventually, Jeremy. Their exploratory process began with a trip to Boeing Surplus to scrounge for inspiration amidst the piles of used parts. Jon and Eliot brought home a few big sheets of aluminum and some aluminum tube to test their initial idea: a geodesic structure formed entirely by bending and riveting. Yet, the authors attest, “early prototypes wouldn’t stand up, proving that we really didn’t know much about mechanical engineering” (p. 144). Through their questioning and testing of materials, the makers realized “weight wasn’t a design constraint for a rocket that never leaves the ground; it would be just fine to use steel” (pp. 144-146). Thus, they defined the design of the rocket’s exterior, or chassis and skin, through an exploration and questioning of the material-constraints.

Tinker, Test & Iterate: Makers explore materials and processes through purposeful play, experimentation, and ongoing evaluation. Makers are doers, rather than planners. Yet, the doing is iterative and sequential. Makers model designs with software, they build and test paper prototypes, and they evaluate their process to discover what is possible or to improve upon what has come before. Makers try, make mistakes, and fail—a lot. Makers value the iterative process of engagement in making and testing out ideas as much as the finished product. For makers, each successive iteration of a project presents an opportunity to develop applicable skills and grow relative knowledge for oneself and for the community of makers.

The authors' portrayal of the design and development of the tree house's internal electronics showcases their deep investment in their iterative learning process. Jon and Jeremy's original goal was to fill the rocket's interior with an array of flashing LED lights, numeric displays and dials. Jeremy went about designing a circuit board that would light up an 80 segment numeric display that the makers intended to build themselves. The authors describe the intricacies of the electrical system, and attest, "An early prototype worked, but even with only 2 LED digits, it took a week of evenings to construct. We had to carefully modify a prototyping board with a rotary tool, and solder in each component and wire connection" (p. 148). Although they describe the process as "time-consuming, error-prone, and not very fun," the challenge provoked them to persist with their iterative design:

> Sane treehouse builders might decide to scale back their ambitions. We went the opposite direction: why not design our own printed circuit board (PCB) and have it fabricated in bulk? The only problem was, we hadn't done anything of the sort before — in fact, we'd only recently learned how to light up an LED (p. 148).

Jon and Jeremy describe an intense readiness to try in the face of the unknown, to test ideas and push beyond their existing boundaries of ability, to persist when challenged, to pursue creative solutions, and to turn to the resources of the maker community for support in order to make progress on their personal project.

Seek Out Resources: Makers are resourceful. They seek out and rely on the expertise of others. Makers know where and to whom to turn for guidance and collaboration. They willingly seek and give advice and feedback. They interact flexibly with the distributed tools, materials and expertise of the community. This practice of seeking out resources is often enacted through Internet searches and online forums. It is also frequently played out through the recruitment of friends and colleagues with diverse skill sets and knowledge, as well as through the active use of local community-developed resources for discussion, design and fabrication.

Jon and Jeremy overcame the challenge of generating enough customized circuit boards to ignite the inside of their rocket-ship with flashing lights and numbers through a little resourcefulness. The authors declare, “The thriving DIY community came to the rescue” (p. 148). Jon and Jeremy turned to their online community for instruction and feedback when creating their own printed circuit board (PCB). They learned PCB design through online tutorials and discussion boards, used readily available software to hone their previously rudimentary skills, created a working schematic and layout drawing, and virtually sent their design to be professionally fabricated. Although there was a learning curve, Jon and Jeremy researched, discovered and activated community resources to suit their creative and functional needs. In so doing, they developed their own knowledge of electronic processes and related design skills, and they also gained a deeper sense of the wealth of expertise among makers that can be harnessed and channeled.

Hack & Repurpose: Makers see the world as made of component parts; pieces and platforms that can be opened, deconstructed, modified, and repurposed to create something new, improved, altered, or recombined to better suit the needs and desires of an individual or community. Makers would rather repurpose a found object or salvaged component than buy something new. The community of makers is one that values affordability, accessibility and ingenuity over sleekness and precision. Hacking and repurposing is a practice of problem solving and improving functionality, but is it is also an act of improvisation, creativity and an opportunity to put the stamp of individuality on a project or process.

To simulate the experience of a pilot’s launch, positioning, and landing, Jon and Jeremy sought to create just the right rumble, vibration, and sound effects of the rocket’s engine using pressurized gas to produce mechanical motion. To do this, they hacked and repurposed a few commonly found products from a hardware supply store. The “booster” was made from an old paint shaker that creates the perfect vibratory feeling during “takeoff,” and the thrusters were made of repurposed automotive engine-cleaning wands, “that aerate water using a supply of compressed air, producing a convincing jet blast of mist” (p. 150). Having mastered electronic programming, the makers nostalgically decided to connect the “boosters” and “thrusters” to the main control panel through electronically actuated valves controlled by a repurposed vintage PC joystick from the computer games of their own youth. They add, “we even created a rocket version of the classic video game *Pong,* to keep crew morale high during long trips to the Moon" (p. 151).

Jon and Jeremy intentionally chose to use repurpose materials that were readily available and inexpensive, familiar simulations of more complex systems, as well as joyful associations that both personalized the experience and introduced Eliot to an element of the adults' own childhood adventures.

Combine & Complexify: Makers look towards a future of endless innovative possibility. Yet, they do so with the recognition that they are standing on the shoulders of past crafts people and makers who created tools, products and platforms, both analog and digital, which can be harnessed, combined and adapted to enable future ingenuity. The practice of developing skilled fluency with a diverse set of physical and digital tools, materials and processes of construction, in order to put these existing pieces and processes together differently, is central to making, and enables makers to extend what is possible. Inherent in this practice is an impulse to learn and an acknowledgement that there is always more to learn—that what is not yet known is of deep personal interest, is learnable, usable, and useful to oneself and to the community of makers. The practice of combining and complexifying is a practice of lifelong learning.

Jon and Jeremy liken their ongoing and increasingly complex project to the "opening of floodgates." The author's write, "we realized the rocket's electronics could do far more interesting things than just display random numbers" (p. 150). The makers combined individual elements to create an overall affect of a takeoff sequence: "A countdown is displayed on a control panel while audio from the real Apollo 11 sequence is played. At zero, the lights start to flicker, and the rocket starts to rumble from the movement of the paint shaker and the bass from our subwoofer" (p. 150). The authors recount with pride:

> Rarely does building a treehouse require welding, grinding, painting, riveting, bending, crimping, plumbing, brazing, laser cutting, sound design, printed circuit board fabrication, distributed network protocols, an embedded operating system, sewing, and even embroidery (p. 144).

Each newly envisioned feature of the rocket revealed a novel skill or tool for the pair to learn, use and hone. As the project expanded in scope, so did makers' roster of familiar tools, materials and processes that they could combine to extend what was possible for this and future making endeavors.

Customize: Making is a personal pursuit. The subtitle of *Make Magazine* originally read, "technology on your time." Since its inception, the community of makers has sought to alter technology to suit individual and community needs, and to express personal and collective beliefs. In 2005, founding editor Dale Dougherty identified the communal drive of makers: "adapting technology to our needs and integrating it into our lives" (Vol. p. 7). Through the practice of customization, makers tailor the features and functions of a technology to make it their own.

As the project evolved, Jon and Jeremy learned about and integrated many maker processes to create a highly customized technological system that combines mechanics, electronics, pneumatics, and software to create a singular experience. Moreover, it is evident that Jon and Jeremy's ambitious rocket ship project was not only motivated by personal aspiration—a tree house for Jon's young son—it became a highly collaborative and joyful pursuit of learning and making that stretched across generations. The authors explain, "It became transparent that the treehouse was just as much an engineering playground for the adults, a place for us to share our joy of making and teach it to the kids" (p. 144). The practice of customization can be seen in the incorporation of personal touches such as the joystick from the makers' youth, to the way in which Jon and Jeremy strongly identify with the process and products of their pursuit, to the intentionality of communicating a shared family and community value through the making process. The authors conclude, "since Eliot was with us every step of the way, he also learned that toys aren't just something you buy, they're something we can build — together" (p. 151).

Share: Makers openly share and access the stuff of making with the entire community of makers through diverse platforms for presentation, reception, and communication. Often characterized as "open source," the make community works to develop repositories of information, kits and systems of communication, which make tools, materials, methods of design and fabrication, and products accessible, customizable, and usable by the entire community. This practice of sharing is at the core of *Make Magazine* itself.

Within the pages of *Make Magazine*, Jon and Jeremy's story is accompanied by photos and drawings of their process, as well as sidebars in which the authors share tips and resources related to the many processes they engaged and eventually mastered through their project: welding, riveting, brazing, etching and programming. The authors provide advice, compare sources and prices of products, review software, link to related articles previously published in the magazine, and add personal tips to encourage the reader to engage in similar endeavors.

The makers also created their own website to share their project (http://rocket.jonh.net/), which describes the entire process, from conception to blast-off, in detail. The extensive site walks the reader through each step in the process, complete with photographs and videos, as well as open source links to download the makers' plumbing and operating system designs, and electronic and PCB schematic files. Here, Jon and Jeremy invite the visitors to provide feedback, and even encourage visitors to "schedule a flight" if ever in the Seattle area.

2.5 DISCUSSION

Through this study of makers as a community of practice, our goal was to explore and identify the core learning practices of making as they are understood and translated by the community of makers themselves. Findings reveal that makers strongly identify as a community and exemplify many of the core tenants of the communities of practices framework (Lave & Wenger, 1991). Principle is the distinction of seven highly integrated practices of making that might be said to characterize recognizable participation in the community of makers. Recall that Lave & Wenger (1991) assert that through legitimate peripheral participation in community practices, community members gain knowledgeable skill and construct identities relative to the community. As they do so, novice members become more central to the community's participatory and reified qualities, and usher generational changes in forms of community participation. Recognized comprehensively and woven together through makers' individual and communal methods of participation, the seven identified maker practices may be considered central to community identification and continuance, communicating community values and orienting future community development.

2.5.1 Makers as a Community of Practice

Recall that Wenger (1998) identifies three interrelated dimensions that together characterize a community of practice: mutual engagement, joint enterprise and shared repertoire.

Mutual engagement involves the recognition and negotiation of relationships and norms of participation, such as individual differences and similarities, relative talents and areas of expertise. Each participant in a community may be positioned in relation to others and in relation to the aspects of practice they take up and provide (Wenger, 1998; Nasir & Cooks, 2004). Participation in the maker community is defined, in part, by the recognition and use of the community's distributed expertise (Hutchins, 1995). The making community has established clear systems of sharing, adopting and adapting one another's knowledge and skill. In so doing, the community has asserted the inherent value in members' development of niche interests and areas of expertise, and therefore, in the learning process itself—intentionally participating in the practices of sharing and seeking out knowledge and skill from others, appreciating that there are always more to learn as individuals and as a community.

Joint enterprise is the pursuit of shared purpose, which lends to accountability among members. Over time, the joint pursuit of an enterprise creates resources for negotiating meaning, as well as the notion that individuals are becoming part of something larger than themselves (Wenger, 1998; Barab & Duffy, 2000). From its very beginnings as a reified community, makers established a joint enterprise of "making technology work for you" (Dougherty, *Make Magazine*, vol. 1, p. 7, 2005). Over time, this declaration has gained meaning and momentum among community members, towards the playful pursuit of personalized learning and innovation. Through participation in practices such as exploring and questioning, tinkering, testing and iterating, hacking and repurposing, combining and complexifying, and customization makers seek to discern, advance and make accessible new mediums, modes and mechanisms for problematizing and enhancing life; for evolving ideas, methods or products for oneself and for the community.

A community of practice creates a *shared repertoire,* or a set of shared resources used in the production of new meaning, which includes participatory and reified aspects of practice. Developed, negotiated and shared repertoires reflect a history of mutual engagement. In the short history of the Maker Movement, community members have established systems of belief, communication, and even commodification that provide the community with a shared discourse and recognizable, yet negotiable and changing expressions of identity around which to unite and debate. For example in Volume 32 (pp. 12-14), an author "soapboxes" about the dynamic tension between the community's foundational belief in sharing through open source hardware—or access to reified aspects of practice, such as schematics, source and code—and the rising tide of entrepreneurism among makers.

2.5.2 Trajectories of Participation

We now turn to evidence of trajectories of individual and community participation. As makers participate legitimately in the practices of the community, to what extent are they developing and transforming knowledgeable skill and identity for themselves and the community? What forms of participation are at the center?

Through this analysis we sought to determine if and how maker community practices align with and point towards the core learning practices and pathways of STEM disciplines, as championed by educational policy. Lave and Wenger's theory (1991) suggests that community practices are contextualized within community participation, and that as one becomes more expert in such practices, he/she becomes more central to the continuation and development of the community. Our analysis suggests that the practices that characterize participation in making (at least as evidenced in *Make Magazine*) cannot be simply described as practices that come from or point to any one educational disciplinary pathway such as engineering, science, or math. It can be argued that aspects of maker practice are drawn from or resemble certain disciplinary practices (e.g. the maker practice of *explore and question* is comparable to the practices of asking questions, for science, and defining problems, for engineering, (NRC, 2013)), but no one discipline or singular set of established disciplinary practices captures the essence of participation in the making community. Makers have developed a set of sophisticated community practices and modes of participation that, as a whole, are unique to making. Simply put, just as tailors are at the center of the tailoring community of practice, makers are at the center of the making community.

Our analysis shows that makers are also members of other learning communities of practice, or multimembers, who exist across boundaries of community participation (Wenger, 1998). This positionality as multimembers who are evolving expertise in the practices of diverse communities is definitional to maker community participation, which relies on members who are disciplinary experts and hobbyists to bring new and complementary knowledge and skill into the community. Our data also reveal that many of the most expert makers do not explicitly identify their making endeavors as affiliated with any one discipline. Rather, the disciplinary knowledge held by the community is accessed and applied instrumentally and in novel interdisciplinary and multidisciplinary combinations as makers become more skilled and knowledgeable in the core practices of making.

Participation in the community of makers may not guarantee a member's orientation towards participation in STEM disciplines. In other words, as one becomes more expert in making, they are not necessarily developing practices that foster expertise in other disciplines. Yet, as disciplinary practices are applied through the communities making activities, becoming a more practiced maker does encourage community members' to tinker at the edges and intersections of other disciplinary participation. Making promotes an understanding, and the purposeful use, of specific facets of disciplinary knowledge and skill that inform and extend making community participation.

Consequently, as a multidisciplinary endeavor, making may have the potential to render disciplinary experiences more accessible, interactive, and motivating for the community of makers, as well as for individuals and communities seeking to integrate making into their own community practice, such as teachers and informal educators. Positioning themselves and their activity at these edges, intersections, and/or boundaries of participation in disciplinary (and other diverse) communities, makers work to transform the refined and inaccessible aspects of disciplinary participation to become accessible to community members. For example, one scientist described how she makes research-grade equipment out of repurposed common kitchen items (Make, Vol. 31, p. 42). Rather than emphasizing the exotic and refined aspects of disciplinary understanding and practice, makers work across disciplinary boundaries to piece together every day objects and processes in innovative ways. This boundary-work, drawing connections across disciplines, is central to maker participation.

2.6 LIMITATIONS & IMPLICATIONS

We recognize the limitations of using *Make Magazine* as a singular data source to characterize the learning practices of an entire community, as well as the small and selective nature of our sample, which together limit the generalizability of our findings and warrant the need for future research that considers a wider and more balanced sample. Yet, we believe that the affordances of the magazine, as the most visible, widely circulated and referenced collection of maker community participation justify its use for a starting place to characterize and qualify the current maker community and its learning practices.

As making is being invited into the educational ecology, attracting the interest of policymakers and funders, we argue that it is important to consider the implications posed by these findings for effectively reaching an increasingly diverse audience of learners. Our findings suggest that educators, and the making community itself, may want to take a critical look at who, exactly, is most visible in the community, and what forms of participation are being positioned as central, and therefore valued, by the community. If making is represented as being, for example, mostly male and mostly about hobbyist technology, how does it differ in substantive ways from other recent educational phenomena that were thought to be new on-ramps to STEM, such as educational gaming or robotics, and that continue foster a complex relationship to gender and access with regard to design and use (e.g. Kafai et al, 2008)? The educational design work ahead of us will need to address issues of broad participation if making is to realize its full educational potential.

Makers are positioned on the edges and intersections of participation in and with other communities of practice. How can this positionality be leveraged to widen the boundaries of participation and legitimize more diverse methods of participation? Wenger discusses the ways in which the activities of a community of practice may create discontinuities or boundaries between those who participate legitimately in the community and those who are outside of the community (1998, p. 104). In these cases, Wenger asserts methods by which continuities across boundaries can be achieved: through *boundary objects*, forms of reification around which communities of participation can organize their interconnections, and *brokering*, connections provided by people who can introduce, coordinate and open elements and new possibilities for meaning of one community's practice to another (Wenger, 1998, pp. 105-109). As the maker movement widens its reach and gains a foothold in educational structures and institutions, the field should seek to identify and design towards the people and reified aspects of community participation that might play an important role, as brokers, in broadening participation to groups and individuals who are outside the current boundaries.

There exist notable examples of platforms, organizations and institutions that are working to establish connections and broker relationships. For instance, the Lily Pond project from MIT Media Lab (http://lilypond.media.mit.edu/) is an online community website which allows people to document and share projects that blend electronics and textiles. It is intended to support learners who want to design and create soft, interactive, wearable circuits primarily with the LilyPad Adruino, a computational construction kit that integrates sewing, programming and electronics. Lily Pond is a reified form of participation that was made to intentionally stretch across established community boundaries. Users are primarily female (67%) who "value projects that are functional, beautiful, colorful and well documented above those that are technically sophisticated but less aesthetically appealing" (Lovell & Buechley, 2011).

Cultural institutions, such as museums, science centers and libraries, are expressing growing interest and investing in the integration of making into exhibits and programs. This wave of activity is changing the ways in which these institutions function and are used by visitors. Many of the visitors to such informal learning environments are families, who use these institutions as resources for shared leisure and learning (e.g. Ellenbogen et al, 2004). The growing presence of maker spaces in designed informal learning environments presents the opportunity for making to widely, and potentially more deeply, reach a diverse audience of children, families and youth. Yet, when maker spaces are incorporated into the fabric of such designed contexts for learning, they must be adapted to the expectations and needs of the populations served by these institutions. For example, today's maker spaces are unlike most conventional family-centered museum exhibits, which often provide defined outcome-based experiences that are designed to enrich content knowledge. Maker spaces encompass open-ended, personally-enriching creative opportunities with shop tools and equipment, raw materials such as wood, textiles, and solder, and often require the active presence and participation of skilled and knowledgeable facilitators. Nascent studies and evaluations of family conversations and behaviors that can be heard and seen as families sew, solder, and build together are distinctly different from those observed through past museum learning research (UPCLOSE, unpublished evaluation). Groups are working to distinguish best practices, authentic indicators and learning outcomes of making as it relates to these designed spaces and the audiences they serve (Gutwill, in submission). As our line of research on making as a learning process continues, we will explore how the practices identified in this study are enacted in designed spaces such as museums and science centers.

Finally, Maker Media, owner of the Make brand, is working to broker boundaries and establish clear pathways for involvement to children, youth and educators through the establishment and support of programs, artifacts and organizations. These include *Young Makers*, local clubs for children to make projects in preparation for annual Maker Faires; *The Makerspace Playbook*, a guide in printable digital format for those wishing to create a maker space in their school or community; and the *Maker Education Initiative*, a non-profit organization which works to create more opportunities for young people to develop confidence, creativity, and spark an interest in science, technology, engineering, math, the arts, and learning as a whole through making.

Making is a multidisciplinary, interest-driven, distributed and evolving form of informal learning. If STEM education policy makers and practitioners are interested in rendering the practices of making to support disciplinary engagement and education, then future work will need to focus on identifying and designing educational experiences that draw clear connections between these practices and the related, but not necessarily identical, disciplinary practices. The pathway from making to workforce participation in STEM disciplines, although assumed, is not clear or well defined. If this definition and orientation is a priority for education, then we must design with awareness of the intricacies of community participation and heed what forms they take and where such pathways point.

3.0 FAMILIES WHO MAKE TOGETHER: LOCATING AND TRACING LEARNING IN THE CONTEXT OF INFORMAL FAMILY ACTIVITY

In this paper, we explore *making* as a learning process in the context of a museum-based maker space, designed for family participation. The creative process of *making*, characterized by methods and modes of creative production at the crossroads and fringes of disciplines such as science, technology, engineering, art and math, has recently developed into a recognized cultural, social, technological and economic movement (Honey & Kanter, 2013). As a creative activity at the intersection of the physical and digital, making integrates current trends in DIY (do-it-yourself) culture, traditional craft, and emerging technologies, such as physical computing and fabrication. From hobbyists who learn to code in order to program a personal fireworks display, to youth who learn to solder in order to fix a broken stereo system, from groups of adults who modify and race ride-on electronic toy cars, to groups of kids working together to create an entrepreneurial start-up, from an automotive technician who made an automatic ball launcher for his dog from things he found in his garage, to a team of artists and technologists who worked together to integrate live street traffic data into a classic video game from the 1980s, the maker movement has evolved into a strong community of self-motivated and innovative makers (Brahms & Crowley, in submission).

This community is formed through social meeting and exchange which take form in popular publications and digital affinity groups, regional Maker Faires (annual showcases of makers' inventions and investigations), and through the development of maker spaces, or places where makers gather to use, share and combine materials, tools, processes, and disciplinary practices in novel ways. These physical and digital spaces are becoming recognized sites of learning as groups composed of diverse ages, genders and backgrounds are motivated to exchange and develop skills, knowledge and ideas (e.g., Sheridan et al, in submission).

Educational policy makers have taken note of this grass-roots phenomenon, and are increasingly characterizing it as a new education reform movement; working to identify the programs and outcomes that may be leveraged to create learning pathways towards employment for children and youth, as well as to further the economic interests of the nation (e.g. Kalil, 2010). In his speech initiating the *Educate to Innovate* campaign, President Obama asserted the importance of making for children and youth, “I want us all to think about new and creative ways to engage young people in science and engineering, whether it's science festivals, robotics competitions, fairs that encourage young people to create and build and invent—to be makers of things, not just consumers of things” (Remarks by the President at the National Academies of Sciences Annual Meeting, April 27, 2009). School administrators, teachers and parents are working to incorporate making into the classroom context (Martinez & Stager, 2013), and designed informal learning environments, such as museums, science centers and libraries, are expressing growing interest and investing in the integration of making into exhibits and programs (Brahms & Werner, 2013).

But what, exactly, does it mean to learn through making? What would evidence of learning look like in the context of making activities? What is needed to leverage what are typically hobbyist practices of adults and transform them into designed learning experiences that incite “new and creative ways…to encourage young people to create and build and invent—to be makers of things, not just consumers of things?”

In this article, we apply the lens of the learning sciences to the maker movement in order to connect maker practices to extant learning theory and to identify potential educational levers in the design of making experiences for learning. We focus particularly upon young children engaged in making experiences as part of family visits to a museum-based maker space. Specifically, we pursue three inter-related research questions:

1. How do young children, in the context of a family learning visit, enact and coordinate maker community learning practices through their participation in a museum-based maker space?
2. What factors support and engender young children’s productive participation in making as a learning process?

3. In what ways do young children, in the context of a family learning visit, establish meaningful trajectories of participation in making as a learning process?

3.1 MAKING AS FAMILY LEARNING

We adopt the community of practice (Lave & Wenger, 1991; Wenger, 1998) approach as our primary framework for describing maker activity. Learning theorists have increasingly considered and demonstrated learning as fundamentally tied to the social and cultural contexts in which it occurs—that what people learn cannot be separated from how they learn it (Brown, Collins, & Daguid, 1989; Lave & Wenger 1991; Gutierrez & Rogoff, 2003), and that learning is dependent on the interaction of multiple factors of complex systems (Greeno, 1991, 1997; Hutchins, 1995, 2002; Greslafi, 2009). This body of work focuses on the "cultural practices" in which "just plain folk" (Brown, Collins, & Daguid, 1989) engage through their lived experiences with the world. Here, learning is considered a to be a change in participation—knowing *through* doing—in a given social practice as it is situated within a given context of activity (Lave & Wenger, 1991; Wenger, 1998; Gresalfi, 2009).

In the now prototypical illustration of learning as social practice, Lave and Wenger (1991), describe the situated learning trajectories of individuals as they apprentice to become members of a community of practice, moving from peripheral participation as a "newcomer," towards mastery as an "oldtimer." This movement depends on newcomers' legitimate participation in the sustained practices of the community, and results in the development of learners' knowledgeable skill and association, or identity, as a member of the community. Equally as important as individual learning, is the cyclical development and transformation of the community, as newcomers eventually become oldtimers, adapting practices and patterns of participation to suit the changing needs of the community (Wenger, 1998; Brown, Collins, & Dugid, 1989).

Over time, members of a community of practice establish trajectories of participation with respect to the practices of the community. Conceptualized as a trajectory[2], learning can be understood as the process by which individuals' and groups' patterns of participation shift and develop in relation to myriad influential factors within a given learning context. Here, context is understood as a "system of social practice that includes patterns of interaction, understandings, assumptions, attitudes, and norms that serve to organize activity" (Greslafi, 2009, p. 330; Engestrom, 1999). Through shared activity and over time, learners participate with intent and greater sophistication in social practices that have structure and history, yet are dynamic and responsive to relative factors, which together influence participation (Greeno & Gresalfi, 2008). Research studies that have pursued this line of thinking in both formal and informal learning environments, have considered the diverse factors that are thought to influence learning through participation in socially-valued community practices, and the ways in which such factors are activated, coordinated and developed through learners' participation in a given context over time (e.g. Nasir & Cooks, 2004; Cobb, McClain, Lamberg & Dean, 2003).

Our first step in applying the community of practice framework to making was to identify core practices at the center of the community (Brahms & Crowley, in submission). In other words, we sought to characterize the ways in which the maker community works to define participation, and therefore itself, through shared practice and forms of experience. Through a textual analysis of *Make Magazine*, the most visible and widely circulated referential text of the maker community, we found that makers strongly identify as a community, exemplifying many of the core tenants of the communities of practices framework (Lave & Wenger, 1991). Notably, we identified seven central learning practices that work to collectively characterize recognizable participation in the maker community: *explore & question, tinker, test, and iterate, hack & repurpose, combine and complexify, customize, seek out resources, and share (Table 1)*. We further found that these practices are highly interrelated and mutually supportive, coexisting in makers' descriptions of their processes and products.

Our second step, which we take in this article, is to consider whether and how such core making practices might be enacted and studied as part of family activity in the museum-based

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2 In regard to family learning with and through designed tools and environments, such as museum exhibits, the time-scale over which learning, or change in participation, may be seen to shift from continuous trajectories over the course of months or years (e.g. Gresalfi, 2009; Azevedo, 2013), to occasions of shared learning across moments or recurring visits.

maker space. Composed of diverse ages and genders, families bring to their museum experience practiced methods of cooperation and communication, systems of shared beliefs and values, and recognized motivations and agendas for participation. Through museum visits, families relate and reinforce past experiences and family history, and develop shared understanding (Falk, Moussouri, & Coulson, 1998; Hilke, 1987, 1989; Ellenbogen, Luke & Dierking, 2004; Ellenbogen, 2002).

Family learning in museums is primarily initiated, directed and maintained through the interests of family members (Ellenbogen, et al, 2004; Hilke, 1987; NRC, 2009). This agenda, or the cognitive, affective, and social expectations or goals the individual or group members intend to pursue or satisfy through their visit, motivate families to purposefully chart individual and collective pathways of experience through and across museum visits. Studies have shown that the goals of individuals and groups may be multiple (e.g., pursuing learning, leisure, and socialization through a single experience), as well as conflicting (child engagement vs. time constraints), and that family learning in these designed contexts is a negotiation of parent and child interest, knowledge, and choice (Crowley & Jacobs, 2002; Palmquist & Crowley, 2007; NRC, 2009).

Empirical research has demonstrated the varied ways in which parents tacitly and explicitly guide, structure and influence children's participation in culturally valued activities in natural environments of family interaction such as the home (e.g. Ochs, 1989; Rogoff, 1999; Plowman, McPake, & Stephen, 2008), as well as in designed environments for family learning such as museum exhibits (e.g. Heath, 1983; Crowley & Callanan, 1998; Crowley, Callanan, Tenenbaum & Allen, 2001; Crowley et al, 2001). Parents indirectly influence children's learning by providing particular tools, toys, or media and by organizing family and peer-oriented experiences that provide new opportunities for conversation (Barron et al, 2009; Takeuchi & Stevens, 2011). For example, Plowman, McPake, and Stephens (2008) studied the tacit ways in which parents, grandparents, and siblings influence their preschool-age children's learning with digital technologies at home. The authors discovered that the adults often believed their children were "just picking up" new technical skills, while in fact they were unknowingly modeling technical practices in front of and with their very young children.

A dominant theme of learning research regarding family social participation with designed tools, such as new media technologies, has been the ways in which participation with these technologies is shifting previously established role structures of familial practice, wherein parents were more expert than their novice children (e.g. Barron, Martin, Takeuchi & Fithian, 2009; Takeuchi & Stevens, 2011). Research and popular media have identified a generational divide that exists between children's and parents' use, suggesting that many parents do not necessarily feel equipped to facilitate their children's use of new media technologies in expert ways (e.g. Gutnick, Robb, Takeuchi & Kotler, 2010). In contexts of shared family practice with emerging technologies, expertise and learner positioning, is not only becoming more flexible, but also more complex and distributed within and across contextual features such as people, setting and tool than in times past.

For example, Palmquist and Crowley (2007) studied the ways in which children's level of expertise about the topic of dinosaurs influences family learning opportunities in a museum setting. Data included video observation and analysis of parent-child conversation during their visit through Dinosaur Hall at a Natural History Museum, followed by child interviews and a parent survey. Analysis of family experiences in Dinosaur Hall suggested that as children develop an island of expertise in dinosaurs, their parents become less active contributors to learning conversations in informal settings. The authors further found that while visiting Dinosaur Hall with their parents, "expert" children mainly recited previously known facts about the dinosaurs on exhibit, rather than engaging their parent in conversation or probing the environment to learn more. Parents generally supported and reinforced this one-sided behavior, playing the role of tester, evaluator, and encouraging audience member to their child's display of knowledge. Whereas novice parent-child dyads appeared to use the shared museum visit as a learning opportunity, using the exhibition as resource to collaboratively learn facts about the objects on display as well as some deeper interpretation of the objects. Novice parents and children became active and responsive learning partners.

Schauble et al (2002) also explored the distributed learning system of the family, in the context of a science center exhibit. Their study went beyond the family system to include museum facilitators as key aspects of activity and learning. Specifically, the authors were interested in forms of learning, adult notions of learning, and learning assistance tailored to visitors' thinking about the domain of science in a museum exhibit targeting elementary-age children. The authors interviewed parents and museum staff to assess what participants thought about children's learning in the exhibit and the adult's role in this process. Over half of the parents interviewed viewed learning in the museum as “doing and playing,” whereas the others saw learning as something “more than doing,” suggesting a notion the authors categorize as “learn and understand.” Those parents who viewed learning in such contexts as primarily “doing and playing” believed the most appropriate role for a parent was “just to stay out of the way” (p. 434). The parents who considered learning to be “learn and understand,” saw it as the parents’ responsibility to actively participate in their child’s informal learning experience by asking questions or providing explanations. The majority of the staff believed that their role as facilitated mediation—through modeling, asking questions, collaborative play and explanation of “how things work”—was instrumental in visitor learning. The authors recognized that there is a dual problem in museums of parent and facilitator influence on children’s learning, and a lack of support for these potential learning partners in such designed contexts.

Finally, Stevens, Satwicz, and McCarthy (2008) presented a collection of vignettes drawn from video-based ethnographic case studies of eight focal children and five of their friends, ages 9-15, depicting how children’s at-home videogame play is “tangled up” in other cultural practices, including children’s relationships with siblings, parents, schools, and children’s current and projected identities. They did this primarily by describing varied learning arrangements that children create among themselves through videogame play that provide opportunities for learning through interactional activity. The authors characterized these arrangements as social and physical apprenticeships; instances of just-in-time expert-novice instruction; and occasions of flexible and shifting learning roles through coordinated talk and embodied display. They found that the social and material resources present “in-room,” but invisible “in-game,” shaped children’s game play, while the arrangements created by the coordination of these resources through game play, in turn, were visible in and influenced children’s collaborative activities and identities beyond the game, or “in-world.” The authors conclude that as designed informal learning contexts, videogames provide opportunities for powerful and active teaching and learning due in large part to the jointly-created, jointly-organized, and jointly-managed nature of learning through play that takes place among children independent of adult guidance or direction.

Together, this work demonstrates that the family is a distributed learning system, who often use designed tools and environments as contexts for sharing, rehearsing, negotiating and developing family members’ relative areas of interest and expertise with regard to content and participation (Crowley & Jacobs, 2002; Palmquist & Crowley, 2007; NRC, 2009). Similarly, participation in the maker community is defined, in part, by the recognition and use of the community's distributed expertise, through participation in the learning practice, which we call *seeking out resources* (Brahms & Crowley, in submission). The maker community practice of *seeking out resources* is the act of reaching out to others for guidance, support and skill relative to one's intentions for a project or process. Inherent in this practice is the recognition of one's own limitations of expertise, a valuing of collaboration and a desire to learn. As a community that is physically dispersed, yet drawn together through social means of communication and sharing, this learning practice includes makers' flexible interaction and use of the distributed tools, materials, and expertise of the community. The maker community has established clear systems of sharing, adopting and adapting one another's knowledge and skill. In so doing, the community has asserted an inherent value in members' development of niche interests and areas of expertise. When designing for making as a learning process situated within a museum-based maker space intended for family participation, it becomes essential to begin with a consideration of the ways in which family members participate in this maker community practice, seeking out, recruiting and coordinating the available and distributed social resources of the context for learning.

We hypothesize that the maker community learning practice of *seeking out resources* will be meaningfully enacted through families' participation in the museum-based maker space, as family members take on social positionings with respect to one another and to the other social and material resources present in the learning context. Based on the previous finding that maker community learning practices are highly interrelated and mutually supportive of makers' participation as members of a community of practice (Brahms & Crowley, in submission), we further hypothesize that through their recruitment and use of the distributed social resources in the context, family members will coordinate their participation in complementary maker practices.

3.2 METHODS

3.2.1 Setting

Our study took place in MAKESHOP at the Children's Museum of Pittsburgh, a maker space designed with the intention of accommodating and supporting the family as a social learning unit. It is designed to be a comfortable, flexible, and supportive space that encourages visitors to instinctively use the distributed social and material resources of the space to gather and collectively engage in interest-driven making endeavors with physical and digital materials, tools and processes. This is done through the architecture and design of the space and material properties, through facilitation, and through the iterative design of supports for learning and engagement.

A minimal architectural structure and choice of materials, such as plywood floors and post-and-beam construction, provide an open feeling with clear sightlines amidst distinguishable activity areas, and allow for abundant natural light to filter through the entire space. The space appears well used and hand built rather than sleek and precious. The furniture and fixtures of the space are flexible and durable. The butcher-block wood rectangular tables, can be combined, separated, and moved to encourage different kinds of engagement and assembly. Seating is abundant and varied to accommodate diverse configurations—both those suggested through design and those created by visitors. The equipment, tools and materials in the space are familiar to many visitors. The presence of common tools such as hammers and sewing machines, often elicit personal connections and shared memories amongst parents or grandparents and children.

The space is divided into three general areas, each of which allows a visitor to potentially broaden or deepen their level of engagement and methods of social interaction. The entrance to the space introduces visitors to the concepts of tool, material and process use through the placement of interactive exhibit components that enable visitors to explore these concepts together. For example, visitors are introduced to materials and methods of attachment through an exhibit component of loose-part repurposed material panels made of wood, metal, plastic and industrial wool felt with metal bolts and nuts that visitors may use to creatively build structures of any shape or size. A variety of print and digital resources are always on hand to provide inspiration, deeper explanation about a making process, or simply a shared family reading experience. This introductory space is often used to prototype new ideas on the floor with visitors.

Beyond the entrance area, lie the shop spaces (See Figure 3.1). In the Open Shop space, visitors can further explore, engage and apply the use of basic tools, materials and processes. The Open Shop features visible and open access to a variety of materials, purposefully chosen tools and designed exhibit components that enable visitors to explore the processes of making, such as learning how to use a standing loom or how to connect a circuit. These explorations can be momentary or extended, they may lead to further investigation or prompt the desire to make a product that integrates the explored processes.

In the Workshop, a defined space with large windowed sliding doors that allow staff to create a more intimate learning environment, visitors are able to bring their product ideas to life through hands-on building at the intersection of the physical and the digital. Families are encouraged to work together to sketch their ideas, select their materials, and engage in the full design process with the assistance of a knowledgeable educator. Visitors use woodworking processes, sewing machines, circuits and solder, 3D printers and a laser cutter, as well as a variety of digital media production tools to create products they can take with them when they leave the museum.

Figure 3.1. Wide view of MAKESHOP at Children's Museum of Pittsburgh, the Open Shop space can be seen in front and the Workshop space can be seen in the distance.

The presence of educators skilled in the domains of making, as well as in the facilitation of informal learning, is an intentional and central factor of the space's design and function. Each of the five core staff members have expertise in a different domain of making, such as textiles, electronics, construction, digital media production, and computer programming. This expertise is made accessible to visitors as a resource, as well as shared among the staff. Importantly, this team of facilitators each identify as being members of the community of makers. They all engage in maker community practices and participate in maker community events outside of their work at the museum. As such, it can be said that their presence, as a group of individuals who participate legitimately in maker community practice and endeavor to continually negotiate and refine their practice in relation to their work with family visitors, grants the designed environment legitimacy as a representative site of maker community participation.

Within this museum-based maker space, and over time, the team of educators has designed various instruments that are intended to help more novice participants feel comfortable beginning to engage and practice making processes, and with which visitors may support their progress through the development of more advanced skill. For example, the process of sewing is quite complex and involves multiple sequential steps. In the maker space, the team has iteratively designed a series of instruments that enable visitors to begin and practice the various aspects of hand sewing, such as threading a needle and the in-and-out weaving motion of making a stitch. This is done by providing materials and tools that allow for a progression of dexterity and freedom of expression, such as peg board squares with large holes, needles and yarn; to latch-hook canvas squares with less defined and more numerous holes; to the use of fabric, where one must make his or her own holes using metal needles and thread. The combination of accessible tools, materials and scaffolds for engagement in the process of sewing enables visitors to begin in a place that is most comfortable and establish their own intentions for and pathways of engagement, depending on their level of comfort, expertise and interest.

3.2.2 Data Collection & Analysis

The goal of this study was to locate and illustrate children's learning through participation in maker community practices, and to determine what factors are most influential in helping children to establish meaningful learning trajectories. We sought to collect a broad and representative range of diverse families' participation in the museum-based maker space. The research team went through multiple stages of collecting, categorizing, comparing, and refining the data (Glasser & Strauss, 1967; Taylor & Bogden 1998) to eventually determine the unit of analysis, definition of an observational episode, reliable data collection procedures, and analytical approach.

The unit of analysis was the family-unit, as it related to the context of activity. A family was operationally defined as consisting of at least one child between the ages 4-10, and one of the child's parents (as identified through the initial screening process). The operational boundaries of an observational episode were defined by family members' intentioned experience with a single exhibit element or making process, thereby allowing a single family to exhibit multiple episodes of participation during their experience in the space on a given day.

We collected 20 video-based observational episodes of family activity over the course of 12 weeks, between June-August, 2013. Episodes were balanced across child age and gender, family composition, and making activity (e.g. sewing, circuits, electronics, etc.). All participating families gave their full consent to participate in research activities prior to data collection. All observations were naturalistic and unobtrusive to families' regular behavior in the museum. Episodes ranged in length from 12 to 120 minutes. Once families indicated that they had completed their making activity, the researcher conducted a semi-structured interview with one of the participating parents regarding their family's background and making experience in context. These interviews took approximately five minutes and were audio recorded.

Analyses were ongoing throughout the period of data collection. Following each day of data collection, contact summary sheets were made for each collected episode that featured summaries of the episode, comparative qualities of the data (e.g. age, gender and family structure), and analytic notes (Miles & Huberman, 1994). Episodes of video-based data, and affiliated documentation were given unique identifiers and entered into a qualitative analysis software program for sharing and further detailed analysis by the research team. Memos were written to explore analytic categories and representative patterns of participant activity (Miles & Huberman, 1994; Jordan & Henderson, 1995).

Select video segments, representing the range of visitor activity, such as area of engagement (e.g. sewing, electronics, woodworking, computer programming) and family structure, were transcribed, separating the speech and behaviors of participants into fifteen-second increments, in order to engage in a microanalysis of participant interaction (Erickson, 1992). Combining our a-priori definitions of maker community learning practices (Table 3.1) with a more grounded approach to data analysis (Glaser & Strauss, 1967), our analysis began with members of our research team independently open coding a subset of transcripts, to explore and compare analytic categories (Miles & Huberman 1994). This process revealed several analytic categories and themes. Using the segmented data and emergent analytic categories, we worked to reduce and analyze the data through the iterative creation and comparison of multiple data displays, including role-ordered and conceptually-ordered matrixes (Miles & Huberman, 1994). Through this process, the ways in which family members arranged themselves for learning, established social roles relative to others, and recruited one another's expertise emerged as a central analytic theme. We then began to see the ways in which children's participation in this practice of recruiting and coordinating social resources meaningfully interacted with their evolving participation in the other identified maker community learning practices.

Table 3.1
Maker Community Learning Practices

Maker Community Practice	**Definition**
Explore & Question	Interrogation of the material properties of the context in order to find inspiration or to determine intention for a process or project.
Tinker, Test & Iterate	Purposeful play, experimentation, evaluation and refinement of the context.
Hack & Repurpose	Harnessing and salvaging component parts of the made world to modify, enhance, or create a product or process.
Combine & Complexify	Developing skilled fluency with diverse tools and materials in order to reconfigure existing pieces and processes and make new meaning.
Seek out Resources	Identifying and pursuing the distributed expertise of others, includes a recognition of one's own not-knowing and desire to learn.
Customize	Tailoring the features and functions of a technology to better suit one's personal interests and express identity.
Share	Making information, methods and modes of participation accessible and usable by members of the community.

3.2.3 Selection of Cases

The research team developed a coding scheme to identify the ways in which focal children participated in maker community learning practices, as well as the dominant learning arrangements and social positioning among family members and staff. After coding all episodes, we developed full cases (Stake, 2008) of five families whose activities are representative of the range of family experience across all episodes with regard to the types of learning arrangements and social positionings shown, as well as to the scope of the focal child's engagement in maker practices. In addition, these five cases represent the range of making activity (e.g. sewing, circuits, electronics, etc.) afforded in the space. We chose to feature the two cases presented in this article because they focus on young children of the same general age, while providing useful points of contrast, including distinctive ways in which adults influence and participate in children's contextualized learning processes, and children's typical orientations for their participation in context—either towards making a product or engaging with maker processes. As in all five cases, the primary maker community learning practice that is observed in these two cases is children's recruitment and coordination, or their *seeking out* of social resources. In addition, as we saw in all five cases, children use their engagement in this primary practice to help evolve their participation in other, complementary maker community learning practices. In the first case presented, we show the ways in which the focal child, Emma, coordinates social resources to help meaningfully evolve her participation in the maker community learning practice of *explore and question*. In the second case, we illustrate how Owen coordinates social resources to help meaningfully evolve his participation in the maker community practice of *tinker, test and iterate*. In so doing, we provide evidence that, through an afternoon visit to a museum-based maker space, young children can establish a meaningful learning trajectory with respect to their participation in and coordination of maker community practices.

3.3 CASE ONE: EXPLORING AND QUESTIONING SEWING

Our first case is of a family who belongs to the museum as members and visits the museum at least twice a month. On this particular weekend day, Mom has brought along her four-year old daughter, Emma, her seven-year old son, Jake, and their baby brother. In a follow up interview, Mom explained that she often visits the museum with Emma and the baby while Jake is in school, "but today we decided to bring the whole gang."

Emma and Mom have had previous shared learning experiences in this museum-based maker space and with its related material resources. With regard to sewing, in a brief interview, Mom describes how she and Emma had "play[ed] with the plastic needles and weaving boards" on past occasions, but that they had never before taken the opportunity "to make something," or a product they could take home through the process of sewing with metal needles, thread and fabric. Mom says with a smile, "it's nice, because all of the sewing stuff is right here for us to use." She goes on to say, "I haven't really sewn since I was in middle school. Well, maybe some mending when it's needed, but I'm no expert."

The "weaving boards" to which Mom refers are a set of instruments that the staff designed and prototyped over time with the intention of scaffolding novice participants' familiarity, confidence and fluency with the tools, materials, and process of hand sewing before they move on to working with cotton fabric, metal needles, and thread (See Figure 2). Some of these tools are made of repurposed wooden peg-board that has been cut up into pieces small enough for a young child to handle, yet large enough to sufficiently practice the in, out, and over motion of sewing. Each piece of peg-board has a long string of yarn connecting the board and a large plastic needle. Similarly, the team stretched and secured pieces of latch-hook canvas across one-foot square wooden frames. The latch-hook canvas still has defined holes, yet the holes are much smaller, closer together and numerous. Like cotton fabric, the material is also more flexible. These designed tools rest on the large square butcher-block table with stools and chairs on all sides for visitors and educators to comfortably gather around. In addition, in the center of the table, smaller implements for hand sewing are casually arranged and stored, such as needles, pins, spools of thread, scissors, and bins of buttons and fabric scraps left over from other visitors' sewing projects (See Figure 3.2). Visitors can independently access these things, and move and share them with others. [3]

[3] Tools and materials that either have specific functions or are potentially dangerous, such as rotary cutters and large swaths of fabric, are visibly accessible, yet stored out of the direct reach of children, and may be accessed when needed by an adult such as a parent or facilitator.

Figure 3.2. Sewing table with practice boards, button box and scraps of fabric used for stuffing, the large rotational bin of fabric can be seen behind the table.

We focus our analysis on Emma's contextualized making process, with respect to her family members and resources in the designed environment. Through the presentation of three episodes, we trace Emma's recruitment and coordination of social resources, and the ways in which her participation in the maker community practice of *explore and question* developed over time and in relation to the context.

Through our analysis of adult makers' descriptions of their processes and products (Brahms & Crowley, in submission), we found that makers approach a project or problem space by *exploring and questioning* the material properties of the context. This practice is often used to find inspiration, or to determine or refine makers' intentions for their project or process. This practice reflects makers' shared sense of curiosity and wonder about the made-world, and a persistent interest in ongoing and subsequent investigations that can be mined and shared.

Emma actively established an intention for making through the recruitment and coordination of social resources and participation in the practice of *explore and question*. In so doing, she gained skills and knowledge relevant to fulfilling her intention, while her participation in the practice became more sophisticated through shared activity.

3.3.1 Episode One

In the first episode, Emma enlisted her Mom's cooperation to engage the practice of *explore and question* as a means to determine her intention for making and to initiate their collaborative learning process.

> As the family enters the Open Shop of the museum-based maker space, they make a slow and casual loop around the space. Mom points to several elements, directing her children's attention to the variety of materials and processes with which they might engage. As they move through the space, Jake pauses at the entrance to the Workshop, which is gated to control the number of visitors who are in the space at any given time. Emma continues to walk slowly towards the back corner of the Open Shop, to a large rotational bin, which stores and makes accessible scraps of fabric of varying colors, textures and sizes. Mom follows behind her daughter, pushing the baby in the stroller. Together, Emma and Mom begin to explore the various scraps of fabric. Soon, Emma selects a piece of dark fabric, which the pair collectively decides will be used to make a small pillow.
>
> Emma and Mom find a place at the sewing table to comfortably sit together. Mom knows, from her own prior experience with hand sewing what the initial steps in the process are, and accesses the needed tools and materials—needle, thread and scissors—with ease. She threads a needle, and places it on the table in front of Emma before standing up to move the baby in his stroller to the opposite side of the table for a nap. Emma, seated at the table, rummages through a small container of assorted buttons. Emma selects two white buttons and places them on the table directly in front of her, beside the threaded needle. Mom circles around the table and sits down on a stool beside her daughter, while Jake sidles up on

Mom's other side. Mom folds the selected piece of fabric in half and prepares to teach Emma how to sew a running stitch in order to attach the two sides of the fabric together to make the pillow. Emma focuses on the activity at hand, as Mom holds the folded fabric, needle and thread, and gently narrates how to make a stitch:

Mom: "Push it [the needle] through," and pushes the threaded needle part way through the fabric.

Emma: Very focused, reaches for the end of the needle

Mom: "If you touch the pointy end of the needle it will make your finger bleed."

Emma: Backs away tentatively.

Mom: "Now, push it through," pointing in the direction the needle is going, "push it,"

Emma: Pushes the needle all the way through the fabric, while Mom holds the fabric steady and taunt.

Mom: "Now take it on the other side" and motions how to grasp the needle with her fingers.

Emma: Grasps the needle with right hand and pulls it a couple inches through the fabric.

Mom: "Pull it all the way through." Gently pushes Emma's hand away from the fabric so the thread is pulled through. Holds the fabric closer to Emma and points to the knot at the end of the thread, now positioned against the fabric, "See that, I made a knot, right here, and you have to pull it all the way to the knot."

Emma: Looking closely, she begins to move the needle into place to make the first stitch.

Jake: Has been observing his mother and sister's activity, presses his body again his mother's left arm.

Mom: Holds the fabric with both hands and adjusts the fabric so Emma can see where to insert the needle. "And watch, the needle's going to come through the other side, and you don't want it to poke you in the finger," as she points to the fabric.

Emma: Pulls thread through with her left hand

Mom: "Perfect," pointing to the fabric again, "back down."

Emma: Follows instruction, pushing and pulling the needle through the cloth as Mom instructs.

Jake: Moves around his family members, to his sister's right side, to gain better access to the needles and thread and selects a needle from the magnetized tray.

Mom: "Keep pulling. Make sure all of your pieces stay together." Pointing to the backside of the fabric, "good, now back through."

Emma and Mom continue to stitch the side of the pillow together, Mom holds the fabric sturdy and provides words of encouragement and guidance such as "perfect," "back down," "good, now back through" as Emma slowly and steadily inserts, pushes, pulls and reinserts the needle and thread into and through the fabric. Notably, the pair becomes increasingly physically intertwined, hands and arms laced together, each limb playing a different and necessary role in order to accomplish the dual task of teaching and learning to hand sew.

Together, through collaborative engagement in exploring the accessible materials and tools, Emma established the intention to construct a small pillow, a product that she may take home with her after the museum visit. From Mom's description of their past experience in the space, it might be assumed that the decision to engage in the intricate process of hand sewing with metal needles, thread and fabric came as a result of previous preparatory shared experiences with related tools and materials in the space, such as the "weaving boards." Today, Emma and Mom decided to apply their previous experience to the creation of a pillow. Although this is a logical next step in the process of learning how to sew, the choice to move from weaving with defined holes, and oversized needles and yarn to attaching fabric with small metal needles and thread is noteworthy, as is the way in which Mom facilitated this process for her daughter.

Emma and Mom arranged themselves for learning. Mom was meaningfully positioned as a social resource for Emma in the role of expert teacher or advisor, directly guiding her daughter's introduction to the materials, tools and processes of hand sewing through verbal coaching, structuring the activity, and keen awareness and involvement in her daughter's process. Likewise, Emma easily positioned herself as a willing and captivated learner—listening, performing and practicing the instructions and tips given by Mom. At this point in the process, Emma was reliant on her mother's structured guidance with regard to the activity at hand.

Having engaged in this collaborative process for about one minute, Emma was learning the basics of hand sewing through her Mom's intimate, focused and direct instruction, including the necessary tools and materials (needle, thread, fabric), and some of their distinguishing qualities (a needle is sharp). Emma learned how to sew a basic running stitch (inserting, pushing and pulling the needle and thread into and through the fabric in a straight line), and important steps in the sewing process (the need to tie a knot at the end of the thread).

Makers *explore and question* the material properties of the context of activity or problem space in order to find inspiration or to determine intention for the initial or subsequent step of their project or process. Through their exploration and consideration of the various fabrics available for their use, Emma and Mom have worked together to establish an intention for their making endeavor. They decided to make a small pillow. Although peripheral to their shared activity up until this point, Emma's further exploration and selection of two buttons meaningfully influenced the ways in which she recruited social resources and coordinated her developed use of this maker practice to fulfill her determined intention for herself and her mother's collective activity.

3.3.2 Episode Two

In this episode, Emma began to engage in the practice of *explore and question* in more sophisticated ways, applying acquired knowledge and skill to advance her established intention of making a pillow. This segment directly followed where the last left off, as Mom continued to support Emma in developing her ability to stitch:

> Emma: Pushes needle through with right hand and pulls it out the other side with her left hand, and asks, "Is it [the needle] making holes in the cloth?"

Mom: “Yeah! Okay, now come back through, come back in this way,” pointing at the front of the fabric.

Emma: Begins to insert needle into cloth, and warns her mother, “Mom, your finger.”

Mom: “I know, now pull it all the way through.”

Emma: Pulls the needle through and begins to reinsert it into the fabric.

Mom: “You’re better at this than I thought you would be.”

Emma: Smiles and pushes the needle with her right hand and pulls it through the other side of the fabric with her left hand as Mom holds the fabric steady with both of her hands.

Jake: Has returned to his mother’s left side, rests his head against his mother’s shoulder, and quietly drones, “Mom…”

Mom: With her eyes focused on her daughter’s activity, and hands intertwined with Emma’s hands, Mom leans into her son and says, “I’ll help you as soon as I’m done with Emma. What did that guy say [about Jake engaging in a workshop-based project]?”

Jake: “Kids have to be eight [years of age] or older to do it [engage in workshop-based projects].”

Baby: [Cries]

Mom: Glances at crying baby, but then refocuses on Emma’s stitching, “okay, now we got to go around the corner.”

Emma: “I’m doing it!” Continues to stitch, pushing the needle into the fabric with her right hand, and pulling the needle through the fabric with her left hand.

Jake: Touches a spool of silver thread, selects a needle and holds a needle upright, leans again his mother, ready to begin.

Mom: Holds the fabric for Emma, leans into Jake and suggests, “Why don’t you go do the battery one.”

Jake: Scans the table of circuit blocks and says, “no. I want to *make something*.”

Mom: “As soon as I am done with this I will help you.” Refocuses on Emma, “watch where you are coming through.”

Emma: Looks at Mom, smiles, looks back to fabric and pulls needle through front with left hand.

Jake: Walks away from his mom and sister, to observe three families sitting around the table filled with circuit blocks.

In this segment, Mom continued to support Emma's stitching, but began to shift her method of guidance, from demonstrating and beginning stitches to the provision of more technical support, creating conditions for Emma's consequential engagement by holding the fabric taunt and steady as Emma stitches. Mom's verbal instruction shifted as well, from showing and telling Emma how to make a stitch, to offers of emotional encouragement, "You're better at this than I thought you would be," and introducing ways to improve the accuracy of her stitching, "watch where you're coming through," and new steps in the overall process, "ok, now we got to go around the corner." Mom was clearly scaffolding (e.g. Pea, 2004) her daughter's understanding and skilled ability to stitch, as she began with very structured instruction of how to use the tools and materials in process, to later "fading" her level of instruction by shifting her role to grant her daughter more control of the overall process. Emma, in turn, responded and took up her Mom's method of engagement as a learning resource, acquiring, practicing and becoming more proficient at stitching, while harnessing, developing and using relevant knowledge.

Through this emergent experience with the materials, tools, and process of hand sewing, Emma began to engage in the practice of *explore and question* in more sophisticated ways, recalling and applying acquired understanding of the materials' qualities, warning her mother to be mindful of the sharp needle, so as not to get poked as she pushes it through the fabric, "Mom, your finger," and asking probing and clarifying questions about the tools and materials of her work, "is this [needle] making holes in the cloth?" Notably, Emma began to increase the speed and accuracy of her stitching, transferring the needle between her hands as she inserted it on either side of the fabric, and displayed signs of rising confidence in her ability to do the task at hand, exclaiming, "I'm doing it!" as her facial expression turned from one of extreme focus to that of joy in her achievements.

The task at hand shifted from learning how to stitch to learning how to construct a pillow. This process included securing the end of the attached sides with a knot and introducing a new material, “stuffing”—which, in this case, consists of repurposed scraps of fabric—and its applied use of filling a pillow to make it fluffy.

> As Emma stitches, Mom signifies the next step in the process of sewing a pillow, “Once we go all the way around, we’ll stuff it with stuffing.” Emma scans the table, looking for a familiar stuffing material. “Go all the way around and I'll show you,” Mom says, holding the fabric steady and taught, as Emma stitches around the corner. " Alright, so let me tie it off and then you got to get--" Mom gently pulls project out of Emma’s hands and reaches over to pick up some small fabric scraps. "You gotta stuff it with stuffing. See these guys here? You gotta stuff it." Mom places some fabric scraps on the table in front of Emma, and starts to tie a knot at the end of the thread. "We'll put it inside. Don't we want a fluffy pillow?" Emma grabs a fist full of scraps and starts rolling and squishing them into a ball in her hands. "Let me just do a knot because we're running out of thread." Emma watches as Mom makes a knot.
>
> Emma: Handling the pile of the fabric scraps, scrunching them in her hands, and attests, “But it’s not done!”
>
> Mom: Acknowledging Emma’s observation, “I know it’s—You’re right, it’s not done.” She demonstrates how to “push it in,” and hands the pillow to Jake, who has returned to his mother’s side, asking “can you help Emma stuff?” as she walks over to the stroller and away from the sewing project.
>
> Emma and Jake work together to stuff the pillow with small fabric scraps. Emma lets go of the pillow, and shifts her attention to the buttons she had placed in front of herself on the table as she began her project. Jake picks up a few more scraps and stuffs them into the pillow. He holds the opening shut, puts the pillow down on the table in front of Emma, picks up a spool of dark thread and looks at it.
>
> Emma: Picks up the buttons and says, "Mommy, you forgot to put on the eyes!" She holds the buttons up to her own eyes, pressing them against her closed

eyelids. Placing the buttons back on the table, she picks up the pillow and stuffs a few more scraps of fabric into it. Frowning, she says, “But it doesn’t look like a pillow!”

Mom: Returns and sits down next to Emma, “It is as stuffy as you want it?”

Jake: “Mom. Ready? Mom!”

Mom: To Jake, “I will help you in a minute.” She takes a needle from the tray, takes the spool of red thread from Emma and begins to unravel it.

Baby: [Cries loudly]

Mom: Looks to crying baby, frowns and gets up to tend to him.

Jake: As his sister handles her buttons, Jake puts down the dark thread at his spot at the table, walks around to the large rotational fabric bin and selects a piece of thick lightly colored fabric. He brings it back over to the worktable and begins rolling it up into a tube shape.

Videographer: “What are you going to make?”

Jake: “A sword.” Jake smiles widely, and says, “I actually think it’s going to work out!”

Through this segment, an interesting tension emerged between Emma’s intention for her project, and Mom’s relative knowledge about the procedure through which a pillow is constructed. Mom simultaneously introduced a new, and for Emma, unexpected step in the process—filling the unfinished pillow with stuffing—as well as a corresponding unfamiliar material—stuffing made of repurposed fabric scraps. Emma took the opportunity to explore the material properties of the stuffing, squishing a collection of scraps in her hands to feel their fluffiness, and consider their function. Yet, her vision for the final project appeared to predominate her ability to internalize the necessary step in the overall process of creation. She seemed to soothe her frustration by refocusing her attention on the buttons, a material she has become acquainted with through repeated exploration of the button bin, and for which she has determined a function to suit her intentions: button eyes for the pillow.

In addition to this apparent tension between parent expertise and child intention, the social learning structure of scaffolded apprenticeship that Emma and Mom have established influenced the learning process. Although Mom has been fading the structure of support for her daughter's development of knowledgeable skill in the task of stitching, she has also distributed responsibility in a way that makes fulfilling the ultimate goal of making a pillow (with button eyes), impossible without her presence and expertise. For instance, when, in the course of sewing, the threads must be knotted to secure and attach the sides of the pillow, a step that requires dexterity and accuracy, Mom assumes the role of technical facilitator, gently taking the project from Emma's hands and tying the knot herself, completing the step in order to move the project along. Perhaps Mom determined that the level of complexity was too high for her daughter to learn and perform successfully and preferred to focus Emma's learning on the isolated task of stitching, or chose to tie the knot herself for the sake of efficiency. In so doing, she established differentiated responsibilities within their learning arrangement, as well as Emma's assumed reliance on Mom as a learning partner.

3.3.3 Episode Three

In this final episode, Emma worked to instrumentally recruit and coordinate the now established social resource structure through her evolving participation in the practice of *explore and question* to fulfill her intended goal. Since the last episode, Emma and Mom completed the initial construction of their pillow, including stuffing and finishing off the fourth side. Mom then turned her attention to the crying baby. Since Emma's intention for her project was to create a pillow with button eyes, she was evidently disappointed with the unadorned final product. She slumped down in her seat, arms crossed. Meanwhile, Jake has recruited an educator in the exhibit space to assist him in constructing a sword, relinquishing his need for Mom's direct attention and facilitation.

> Emma begins exploring the bin of buttons again, carefully sifting through the assorted colors and sizes. Mom returns to Emma's side, with the baby in the stroller and stands next to Emma pushing the stroller back and forth in an attempt to calm the crying baby. Mom's physical return to the learning arrangement, and therefore Emma's restored access to Mom's expertise and assistance, has reinitiated Emma's intention to add the buttons to her project. She selects a button

from the box and places it on the table in front of her. Standing beside her daughter, Mom silently selects a needle from the pin tray, and picks up the thread Emma had previously chosen to stitch the pillow, as she does so, she gently strokes the girl's back, while Emma continues to peer into the box of buttons and carefully select another. Mom unwinds and cuts a piece of thread from a spool, and begins to thread the needle. Emma begins singing to herself. She takes her selected buttons and holds them up in the air, as if handing them to her mother. Mom says, "Okay." Emma smiles, swings around, and watches her mother thread the needle.

Once Mom has the needle threaded, she sits down on the stool beside Emma and says, "Ok, now your pillow, we'll put buttons on it." Emma turns towards her mother, hands her the buttons and refocuses on the pillow. Mom takes a button from Emma's hand, threads it onto the needle and starts to adjust and attach it. Emma sits up and leans close, watching how Mom is attaching the button. Mom begins to narrate for Emma what she is doing, "go through here. Then come back up through. Then we'll sew the other button on." Emma is watching closely, as Mom secures the first button. She pauses and asks Emma, "Do you want to do the other button?" Emma nods and Mom hands her the needle, thread, and pillow and places the second button on the table. Mom stands up, takes a small step away from the table, and begins pushing the stroller back and forth to calm the baby.

Emma places the pillow on the table, and begins to position the button on the pillow with both hands. Mom looks over and inquires about her progress. Emma is focused on the pillow and does not respond to her mother. Emma picks up the needle with her left hand, and holds the button in place against the pillow with her right hand. She picks up the pillow, pinching the button to hold it in place and begins to insert the needle through the backside of the pillow. Mom is standing behind Emma, watching her as she pushes the stroller back and forth. Very focused, Emma pushes the needle through the pillow and up through the button's hole on the front, drawing the thread through. Mom sees the accomplishment, rubs her daughter's back and kisses her head as she says; "you got it all through yourself!"

Emma Looks up at her mother and asks, "How did you do it straight?"

Mom sits down next to Emma, gently takes the project from her hands and again, narrates the process for her daughter, "perfect, so your eye, you have to go through your fabric, so go in through the hole," Mom points the needle towards the second hole of the button, showing Emma where to push the needle in next. Mom hands Emma the needle. Emma pushes and draws the needle through the hole and pillow. Mom is rocking the stroller with her left hand and leaning in to look at Emma's progress. "Good, now go through on the other side." Mom looks at Emma, smiling, "Perfect, Emma!" Emma makes another stitch as her mother looks on. As she finishes independently stitching the button onto the pillow, she holds the project up to her mother to knot the thread, and finish it off. As they work together to snip the thread, Mom smiles at Emma and pushes pillow towards her. Emma picks up the pillow and excitedly bounces the pillow across the table towards Jake, singing, "Pillow, pillow, pillow! Guys watch out! There's a pillow monster coming your way!"

Through this final stage in the process of Emma and Mom's pillow project, Mom further faded her level of support and shifted her role, granting Emma more autonomy over the sewing process. In an afternoon at the museum, Emma grew her knowledge and skill with respect to the task of stitching. She began as a novice, and through her mother's careful scaffolding, she apprenticed to acquire, practice, and now use her developed understanding and ability in slightly more advanced application of the task. In so doing, she has also furthered her engagement in the maker community practice of *explore and question*, continuing to ask increasingly targeted questions that aid in the refinement of her skill and fulfillment of her goal, as she asks, "how did you do it [attach the button] straight?" Likewise, Emma used her persistent exploration of the buttons as a way to communicate her intentionality to her mother. Although Emma has developed usable knowledge and skill apropos to stitching, in order to achieve her intended goal, she must recruit her mother's participation in the distributed system of expertise that they have established for themselves and their learning process: Emma is in charge of stitching, while Mom is in charge of knot-tying and needle threading.

3.3.4 Emma's Trajectory of Participation

Through Emma and Mom's initial engagement in the maker community practice of *explore and question*—selecting a piece of fabric and establishing a functional use for buttons—Emma determined that her intention for their collaborative and contextualized making activity would be the creation of a product. By way of her mother's scaffolding, Emma developed knowledge and skill with regard to the task of stitching, as her participation in the maker community practice of *explore and question* became increasingly more sophisticated and useful in refining her understanding and ability. Yet throughout her learning trajectory, Emma's intention for her project never changed. In the end, she worked to instrumentally recruit and coordinate her developed knowledge and skill, her access to social resources and expertise, and her evolving practice of *exploring and questioning* the context to fulfill her ultimate goal of making a pillow monster with button eyes. As Emma proudly and playfully shared her project with her brother, we may infer that she identifies her making experience, and perhaps herself as a maker, with the product she has made.

3.4 CASE TWO: TINKERING, TESTING, AND ITERATING WITH ELECTRONICS

Our second case is a family who was visiting the museum from out of town. The family, composed of Mom, her 8 year-old daughter, Anna, and 5 year-old son, Owen had visited the museum the day before, and returned in order to intentionally extend their making experience in the space. During their visit the day before, Mom contended that both children had explored the collection of circuit blocks for about an hour.

The blocks to which Mom is refers are a collection of wooden blocks with different components and power sources affixed to them. Components are made of a variety of materials, most of which are harvested from electronic toys or appliances, such as small motors, buzzers, speakers, propellers and wheels. Each of these components is fastened to a different wooden block with its wire leads exposed and attached to conductive nails that can be easily clipped by a variety of alligator wire test leads. A number of power sources are available, such as battery packs and cranks, as well as diverse forms of switches, including traditional light switches such as those found in a home, binder clips, paperclips and even conductive hair pins. Visitors may connect and reconnect the various components and switches to a power source with the loose wire leads.

The day before, an educator in the space had told the family that the next day the Workshop space would be open, which prompted Anna’s interest in making her own circuit block to take home, while Owen’s wish to extend his exploration motivated the family’s subsequent return to the museum. As they entered the space, Anna walked directly into the workshop and found Kurt, an educator to assist her in the process of creating a circuit block from repurposed materials. Owen decided to re-engage with the table full of circuit blocks. Dustin, another educator, was seated at the table as Owen approached. Initially, Mom positioned herself between the two children, walking back and forth, observing both situations.

Our descriptive findings and analysis will focus on five-year old Owen, relative to the other family members and educators with whom he interacts in context. In a brief interview, Owen’s mother describes her son as “very, very interested in taking things apart.” She explains,

> "When he took apart a mouse at our house, like a computer mouse, it had stopped working and he just took it apart, and he got it down to the circuit board, and then he proceeded to create a story for me about why these certain anomalies on the circuit board had caused the mouse to stop working. He created an elaborate explanation for why it hadn't worked. And then, since he finished destroying that particular piece of electronics, we haven't hand a chance--he keeps asking for things to fall apart. Like he has said, 'Mommy, when the car breaks I think we

should give it to a little boy who wants to take apart cars. Can I have the car when it breaks?' So that's kind of very much his thing."

Owen's Mom clearly identified her son's intense interest in electronics. Simultaneously, she attested to her own lack of knowledge about her son's area of interest: "Their parents are both Humanities scholars. So we don't--I don't do a lot of things like circuits or you know, the more sciencey side of things is not necessarily something that I'm particularly strong in, nor is their father. So this is an awesome experience for them." Mom positioned herself as a novice and the museum as an expert resource in her children's development of interest and expertise. By bringing her children to the museum, Mom was actively recruiting the museum's resources to fill her perceived void.

We present three sequential episodes, which capture significant moments in Owen's contextualized learning process. Together, these vignettes illustrate the ways in which Owen took up and coordinated social resources through his evolving participation in the complimentary maker practice of *tinker, test and iterate*. This maker practice emphasizes makers' process-oriented intentions. Through our analysis of adult maker's descriptions of their process (Brahms & Crowley, in submission), we found that community members' engage in the iterative exploration of materials and processes through purposeful play, experimentation, and ongoing evaluation, as a learning practice. Each successive iteration of a project presents an opportunity to develop applicable skills and grow relative knowledge for oneself and for the community.

Through Owen's active coordination of social resources and engagement in this maker practice, he not only sharpened his intentions for and relationship to his contextualized learning, he developed demonstrable knowledge and skill, forming a meaningful trajectory of participation through an afternoon of making.

3.4.1 Episode One

In this episode, Dustin, an educator in the maker space, facilitated Owen's development of understanding of how a circuit works. Through their interaction, Owen took up Dustin as a social resource for learning, and begins to participate in the maker community practice *of tinker, test* *and iterate* as a means to initiate his intention for making, as well as to define their shared problem space.

> Dustin is casually seated at the table full of circuit blocks, as Owen approaches and begins to touch the blocks and wire leads, moving components around on the table. Dustin recognizes Owens strong interest in the circuit blocks. After observing Owen handling the materials for about two minutes, Dustin challenges him to connect a particular component to a battery pack, "Can you get this wheel spinning?" he moves a component with a motor and a wheel towards Owen and spins the wheel with his finger. Owen looks at the component and smiles, touching other circuit blocks, and reaching for the plastic box of wire leads. Dustin says, "go for it," as he pushes the box of alligator wire leads towards Owen.

Dustin quickly recognized Owen's initial intention to explore the process of connecting a circuit, and joined the boy in this self-determined and self-initiated process by posing a challenge, "Can you get this wheel spinning?" Owen immediately responded, clarifying the challenge and strategizing his approach:

> "First, let's connect these wires together," Owen says to himself. He grasps one of the alligator clips with both hands. He holds the clip in his right hand and holds the battery pack block steady on the table with his left hand. He leans in and attaches that clip to a battery pack block. He then takes the other end of the lead, struggles to squeeze the clip open, but eventually connects the clip to a second battery pack block. With the battery back blocks connected to each other, he separates them a bit on the table. He picks up the wheel component, and positions it between the two battery packs on the table. He grabs another wire lead from the plastic box of leads and attaches one end to the battery pack block and the other to the wheel component. "I'm getting close, okay, a little bit," Owen says to himself, as he reaches towards the plastic box again.

Dustin: Confirms, "I think you're really close."

Owen: Selects another wire lead from the box and answers, "Just need one last wire." He holds the wire with both hands and looks at his components, "right?" he asks without looking up.

Dustin: "Um hmm," in agreement

Owen: Examines the circuit he is building. He rocks on his feet, and exerts a great deal of energy in his effort to squeeze open the clip of the wire lead. He leans towards the battery pack block to attach it, but doesn't see right away where to attach it.

Dustin: Reaches over and points to the nail on the battery pack block on boy's right.

Owen: Squeezes the clip open, near his face, and leans towards to the component but can't hold the clip open.

Dustin: "You got it?"

Owen: “You know how to open it?" he holds the clip toward Dustin.

Dustin: "Yeah, I can help you."

Owen: Touches the nail where he wants it attached, "right there."

Dustin: Gently takes the wire from him, "okay, so you want me to clip it on there?" as he attaches the clip to the nail on the battery pack block.

Owen: "Yeah, and then plug it on the other one and see if we can make it work." He points to a nail on the motor component. He watches Dustin attach the clip.

Dustin: "I'm noticing something that might be a problem for our set-up here." He moves the motor component to stretch the wires a bit between the motor and the batteries.

Here, Dustin negotiated his relationship as a social resource to Owen’s intended learning process. He involved himself, or “pushed” his way into Owen’s learning context by challenging Owen to investigate the materials in a certain way. Owen immediately took up Dustin’s accessible participation as an affordance for reaching his intended goal of exploring and connecting circuits, and invited, or “pulled” him into the context more fully. It is through this push-pull negotiation that this maker community practice of *seeking out social resources* began to be enacted in this context.

Minutes into the activity, Owen and Dustin began to differentiate roles and to establish a shared repertoire for their joint participation (Wenger, 1998; Barron et al, 2009). Owen was clearly in control of the course of activity, deciding the pair's next move, while Dustin offered encouragement, "I think you're really close." Dustin provided technical facilitation by opening and attaching the clips to the wire leads of the components as Owen instructed, and participating in a way that conveys the feeling of both his and Owen's mutual engagement (Takeuchi & Stevens, 2011) in Owen's intended activity. Mutual engagement was evidenced through the language of reciprocity used by both Dustin and Owen. For example Owen began his process by saying, "First *we* need to connect the circuit," and Dustin closed out the segment with, "I'm noticing something that might be a problem with *our* set up."

Simultaneously, Dustin assessed Owen's level of understanding, or expertise, with regard to building a circuit. Although Owen's interest was high, his knowledge and skill with respect to correctly connecting a circuit was relatively low. By allowing Owen to lead the course of activity, Dustin was able to gauge these factors and can now help Owen establish foundational knowledge through their collaborative effort in fulfilling Owen's intended goal. As the pair continued, Dustin worked with Owen to clarify the path of electricity relative to the circuit blocks, wire leads and component parts. As he did so, he invited Owen's emergent participation in the maker community practice of *tinker, test, and iterate* as a means by which to define the shared problem space:

> Dustin explains through an analogy: "imagine these are like a train station" pointing to the nails on the battery component, "and they send out the electricity on the train line," Dustin gestures with his hand, indicating electricity moving along the wire, "they send it out on the red one," Dustin points to the nail with the small red wire connecting it to the battery, "and it comes back on the black one." Owen watches Dustin intently as he shows the boy that his current set up will make the "trains crash together." He flips the switch on the battery component to demonstrate that the current set up will not make the wheel spin.

Owen engages Dustin's explanation as if it were a conversation, reaching one hand to each battery component,

Owen: "So maybe if the trains go like," he points with his right hand along the wire connecting the batteries, "both the trains [will] go the same way," making a circular movement with his hands.

Dustin: Extending Owen's path of reasoning, "we've got to have opposites," moving a wire so that the connection is made, "so this black can connect to this red."

Owen: Retorts with an enthusiastic "yeah," and throws his hands up over his head in excitement, as the wheel begins to spin very fast.

The maker community practice of *tinker, test and iterate*, is that of purposeful play, experimentation and ongoing evaluation. Successive iterations of a project or problem space present opportunities to develop applicable skills and grow relative knowledge. Through a process of dialogic inquiry (e.g. Wells & Arauz, 2006; Ash, 2003), or building on each other's ideas, posing problems, and testing scenarios, Dustin has facilitated Owen's emergent understanding, and participation in this core learning practice of the maker community.

3.4.2 Episode Two

In this episode, Owen continued his exploration of the circuit blocks, refined his intention, and deepened his understanding of how to connect a circuit through his participation in and coordination of learning practices. This vignette took place minutes after the last. In the meantime, Owen and Dustin discussed the concept of a switch, and its role in connecting and disconnecting the electrical current as it moves through components, as well as in the conservation of energy—saving the batteries energy life by switching the circuit "off." Owen related this idea to an electronic toy he has at home, which has sparked Mom's participation. She began interpreting this connection for Dustin through conversation. While Dustin and Mom discussed the toy, Owen slid down the table and began to explore another component block independently.

> Owen approaches the new component, made from an old compact disk player cartridge (See Figure 3.3) and starts handling the pieces to see which parts move. The particular component has two interconnected gears and associated motors that are attached to four conductive nails. Owen begins exploring the component, "First we need to find how it works," he says to himself. There is a small white gear on the side of the component that Owen is spinning with his left finger. He then sees another movable gear on top of the component and begins to gently spin it. Focused, he says to himself, "makes stuff move," as he looks closely at the component and moves the two gears. He continues to talk to himself, as he moves the gears with is fingers, "the right size and full power and it will work and it will move this," he points to the other gear that spins when the side gear is turned by his thumb. "Pretend my thumb's not moving it. And pretend it's just working by itself. Like that, right? So then when we put all those wires on here," he points to the four nails on this component, "it works." He bends over to see the inside of the component, "like it's supposed to." He keeps looking at the gears, touching them. "So when it works, it actually, um, it powers up really good and it actually spins this thing," he spins the black gear on top of the component. Then he spins the white gear with his thumb, "and if these wheels were spinning it will move this," he points to another area on top of the component, "and it will go over to here and this wheel might even spin. The really powerful kind of spin." He pushes the side gear with his finger. "It might even do that. If it had a lot, if all the wires were connected to here."
>
> He touches the four nails and then is distracted by the sound of visitors across the table from him. There are now more visitors sitting around the table. Another unrelated visitor across the table says to her child, "are you going to connect that one?" Owen looks back at his component, touching it with both hands, and says to himself, "Yeah, let's connect it." He picks the component up, looks towards

Dustin and carries it over to Dustin, who is standing at the opposite end of the table, assisting visitors with the adjacent floor loom. "Hey, you want to connect this one?" Owen says to Dustin, showing him the component.

Dustin casually shifts his focus to Owen, and responds, "Sure--let's do it."

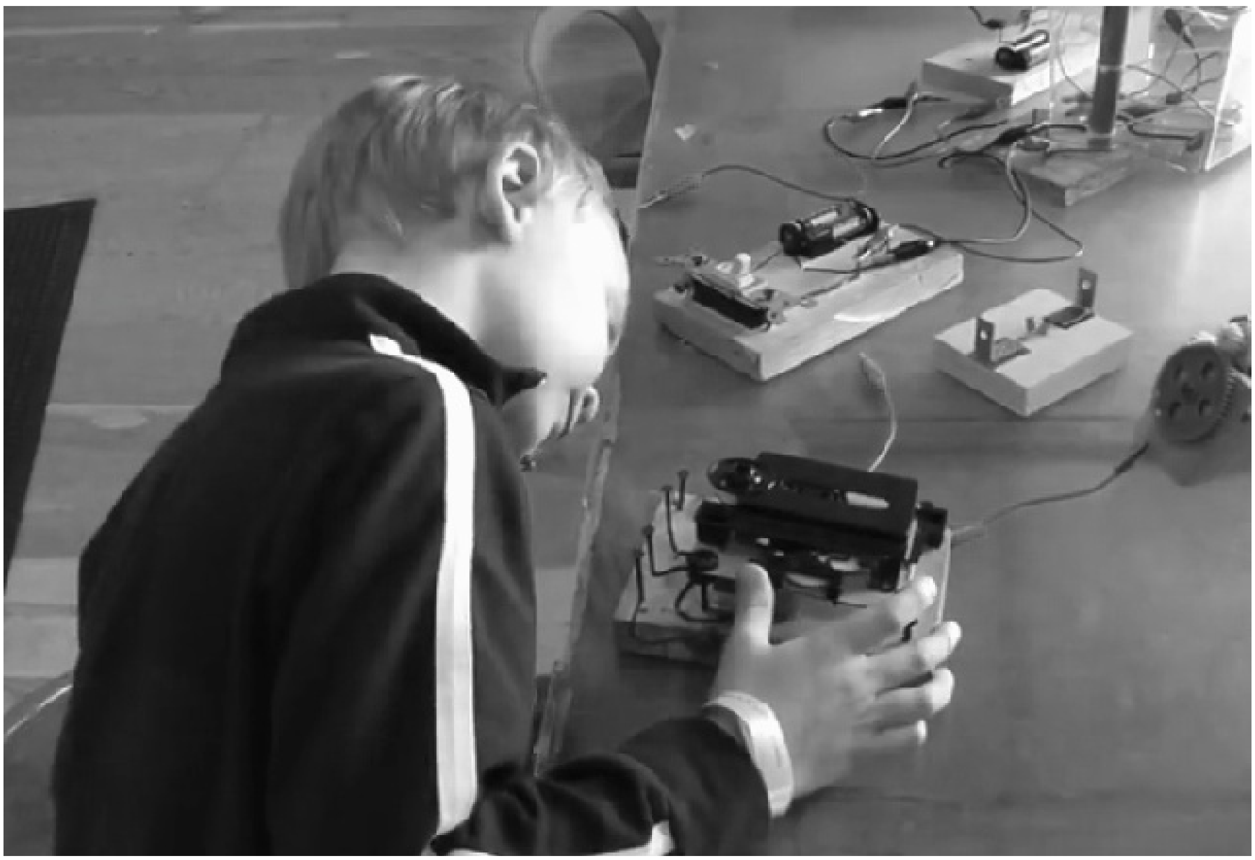

Figure 3.3. Owen investigating the circuit block component that features a compact disk player cartridge.

Here, Owen initiated his own participation in the corresponding maker practice of *explore and question,* investigating the material properties of the component, making connections and explaining the imagined workings of the device to himself through his investigation. He did this in preparation for connecting the component to a power source, as he said to himself, “first we need to find how it works.” Deeply invested in this exploratory process, Owen was prompted by the activities of another visiting family to take the next step to actually connect the component to an energy source. Yet, in order to do this, Owen actively recruited Dustin's collaboration, and perhaps the educator's expert guidance. In this way, Owen *sought out*, or pulled Dustin in as a social resource, in this phase of his intended activity.

Together, Owen and Dustin further engaged in the practice of *tinker, test, and iterate* in order to correctly connect this component to a power source, yet also as a way to refine Owen's foundational understanding of how to trace the path of electrical energy through the component parts.

> Dustin circles around the table to sit on a stool beside Owen. Owen begins by successfully connecting the end of a wire lead that was already attached to the red line of a battery pack, to one of the black lines of the component block. As Owen directs their collaborative process of connecting the battery to the component, Dustin asks clarifying and directional questions in an effort to steer the accuracy of Owen's choices:
>
> Dustin: "Okay, so you got the red line matched up with this black line," Owen is rocking from one foot to the other looking at the connections Dustin is pointing out. Dustin continues, "Where's our black line going to go?"
>
> Owen: Looks at where Dustin pointed, and responds, "our other black line." Owen picks up the other wire that is already attached to the battery and brings the clip towards the component. "Right here. It's going to go right there." Owen attaches the clip to the nail and steps back.
>
> Dustin "Okay, hit the switch let's see if it works." Dustin moves some extra wires out of the way.
>
> Owen: Flips the switch, looks at the motor and it is not working. "No. We need more wires," he says as he turns the switch to the off position.
>
> Dustin: Points at the other nails on the motor component and asks, "Do we need any of these red ones hooked up?"
>
> Owen: Nods head vigorously.

Dustin allowed Owen to discover his own mistakes and misunderstanding by encouraging him to "flip the switch" once he believed he had made the circuit. While they tried different combinations, in an effort to connect the blocks correctly, their conversation continued, shifted and evolved as Owen invited Dustin into his process of *exploring and questioning* the workings and function of the compact disk component.

> Owen: "So if we do it like, if it powers up, right? So when these gears move," he uses his left hand to move the side gear on the component, "it will connect and then it will move to here." He gestures to the top of the component where there is a sliding piece.
>
> Dustin: "Yeah, there's a motor in here," points under the black wheel on the component, "that will spin this. And there's a motor here," points to the area under the thumb wheel.
>
> Owen: "That will spin that."
>
> Dustin: "It's going to move this thing," and he uses his finger to slide the slider part over. Owen is watching. Dustin slides it back and forth. "See how this thing can move?"

It appears that Owen was confirming his understanding of the way in which the component was meant to work, which he had begun through his previous independent investigation, in conversation with Dustin, the expert. Dustin willingly followed Owen's line of thinking, distilling the functions of each gear and affiliated motor, as well as the ways in which the pieces are mechanically connected to one another. This exploration evidently excited Owen, as he began to rock back and forth on his feet with greater speed and the conversation grew more reciprocal, each participant building on the ideas of the other. For Owen, understanding *how* the component operated was equally as important as understanding how to *make it work* through a proper connection to an energy source.

Soon, it became clear that Owen refined his intention through their collaborative participation. Initially, Owen's intention was to explore the process of correctly connecting a circuit. In recruiting Dustin's expertise, interest and collaboration as a social learning resource, Owen was better able to coordinate his participation in tandem maker community practices:

tinkering and testing combinations of wire leads, components and energy source, and *exploring and questioning* the functionality of the component's mechanical parts. In so doing, Owen revised his intention to accommodate his more sophisticated participation in such practices. Next, Owen intended to prove that the complex component functioned as he conjectured it would once it was correctly powered.

At the same time, Dustin recognized the need to solidify Owen's foundational understanding of how an electrical component is powered, making a point to "trace out" the path of energy. As their activity continued, Dustin worked to fulfill Owen's intentions, while sharpening his understanding, as he moved their investigation in a new direction.

Owen: Leans in to the component and touches the slider on top, "If this was going to power up to here and then when this one moves it's going to shock this and make it move again." He gestures with his hands to show how he understands the moving parts to interact with each other. Then he steps back a bit and looks at Dustin, "right?"

Dustin: Nods and touches one of the unconnected nails on the motor component. "Should we get this one hooked up?"

Owen: Nods

Dustin: "Or should we try to get this," points to the white gear, "to spin better?"

Owen: Points at black wheel, "Make this, up that" (make the parts effect one another).

Dustin: "Alright, right now there's one wire on there," he picks up the end of the black wire that is unattached on one end, but attached to the motor component at the other end.

Owen: Takes it from Dustin and tries to attach it the battery component. "I need--it goes right--just put it here."

Dustin: "Okay."

Owen: Hands the wire lead to Dustin and he attaches it to the nail on the battery component. Owen leans very close to the motor component to see if anything is happening.

Dustin: "And then, what about this one?" Dustin has attached a fourth wire to the battery component and hands the other end of that wire to Owen.

Owen: Takes it, looks at the motor and says, "Let's shock it." He touches the alligator clip to the nail on the motor component and can see right away that the black wheel starts spinning as soon as the circuit is complete. "Whoa! I made it work!" He takes the clip away from the nail.

Dustin: "You want to clip it on there?"

Owen: Hands the clip to Dustin says, "can you clip it on there?"

Dustin: "Yeah, sure," and attaches it.

Owen: "Because then all of them will be," adjusting the connection, he looks closely at the component.

Dustin: "There you go, now both of them are working."

Owen: "Yeah, both of them are working!" Jumps up and down in place, shakes his hands and smiles widely.

Dustin posed options for their collaborative investigation, enabling Owen to choose their next challenge. As they worked together to power the related mechanisms of the component, their conversation and behaviors became more reciprocal, as their roles became more defined and distributed—Owen was in control of decision making, showing and confirming his hypotheses and developed understanding, while Dustin acted as technical support, creating conditions for Owen's success by chunking information and narrating each step in the sequence to make the information more manageable. Dustin, as the expert, affirmed Owen's interpretations, and relieved Owen of the burdensome task of clipping the wires to the nails.

3.4.3 Episode Three

In this final episode, Owen was prompted to shift his focus from the table of designed circuit blocks to a new, yet related task of testing and reconstructing a collection of broken circuit block components. Through this activity, he applied his participation in the maker practice of *tinker*, *test and iterate* to a new context of activity and, in so doing, further refined his intention for learning.

In this episode, Owen's sister, Anna, became a part of the learning arrangement. While Owen and Dustin had been exploring circuits and deepening understanding, Anna had been in the workshop, building her own circuit block with Kurt, who is another educator in the exhibit space. Anna constructed a fan circuit block component out of wooden blocks, a motor and zip ties. After completing her construction, and testing it a number of times, Anna prepared to share her creation with her brother, explaining to Mom, "I'm going to show it to Owen. He's gonna think it's the coolest thing in the universe!" Anna approached Owen, and proudly placed her fan circuit on the table beside his compact disk player circuit:

Anna: "Hey Owen, look what I made."

Owen: He turns to see her and asks, "Is that a different kind of fan?"

Anna: "Um, I made it," she twists it around on the table, showing him.

Owen: "It looks like a fan." He turns to his own circuit, touching each piece with one hand, and says, "And look what I made," he slides the slider, and flips the switch to show her how it works.

Anna: Turns her circuit on and off and looks at his circuit. "You didn't make that, did you?"

Owen: Leans towards her, "I did actually."

Anna: Turns back to her fan and turns it back on.

Owen: He looks at his pieces, touching them, "I found this and then I found this."

Anna: Touches a wire on his circuit and says, "You're only attaching it. I MADE this," she spreads her hands, as if to demonstrate the magnificence of her circuit as the fan runs. He looks at her fan, still touching his circuit. "I made this out of old parts," she says, touching a wire to the nail to make the fan run.

Owen: Leans over towards Anna, "I love that. It looks like a fan." He leans the other way to see it from the front.

Anna: "It is a fan."

Owen: Looking closely at it, "That's because it's so cool. I like fans."

Anna: "You want to try it? All you have to do is touch the metal together to make it work." He is looking at how she is doing it. She lets him take the alligator clip from her hand and he reaches and touches it to the nail.

Owen: "Okay," makes the connection. They both look at the fan blades spinning.

Anna: Takes the alligator clip back out of his hand, and leans towards him, saying, "And Owen, (pauses) I get to take it home."

Owen: His eyes light up and he gasps. Jumping up, Owen puts his hands around his circuit and asks excitedly, "Do I get to take *this* home!?"

Anna: "No, no," shaking her head. "If you want, you can work with the guy I worked with to make anything you want." She has clipped the alligator clip to the nail to make her fan run again. She looks at Owen.

Owen: Looks at his circuit, then says in the direction of Dustin, "okay, you can have this back," pointing to his circuit block. "Okay?"

Anna was proud of her creation and showed it off, explaining her use of repurposed parts. She was also proud of her understanding of the method by which to connect and disconnect the circuit to make the fan spin. She was as eager to share the *experience* of making a circuit block as she was to share the actual made product with her brother. As siblings, she knew that her brother "loves stuff like this," and that Owen would enjoy this making activity as much, if not more, than she did. In this case, Anna associated Kurt, another educator in the space, as the social resource, which made possible such an experience, as she says, "If you want, you can work with the guy I worked with to make anything you want!" Further, Anna perceived the ways in which social resources and expertise were distributed throughout the exhibit space as an affordance for differentiated learning opportunities. In so doing, she was recruiting social resources, pulling herself and her brother as learners into another intentional learning arrangement by accessing specific social resources available in the learning context.

Anna's sharing of her process and product, invited her brother to share the result of his making experience as well. This instance sparked an interesting comparison of each child's intention for his and her contextualized learning experience. While it has been determined that Owen's evolving intention is process-based, Anna's intention, like Emma's above, has been to make a product; her very own set of circuit blocks. While Anna asserted that her creation of a product is definitional to making, Owen affirms a different conception of making as a learning process. By realizing his intentions with Dustin, Owen believed he had engaged in an act of making: he had explored and identified repurposed parts from a complex system, he had developed the understanding and skill needed to correctly connect a circuit, and he had solved his personally-identified problem, proving that a component worked as conjectured by connecting it correctly, and in complex ways, to a power source. It is clear that Owen personally identifies with this intentional making process, and, as we shall see, even more so, with the practice of *tinkering, testing, and iterating*.

Although Owen is prompted to leave the circuit block table by the promise of making his very own circuit block to take home, his intention quickly shifted when he is introduced, by Kurt, to a slightly different problem space to which he now feels he can meaningfully contribute:

Anna: “Owen, come here. I'll show you the guy you want--" and she turns and walks towards the workshop and Kurt. Owen follows. She says to Kurt, "He wants to make something like this," showing Kurt her fan circuit block.

Mom: Follows the pair, "You want to try making something, Owen?"

Owen: Walks over to a workbench and says, "Yeah I want to make a circuit." Owen pauses in front of the workbench, looks around at all the tools and supplies.

Kurt: "You want to try fixing a circuit block?" Kurt says as he squats down to a bin of old electronic components on the floor. "This bin, it’s full of broken circuit blocks." Owen throws his hands up into the air in excitement, promptly sits on the floor in front of the bin and starts rummaging through the components. He pulls out a small speaker.

Kurt: “What do you think that one is going to do?”

Owen: Lifts the speaker out of the bin and says, "I don't know, lets' try." Turning the speaker in his hand, looking at it, he says, "Okay, let's try it."

Kurt: "Is there a place to attach things?" Kurt takes the speaker from Owen, and they look at it together. "There's the wires," and points his finger at the small tabs that are coming out of the speaker base.

Owen: Takes the speaker from him, looking closely at the places where Kurt has pointed.

Kurt: "We need a battery." Stands up and says, "Let me go grab a battery" and he walks away.

Owen: Takes the speaker in both hands, turns it around looking at it carefully. "Um. Yeah, let's try connecting these to a battery, in the middle."

Kurt: Reappears, "Okay," and puts a battery component on the floor near Owen.

Owen: Looks up at him, "Thanks for the batteries." The battery component already has two wires leads (one black and one green) attached to it. Owen picks up the unattached end of the black wire, and starts to move the alligator clip towards the component. "Let's try the speaker."

Kurt: "Alright. Why don't I hold the speaker, while you try connecting to those little metal tabs in there," Kurt holds the speaker and points at where to connect the clips.

Owen: "And see how it works," as he tries to attach the clip. He clips the wire into place, and reaches for the green wire.

Kurt "So okay, you have the black wire on. The green wire needs to go--." Owen leans in and points to where to attach the green wire. Kurt says, "I don't know if this is going to work or not." As the green wire clip touches the metal tab on the speaker, there is a clicking sound. "Oh! That was cool." Owen shifts his position and Kurt points to where the clip had touched the tab. "Every time you touch it to there," Owen reaches and touches clip to the tab, Kurt continues, "it makes a little sound."

Owen: Modifying Kurt's line of reasoning, "It makes a different kind of sound. A really weird sound." He looks up at Kurt's face.

Kurt: "It did sound weird," Kurt says in agreement and puts the speaker down on the floor and moves his hands away.

Owen: Leans towards the speaker, holding it steady, testing it again and again.

Kurt "I think if you just hook it up, I don't know if it's going to do anything more."

Owen: Touches the clip to the tab and says, "Yeah, it only works like this."

Kurt: Gestures with his hand, "I think it's every time you tap it there."

Owen: Owen taps the clip on the tab several times, and exclaims, "Ooo, that's how you do that." Owen turns, letting go of the green wire and picks up another component from the bin. "Now do you want to hook up this?"

Kurt "Sure," and unclips the black wire from the speaker. "So now we know that speaker works, so."

Owen: "Yes," and touches the wires.

Kurt: "A big speaker," and laughs.

Owen: "Yeah, a big one." Kurt stands up, moves the speaker.

Owen successfully tests two more components independently by correctly attaching the same set of wires and battery pack to the various mechanisms. Before initiating each test, he says to himself "let's try this one," and continues to investigate, touch and test. Owen and Kurt begin sorting components that work and those that do not work into two different piles. Eventually, Kurt encourages Owen to show his sister how to test a speaker by pulling out a smaller speaker and inquiring as to if the large and small speakers will make similar or different sounds. Owen takes the smaller speaker in his hands and says, "alright, let's try this one," as Anna slides closer towards him.

Anna: Leans in, reaches for the clip of the wire and says, "Can I try it?" as she touches the clip to the tab on the big speaker. Owen sits still and watches until she asks, "where do you have to touch it?"

Owen: Leans in and points to the correct tab.

Kurt "You can kind of see where the wires are coming out--they come out of there," Kurt leans down and points, "and into the--"

Owen: "And in here," pointing to the center of the speaker.

Anna: Continues to move the clip around, looking at where to connect it. She gets it into position and says, "It makes noise."

Owen: "See? Watch."

Anna: "Not the same, but, kind of different."

Kurt: “Kind of, not as loud." Owen is looking closely at the speaker and continues to tap the clip of the wire to the speaker’s metal tab.

With a simple invitation into making, "You want to try fixing a circuit block?" Kurt redirected Owen’s intention from building his own circuit block, to assisting him in a task that will benefit the community, enabling Owen to participate, in more intentional and sophisticated ways, in the maker practice of *tinker, test, and iterate*. Kurt greeted Owen with respect, as he “pulled” the boy into his own activity space as a learning partner. Similar to Dustin’s initial engagement with Owen, Kurt quickly assessed Owen’s understanding through the joint process of testing out the speaker. As Owen proved to Kurt, and to himself, that he can “make it work” Kurt extended and directed the path inquiry in a way that enabled Owen to feel as though he was meaningfully contributing to the work of being a maker in the space—sharing the task of testing the components that will be used by others in the future. The two began to sort and compare components. Kurt encouraged Owen to share his knowledge, through the tinkering process, with his sister. Owen then co-facilitated his sister’s engagement in the practice of *tinkering and testing* the speaker component, as they all collaboratively compared the sounds of the speakers, large and small. Throughout their mutual engagement, Kurt conveyed the feeling and sentiment that he was excited and challenged by the shared problems they were forming and working to solve together, as they constructed meaning through reciprocal conversation and complementary behaviors.

3.4.4 Owen’s Trajectory of Participation

Through an afternoon of making, Owen was able to establish a meaningful trajectory of participation wherein he developed skill and knowledge relevant to connecting an electronic component to a power source; recruited, coordinated, and participated in the social resource structure of the context with increasing purpose; and engaged in the maker community practice of *tinker, test, and iterate* as a means to modifying and evolving his intention for his own contextualized learning experience. Through Owen’s process-oriented trajectory, his intentions for learning changed and evolved in response to the context, meaningfully building on his cultivated skill and knowledge. As Owen tinkered with the various concepts and complexities of the circuit block components, it is evident that he began to develop a personal association, or identification with the practice itself, iteratively exploring the possibilities in anticipation for the next connection to "try" and "make it work."

Table 3.2
Comparison of Emma and Owen's Trajectories of Participation

Emma **Product-Orientation**	**Episode One**	**Episode Two**	**Episode Three**
Participation in Practice: ***Explore & Question***	Used as a means to initiate intention for making	Used to verify knowledge and skill to fulfill intention	Used to refine knowledge and skill to fulfill intention
Adult Social Resource Recruitment & Coordination	Parent expertise as dependent resource Parent as Collaborator & Technical Advisor	Parent expertise as accessible resource Parent as Learning Partner, Technical Support, & Technical Facilitator	Parent expertise as instrumental resource Parent as Technical Facilitator
Method of Engagement	Scaffolded Apprenticeship		
Emma's Intention	Make a pillow with button eyes		

Owen **Process-Orientation**	**Episode One**	**Episode Two**	**Episode 3**
Participation in Practice: ***Tinker, Test & Iterate***	Used as a means to initiate intention for making	Used as a means to refine intention and strengthen understanding	Used as a means to meaningfully participate in joint community enterprise
Adult Social Resource Recruitment & Coordination	Educator expertise "pushed" into Owen's learning context Educator as Technical Advisor &Technical Facilitator	Educator expertise "pulled" into Owen's learning context Educator as Technical Support & Technical Facilitator	Owen "pulled" into learning context as a learning partner Educator as Collaborator
Method of Engagement	Mutual Engagement in Shared Learning Endeavor		
Owen's Intention	Connect a circuit	Prove function of complex component by connecting a circuit	To diagnose and restore circuit blocks for community

3.4.5 Comparison of Children's Trajectories

When comparing Emma and Owen's trajectories of participation (Table 3.2), we found that both children meaningfully engaged the social resources of an adult learning partner in order establish an intention for making, and so, to participate as a learner in context. Both children recruited and coordinated the available social resources to form a meaningful trajectory with respect to their participation in a complementary maker community practice, as well as in their development of relevant knowledge and skill. For Emma, this practice was *exploring and questioning* the material resources of the context, and for Owen, it was *tinkering, testing, and iterating* with electronic components.

There are notable differences in these children's contextualized trajectories of participation. Through Emma's product-oriented trajectory, she coordinated the available social resources with her development of skill and knowledge in order to fulfill the goal, which she established for herself at the beginning of the making experience. At each phase in her trajectory, Emma evolved her participation in the maker community practice of *explore and question*, as well as her recruitment of her mother's technical assistance and expertise in instrumental ways, in order to fulfill her intention to make a pillow with button eyes. In contrast, Owen's trajectory was process-oriented. His intention and participation in the practice of *tinker test and iterate*, evolved in response to the available social resources, his own social positioning, and his development of relevant skill and knowledge.

Another clear difference was the way in which the respective adults facilitated each child's learning. For Emma and Mom, the engagement was one of scaffolded apprenticeship, as Mom began by providing Emma with very structured instruction and progressively "faded" her level of support by shifting her role to grant her daughter more control of the overall process as her relative skill and knowledge improved. For Owen, the educators with whom he worked took an approach of mutual engagement (Takeuchi & Stevens, 2011) in the making process, connecting circuits to reveal how diverse components work. The educators were equally motivated to participate in the activity and found it sufficiently appealing and challenging to sustain engagement (p. 43). They did this through an evolving process of dialogic inquiry (Wells & Arauz, 2006; Ash, 2003), as they constructed meaning together through reciprocal conversation and complementary behaviors. This dialogue became more balanced as their engagement deepened, each elaborating on their others' questions, conjectures and statements. In the end, both children identified with an aspect of their participation: Emma with the product she had made, and Owen the practice in which he had participated.

3.5 DISCUSSION

Through this study of family participation in a museum-based maker space, our goal was to make progress on the notion of making as a learning process. We did this by investigating the ways in which young children enact and coordinate the learning practices of the making community to form contextualized trajectories of participation. Our findings show that young children are able to form meaningful trajectories of participation with respect to their participation in and coordination of maker community practices, as well as to the development of relevant skill and knowledge through an afternoon of making in a museum-based maker space. Our analyses reveal that there are a number of key factors that support, influence, and engender children's paths of participation. These include the accessibility and positionality of adult assistance and expertise, the child's intentions and orientations for their own making endeavor, and the priorities and relevant design choices of the learning environment.

3.5.1 Adults as Learning Partners

Our analyses show that adults are highly influential in enabling children to participate in meaningful trajectories of participation through making in designed informal learning environments. In the cases presented here, young children relied on and actively recruited adults' expertise and technical assistance in order to initiate and sustain their participation, engaging in the maker community practice of *seeking out resources*.

These adults became learning partners to the children, readily available and accessible, yet flexible in their role relative to the child's learning intentions. For example, in the first episode of Owen's activity, Dustin took on the primary role of technical advisor, working to clearly convey information about how to accurately connect a circuit to make it work in ways that Owen would understand and internalize. He then shifted his role in response to Owen's shifting intentions, to become a technical support, creating conditions for Owen's success through dialogic inquiry, chunking information and narrating each step in the sequence to make the information more manageable for Owen. Throughout their interaction, Dustin played the role of technical facilitator, attaching the wire leads to attach the components, a task that, without Dustin's facilitation, would be an obstacle to Owen's success in achieving his learning goal. Likewise, Mom quickly shifted her role in relation to Emma's stitching, from teacher or advisor through direct instruction, to technical support, holding the fabric taunt and angling it so as to enable Emma to stitch with ease as she developed relevant knowledge and skill. Soon, Emma was accessing Mom's technical assistance and facilitation in instrumental ways, handing her the project to tie a knot or thread a needle.

The fluidity with which adults change their roles relative to children's learning intentions pushes our thinking about the ways in which expertise is distributed and used across the family-museum system. In participating in the community learning practice of *seeking out resources*, the maker community values members' development of niche interests and areas of expertise, relying on one another's knowledge and skill in order to participate in the learning practices of the community in more sophisticated ways (Brahms & Crowley, in submission). Therefore, Emma's instrumental use of Mom's technical skill, and Owen's recruitment of Dustin's expertise to confirm his hypotheses and challenge him further are emblematic of evolving participation in this community practice. The distribution of expertise becomes a negotiation and of knowledge, skill and intention, which necessarily changes and evolves through joint-participation.

The museum educators in the museum-based maker space identify as being members of the maker community, and each bring deep knowledge, skill and personal interest in a particular area or medium of making, as well as training in inquiry-based facilitation. Together, they offer visitors access to the range of knowledge and skill that might be relevant to children's making intentions, but also access to the dispositional qualities of the maker community, including their own inherent participation in the learning practices as more central members. This is in contrast to the parents featured in these case studies, who claim to be novice relative to the topics and tasks in which their children show interest and intention. Yet both parents express and show deep knowledge of their respective child's passions and past experiences, their abilities, emotional sensitivities and thresholds. This suggests that children, adult family members, and educators must work together as learning partners in order to foster young children's meaningful learning experiences through making in designed informal learning environments.

We further found that, as learning partners, adults must have a wealth of expertise in various aspects of the shared experience in order to meaningfully facilitate children's learning. These include skill and knowledge of the materials, tools, processes, and practices of making; strategies for facilitating children's development of accurate knowledge, skill, and progressive engagement in the learning practices of the making community; and an understanding of the child as a learner, his or her prior experiences, interests, intentions, and temperament. It is recognized that adult family members and museum educators each bring these different, but equally important areas of expertise to the learning context. How, then, can each learning partner's relative expertise be leveraged to form a productive context for making as a learning process? As informal learning environments and opportunities are designed for learning through making, we must be thoughtful about how the relative expertise of consequential adults in a child's learning experience is dawn upon and positioned relative to others' expertise.

Prior research on family learning in museums has tended to treat the museum environment and the material resources therein, such as exhibit components and signage, as interventions or as a unique setting for learning (e.g. Humphrey & Gutwill, 2005; Borun & Dristas, 1997). Here, we see aspects of the museum becoming an embedded part of the family learning process as family members identify, seek out and purposefully use the museum as an accessible and expected multifaceted learning resource. Our findings in both cases reveal distinctive ways in which the museum, as a site of making, is becoming an embedded resource of the family's contextualized learning.

With Owen, we see the significant roles played by museum educators in the family learning process. In this case, the educators were more than simply content providers or conduits for children's momentary engagement. Rather, these educators played critical roles, as representative and communicative of what it means to make and what it means to learn in the designed environment. Dustin & Kurt became intensely engaged in the making endeavor, welcoming family members into the participatory context and investing their time and attention in a relatively deep and highly collaborative learning experience. In so doing, the educators purposefully encouraged Owen's participation in the valued social practices of the learning community, as they honored and were responsive to his intentions as well as to the family's priorities and constraints. With few exceptions (e.g. Schauble et al, 2002), the study of the role and associated techniques for facilitating family learning in designed informal learning environments is in its infancy. With the rapid development and increasing presence of making and maker spaces in sites designed for family participation, our findings reveal a strong need for focused study of the roles museum educators play as social resources for families' engagement in making as a learning process, as well as a consideration of the critical role of the museum educator, as representative and communicative of both what it means to make and what it means to learn in the designed environment.

In contrast to Owen's family who was visiting the museum from out of town, Emma's family belongs to the museum as members, and visits the museum-based maker space on a regular basis. As such, they are familiar with the design and distribution of social and material resources of the space. With these prior participatory experiences in the maker space, Mom now knowingly positions herself as Emma's primary accessible learning partner, using the tools and materials at their disposal to facilitate Emma's learning to stitch, as well as Emma's progressive participation in community learning practices. Mom attests to being detached and unskilled at the sewing process, yet it is clear that she has grown to embrace and use the museum, and its distributed resources, as a uniquely enabling context for herself as a capable and confident social resource of her child's learning through making. Here, we see the family using the museum as a space, distinguished from everyday activities and routines, where private learning moments may be had and shared in the arena of broader community participation. Although Emma did not seek out social resources beyond the boundaries of her family, we find that the family, as a learning unit, has developed a relationship to the museum, and uses it as an embedded and reliable resource in the their personal learning ecology (Barron, 2006).

3.5.2 Intentionality and Orientation

For the children in these cases, intention, or self-determined goal-orientation was highly influential in shaping their trajectories of participation through making, and the ways in which they recruited and coordinated the available social resources. Research has determined that family learning in museums is primarily interest-driven, as family members' choose, negotiate and carry out aligned and diverse personal and collective agendas through shared museum visits (Ellenbogen et al., 2004; Hilke, 1987; NRC, 2009; Crowley & Jacobs, 2002; Palmquist & Crowley, 2007). It has also been recognized that makers choose their own agendas for learning, including what, when and how they intend to make, and arrange themselves accordingly (Sheridan et al, in submission). Additionally, it has been found that makers tend to direct their participation towards both process- and product-oriented intentions (Sheridan et al, in submission; Brahms & Crowley, in submission). Our analyses show that, in regards to children's learning through making in a museum-based maker space, both orientations lead to participation in meaningful learning trajectories. What is worth noting, however, is that the goals towards which each child directed their making altered the learning path by which they traveled, as well as the aspects of their learning with which each ultimately identified. By orientating her making towards a product, Emma established an intention, and used her evolving participation in the community learning practices to support the fulfillment of her goal. This product-orientation resulted in her identification with her made artifact. Through Owen's process-oriented experience, his intention changed through his participation in and coordination of the community learning practices, resulting in his identification with the practice and the ways in which he could use his growing expertise to support the interests of the community. Thus, when designing for children's learning through making, it becomes essential to honor children's self-determined intentions and interest-driven pathways of participation. Respectively, it is important to consider how the elements of design influence the goals children establish for themselves, as well as those determined by the environment or curriculum, and the paths learners' take in pursuit of those intentions.

3.5.3 Prioritizing and Designing for Practice

Through our analysis, we chose to focus on one central making community practice, *seeking out resources*, and to investigate the ways in which children enacted, coordinated and evolved their participation in this practice to form a meaningful trajectory of participation. We chose to concentrate on this practice because it is inherent to the mission of the designed environment. The museum-based maker space in which this study took place is set within a children's museum, whose aim is to provide enriching learning experiences for families with young children, and which actively designs the environment and its tools to encourage social learning. Table 3.3 displays the designed features of the environment and facilitation that were seen to support young children's coordinated participation in the learning practices of the maker community, as addressed in the findings portrayed in this paper. From here, the field may continue to investigate and determine generalizable principles of design that may guide the development and facilitation of making in designed informal learning environments for making as a learning process.

Table 3.3
Designed Features of Museum-Based Maker Space for Supporting Family Learning through Making

Maker Community Practice	**Designed Features of Space & Activity**	**Facilitation Technique or Strategy**
Seeking out Resources	Architecture of space; zones of activity Distribution of material resources Flexibly arranged furniture & fixtures	Dedicated team with domain-specific expertise Distribution of social resources Leveraging adult family members' expertise
Tinker, Test & Iterate	Process- and product-driven orientations supported and valued Components made to simplify interaction, skill and knowledge development Components that allow for and encourage variety, complexity and possibility	Mutual engagement Dialogic inquiry
Explore & Question	Visible, accessible & abundant tools and materials	Mutual engagement Dialogic inquiry Connections to prior experience

Making is a multifarious and multidisciplinary endeavor that may take many forms (Brahms & Crowley, in submission). These findings further suggest that as a learning process contextualized in designed learning environments, designers may prioritize different aspects of practice to suit environmental, organizational and learner interests, needs or agendas. For example, while the children's museum chose to focus on *seek out resources* as a central learning practice of family visitors, when designing for learning through making, a kindergarten classroom may prioritize *explore and question*, as children learn to investigate the world, identify and categorize it's related parts; a high school social studies class may highlight the practice of *combine and complexify*, as students are encouraged to build on and reference the ideas and achievements of the past and present; and an afterschool club for youth may emphasize the practice of *customization*, encouraging youth to express their unique qualities and identities through their making. Similarly, educational policymakers and institutions are positioning making as a point of departure for participation in STEM learning pathways for children and youth. Our findings here and elsewhere (Brahms & Crowley, in submission) suggest that in order for making to be an effective method and mode of learning, the learning practices—those of the making community, or those of aligned disciplines—which engagement in making is meant to inspire, support and enrich, must be purposely and thoughtfully designed for. It follows that the elements of design, such as methods of facilitation, structure of the learning environment and the tools and materials that are made available, may change based on the learning practices which are given precedence in order to enable learners' participation in meaningful trajectories. Our findings encourage organizations and educators interested in incorporating making into their designs and instruction to consider which aspects of making community participation should be prioritized to best meet the intentions of the learner, but also of the learning institution. Although popular and marketable, making, as a learning process, may not suit the interests and objectives of every learning institution or situation.

The study of making as a learning process is just beginning. This analysis of family learning through making in a museum-based maker space contributes to a small collection of work that is building understanding and a vocabulary about what it means to make, and how this meaning can be leveraged for learning through the design of tools, programs and environments (e.g. Sheridan et al, in submission; Peppler & Bender, in press). The purpose of this article is not to present a generalizable model of learning in all designed informal learning environments, or to disprove an established theory of learning through making. Rather, in conducting this research, we sought to provide a lens through which one may locate and trace young children's contextualized learning through participation in making, and to highlight some of the key factors that influence and support children in making as a learning process. It is recognized that the data presented come from a narrow sample of momentary family learning experiences in one museum-based maker space. Yet, with its limitations, the results of this study point towards promising directions for future research.

In addition to the suggestions noted above regarding research of facilitation and consideration and prioritization of learning outcomes, more work is needed to develop a comprehensive understanding of family making as a learning process within and across diverse places and platforms of family learning such as disciplinary museums, science centers, libraries, and home environments. In addition, the learning trajectories evidenced in this paper must be complemented by longitudinal studies of family participation in and with museum-based maker spaces. Studies should consider what role the museum-based maker space, and its related resources, play in extended learning trajectories, as well as how practices are enacted and coordinated over time and across contexts of families' learning lives.

As a learning process, making may be seen through the lens of participation, as learners engage in the practices of a learning community by recruiting and coordinating contextual resources to form meaningful learning trajectories. We have shown that learners' may establish intention, develop and apply skill and knowledge, and dynamically participate in the social practices of a broader learning community. This process can happen within moments, over the course of months, or throughout a lifetime. Although learning through making is achievable by all, regardless of age or gender, the context of participation including the resources that are made available to learners matter, as they may be designed to support and enrich learning opportunities. Through the study of young children's trajectories of participation within the context of a museum-based maker space designed for family learning, we have been able to show that the provision and design of material resources is influential in sparking and shaping children's intentional learning through making; and be have provided clear evidence that the presence of and children's access to adult learning partners is essential in enabling young children to meaningfully participate and evolve their participation in context.

4.0 CONCLUSION

Together, the research studies comprising this dissertation use the learning sciences as an analytic lens through which to consider, locate and trace participation in making as a learning process. Theoretically, the work is based in the communities of practice framework (Lave & Wenger, 1991; Wenger, 1998), which understands learning as change through participation in the socially-relevant practices of a given community, within a given activity setting (e.g. Brown, Collins, & Daguid, 1989; Gutierrez and Rogoff 2003; Greeno, 1991, Hutchins, 1995; Gresalfi, 2009). In adopting this approach, we are able to distinguish *what* making is as a learning process, through the identification of the core learning practices of the making community, and *how* such learning can be evidenced in the context of a designed informal learning environment.

The articles presented in this dissertation describe two initial steps in a program of research on making as a learning process. As such, they follow a sequential path, using the findings of the first study as analytical foundation for the next study. This dissertation meaningfully contributes to the current theoretical and practical discussions of what making is as an educational process by characterizing participation in the maker community through the identification of the community's core learning practices, by providing an empirical lens through which we may locate and trace children's contextualized learning through participation in making, and by highlighting key factors that influence children's participation in making as a learning practice.

4.1 SUMMARY OF FINDINGS AND DISCUSSION

In the first article, presented as Chapter 2 of this dissertation, I explored and identified the seven core learning practices of the making community through a textual analysis of *Make Magazine*.

This investigation responds to current interest and efforts to position making as support for young learner's participation in STEM disciplines and related workforce pathways. Findings reveal that, through their participation in shared learning practices, makers identify as a community and demonstrate fundamental aspects of the communities of practice framework (Wenger, 1998). I characterize and discuss the ways in which makers participate in these definitional aspects of a community of practice: *mutual engagement*, or recognition and negotiation of relationships and norms of participation; *joint enterprise*, or the pursuit of shared purpose, which lends to accountability among members; and developing a *shared repertoire*, or a set of shared resources used in the production of new meaning.

I found that the core learning practices of makers do not come from or point towards a clear disciplinary pathway, but that aspects of maker practice resemble and may support learner's participation in certain disciplinary practices. As such, making is multidisciplinary. The community is composed of individuals who meaningfully participate in other, complementary communities of practice, and who bring the knowledge, skill and associations germane to those communities to their participation in making. As such, disciplinary knowledge and skill is held by the community through its distribution among members, and is accessed and applied in instrumental, multidisciplinary and novel ways through diverse forms of participation and reification. I discuss how participation in the making community may not necessarily set members on a trajectory towards participation a single STEM discipline, yet, it does encourage community members' to tinker at the edges and intersections of disciplinary participation, as it has the potential to make disciplinary knowledge and skill more accessible to people who feel peripheral to the more refined and inaccessible aspects of disciplinary practice. Finally, I found that the vast majority of makers featured in *Make Magazine* are men. In light of these findings, I consider the implications of these analyses for leveraging making as a learning process that is accessible and accommodating to a broad and diverse range of learners. In particular, I highlight the people and programs that must be identified and designed to be *brokers* of meaningful participation between and among more central and peripheral forms of participation, as well as across existing boundaries of participation.

In the second article, presented as Chapter 3 of this dissertation, I extend the analysis of making as a learning process to family participation in designed informal learning environments. I apply the communities of practice framework to two comparative case studies of family activity in a museum-based maker space, in order to locate and trace evidence of learning through young children's contextualized participation in an informal learning environment designed for family engagement in making. In line with the first article, the second study is responsive to the current demand from educators and policy makers for definitions, measures, and guidelines of design that capture the distinguishing qualities of making as a learning process. While the findings of the first article provided a possible definition to *what* the practices of making are, our findings in this second article show *how* learners enact and coordinate the learning practices of the making community to form contextualized trajectories of participation during an afternoon of making activity. In the first article, I found that the learning practices of the making community are highly interrelated and mutually supportive of one another. In this second article, I saw the ways in which these interrelationships take shape, as children used their engagement in the primary learning practice of *seeking out social resources*, to evolve their participation in another, complementary maker community learning practice. I further found that young children's learning process involved the development of skill and knowledge instrumentally relevant to the topic of their creative intentions, which were either oriented towards making a product or engaging in a making process. Finally, our analyses reveal that there are a number of key factors that support, influence, and engender children's paths of participation. These include the accessibility and positionality of adult assistance and expertise, the child's intentions and orientations for their own making endeavor, and the priorities and relevant design choices of the learning environment.

In chapter 3, I discuss each of these key factors and their relative implications for design. First, I consider the ways in which the young children rely on and actively recruit adults as learning partners in order to develop their participation in context. As children's learning partners, family members and museum educators bring different, but equally relevant expertise to the learning context. As they work in partnership with the child, this distribution of expertise evolves with children's developing skill, knowledge and intention. I further discuss how the integration of making into informal learning environments is changing visitors' relationship to such spaces, as museums become embedded resources for family learning, either through families' ongoing and increasingly personalized use of the space and its material resources, or through the critical role educators' play in facilitating visitors' participation in the practices of the making community. I further found that children's intentions, or the goals towards which each child directed his or her making altered the learning path by which they traveled and the aspects of their learning with which they ultimately identified as a maker. I consider the implications of these findings for the design of informal learning environments that support family learning through making, including the critical role of the museum educator as both a facilitator of informal learning and a representative of making as a learning process; and the ways in which children's intentions and personal learning pathways are authentically guided, sustained and enriched. Finally, I reflect on how designers of educational experiences and environments may wish to prioritize different aspects of maker community practice to suit the needs and agendas of their environment, organization or intended audience in order to foster learners' meaningful participation in making as a learning process.

4.2 EMERGING LINES OF INQUIRY

As noted previously, the study of making as a learning process is in its initial stages. The articles included in this dissertation are among the first empirical research studies to be conducted with regard to this new movement of making and its potential as a change agent of educational reform. Together, these studies work to lay a foundation for future research of *what* making is as a learning process, and *how* it takes shape in designed spaces, programs and platforms. From the findings and limitations of this work, emerge interesting lines of inquiry for future research and design.

While this dissertation recognizes the rush, among educators, designers and policymakers to equate young people's engagement in making with their participation in the disciplinary practices of science, technology, engineering, and math, it does not directly test the hypothesis that making is an explicit link to or pathway towards participation in STEM learning, nor has any known research to date. Future work is needed to better address and prove these current assumptions. Useful research that would help unpack and inform this conversation should include a comprehensive mapping of the identified maker community learning practices to the core practices of science, technology, engineering, math and the arts. This would likely feature the important multidisciplinary overlaps among disciplinary practices and maker community practices, as well as an identification of the distinguishing features of the learning practices of makers. Additionally, there appear to be interesting connections between maker community learning practices and aspects of participation, and the espoused 21st Century Learning and Innovation Skills, such as creativity, innovation, critical thinking, problem solving, communication and collaboration (Partnership for 21st Century Skills, 2014). Future work should take a critical look at the ways in which engagement in making may support learner's development of such skills and distinguish measurable evidence of this engagement and associated skill development. Additional research should further investigate the people, both adults and children, who participate in making deeply; the contexts of their participation and the ways in which their participation in making extends, or not, to participation in STEM disciplines. This could include retrospective studies of adult makers, to trace their trajectories of participation in related STEM disciplines throughout their development; and studies of children who currently participate in making, and the potential overlaps or ease with which making affords their engagement and participation in disciplinary practice.

A second line of inquiry considers making as a learning process of children and families. Through this work, I assert that by engaging in the learning practices of the maker community, children develop skill and knowledge relevant to the task at hand, but that they also develop a relationship to the content and to the people with whom they are learning through their participation. Future work should further investigate the affordances and challenges of making for the development of learners' content knowledge, inter-personal relationships and identity.

This dissertation did not directly address questions about race, socio-economic status and gender. If making is going to be an effective agent of educational reform, it will need to confront the identified imbalances and barriers to broad STEM participation, especially since Study 1 suggested that at least some parts of making community appear to be, for example, mostly composed of men. Future research should investigate diverse groups' participation in making as a learning practice within and across families, personal communities and generations. We now know that parents and significant adults in children's lives play an essential part in enabling young children's engagement in making as a learning process. We also know that parents and consequential adults have a significant influence on children's development of topic or domain-specific interests (e.g. Crowley, Barron, Knutson, & Martin, in press). How might adults, and their diverse areas of personal, cultural and professional interest and expertise be meaningfully recognized and leveraged to encourage children's participation in making? How might adult makers' positioning on the edges and intersections of disciplinary practice and craft, become models for children to step across traditionally gendered or stereotypical margins of participation? How might making, as an informal learning process, better reach communities who feel marginalized or unwelcomed by societal learning structures like schools and museums? These are just some of the questions that must be addressed in order for making to reach beyond its current social boundaries.

Likewise, we must extend the timespan by which we investigate and measure children and families' engagement in making as a learning process, from the moments of a museum visit, to a collection of visits over months or years, as well as the influences and intersections of family members' participation in designed environments, with other contexts of participation in making, such as home, school and online. Such research should consider the ways in which time influences family members' relationship to practice, to their development of skill and knowledge, as well as their relationship to the contexts of participation as learning resources.

A third line of inquiry considers the ways in which these analyses of making inform an understanding of the communities of practice framework (Lave & Wenger, 1991). Both articles featured in this dissertation use the communities of practice framework as a theoretical lens to understand, identify and trace learning through practice. Participation in community learning practices is but one lens through which one may see evidence of learning, but here I found the framework particularly useful as a tool for mapping an emerging social phenomenon to extant learning theory. Through it, I was able to clearly see the how the maker community functions as a learning community. It is my hope that the identification of core maker learning practices featured in these articles sparks a lively debate and further study of what characterizes making as a learning process.

The use of a community of practice approach also presented challenges to data analysis and interpretation, as the social learning structure of the maker community does not necessarily align with the typical novice-to-expert trajectory of the communities studied by Lave and Wenger (1991). Rather, the community of makers is composed of individuals with diverse areas of expertise, including specific skill and knowledge. This distribution of expertise is accessed in instrumental ways by other members of the community, and integrated on an as-needed basis, often for personal projects or erudition. Additionally, it may be the novice eye, or a playful mistake, that prompts an influential innovation for the making community. In this current conception of maker community participation, having skill and knowledge relevant to the content of making does not necessarily mean one is more or less central to community participation. Rather, it is the ways in with which one accesses, shares, applies and uses such skill and knowledge that is associated with more central community participation. Future work should pursue these, and other nuanced differences between the established learning theory and the learning practices and methods of participation of this new learning community. This might include ethnographic work tracing community members' participatory activities, similar to that conducted by Lave and Wenger (1991). What does peripheral participation look like in the maker community? What sorts of trajectories are formed over time among members with diverse areas of interest and expertise? How does one's identity or association with the community shift and develop through participation over time?

Practically, there is a significant need for further research around the design of places, programs, and platforms for making as a learning process for children and families. Analyses point towards the need for concerted attention to be paid to the role of the museum educator—the approaches and techniques that are used, and the identities these individuals bring to and negotiate through their participation in context—as they guide and facilitate visitors' meaningful engagement in making.

This work further suggests that making may take quite different forms as it is integrated in ways responsive to the diverse needs and objectives of varied learning environments and organizations. A useful contribution to the fields of research, design and practice would be a comprehensive and comparative assessment of how making is being incorporated into diverse designed informal learning environments. This would entail looking across types of informal learning environments such as science centers, disciplinary museums and libraries as contexts of learning through making. Aspects of comparison might include the format of making experience (e.g. exhibit, program, etc.), the tools and materials of use, and the principles that guide the design of space, activity and facilitation across spaces and programs, and how such principles are evidenced. Other factors worthy of consideration include the infrastructural needs and limitations of organizations, such as staffing structures, budgetary constraints, and organizational culture. With such a comprehensive understanding of the similarities and differences; organizational interests and learning objectives, the fields of research, design and practice may begin to reliably distill and generalize a framework, or rubric for the effective design of space, activity and facilitation of making experiences in informal learning environments.

Finally, this work encourages a consideration of the boundaries, distinctions and pathways of the maker movement, itself. As a community of practice, the maker community will necessarily evolve through participation across generations, as members negotiate meaning through social practice. It is in this negotiation, across generations, where Wenger (1998) believes learning to take place. As the maker movement develops, which aspects of maker community participation will future generations of makers most strongly identify with? As the movement is pulled into the more structured worlds of informal and formal education, design-based research, and workforce development, what is lost and what is gained, and how does this positionality of the movement alter the participatory, reified and identify-based aspects of the community?

There are obvious tensions that emerge when making is positioned as an integral aspect of these formal learning environments and societal structures. The analyses presented in this dissertation illuminate the boundary work that must be done regarding the connections and distinctions between making and STEM disciplines, yet there are other, important tensions that must be addressed when looking towards the future of making. For example, many makers have an amateur spirit, tinkering in unfamiliar areas and identifying with making as a hobby that brings them joy and fulfillment outside of their career. Yet, this stance is at odds with the notion of making as the on-ramp to skilled workforce pathways that will pave the way for the nation's economic prosperity. Or, for example, the tension between the maker practices of hacking & repurposing and combining & complexifying which champion the maker movement's resistance to consumerism, and the current trend to "shrink-wrap" making experiences into kits and step-by-step how-to guides that can be easily incorporated into classrooms or purchased by consumers. Even, the experimental manipulation and quantification of aspects of learning through making, which are at the heart of good research, have the potential to alter the course of maker community participation. These tensions between making-as-it-has-been, making-as-it-is, and making-as-it-may-become must be addressed and considered as making is incorporated into the fabric of society's educational structures.

Making has taken root as a means of social belonging and participation, and as an informal learning phenomenon. The two studies presented in this dissertation work together to lay a valuable foundation for future research and practice, as they shine an empirical and interpretive light on making as a learning process. While there is work to be done, the path ahead is as relevant and promising as it is ambitious. Educators, designers and researchers are meaningfully positioned to advance an integrated agenda of learning sciences theory and informal learning practice to design spaces, tools, programs and platforms that leverage an understanding of making as an evolving and participatory learning endeavor. As a potentially new form of, or perspective from which to view participation in traditional learning structures and disciplines, making has the ability to broaden our understanding of what STEM learning is, could or should be for children and youth. Likewise, with further study and design, making may offer us new ways to think about the meaning and utility of fundamental aspects of learning, such as knowledge, skill, and practice for the "production of persons" (Lave, 1996) motivated and able to innovatively contribute to society.

APPENDIX A

TABLE A1 CODING CATEGORIES FOR TEXTUAL ANALYSIS OF MAKE MAGAZINE

Maker Community Practice	Definition	Example
Explore & Question	Interrogation of the material properties of the context in order to find inspiration or to determine intention for a process or project.	What does DNA taste like? Aside from the fact that DNA is very small, the materials needed to extract it often aren't edible, or if they are, they're not as delightful as a cocktail. (Vol. 31, pp. 71-73)
		So what's the best way for a handful of people to collect data about nuclear fallout around Japan? Huddled in an office in Tokyo, we wrestled with the question, and then Ray Ozzie (former chief technical officer at Microsoft) delivered the answer at a brain- storming session with other Safecast members: strap a Geiger counter to a car and go for a drive, obviously. (Vol. 31, pp. 52-55)
		Krause explores what mathematicians and astronomers once called "the music of the spheres" — a sacred geometry of harmonic proportions discoverable through mathematics. He's fascinated by the connection between the tiny patch of Earth he occupies and the big universe out there. In retirement, he explores what interests him on his own terms. Chuckling, he says, "I don't know what I'm doing, but I'm in a position in life where I can play." (Vol. 31, pp. 30-33)
Iterate, Test & Tinker	Purposeful play, experimentation, evaluation and refinement of the context.	First, we made non-functional prototypes using wood and acrylic, to try different sizes for the devices and ideas for applications…When the first circuit boards arrived, we assembled a handful of barely functional Siftables that kicked off two full years of trial and error. We made three generations of working prototypes, each generation fixing the bugs of the previous and allowing us to try new application ideas more easily. We let people use them a lot along the way, and

		noticed something surprising and exciting: our testers were having a lot of fun. (Vol. 33, pp. 32-35)
		Aside from that, I've learned from trial and error more than anything else. This usually means that I know all sorts of technical things without having any of the proper terminology to describe them. I also spend a lot of time looking at materials and thinking of what they could be used for, above and beyond the manufacturer's recommendations. (Vol. 32, pp. 29-32).
Seek Out Resources	Identifying and pursuing the distributed expertise of others, includes recognition of one's own not-knowing and desire to learn.	The thriving DIY community came to the rescue. We learned basic PCB design from online tutorials (Instructables, Adafruit, Seattle Robotics Society, UK Electronics Club) and discussion boards (SparkFun, AVR Freaks). We scoured the web for the best deals on board manufacturing (Vol. 31, p. 148).
		You can design your own circuit traces, or use existing artwork of proven designs. Search the Open Circuits wiki, Adafruit's Github repository, and hobbyist websites like diystompboxes. com to get a taste of what's out there for free. And remember, you can also transform schematic diagrams into circuit board layouts using free software tools (see page 44). We designed this board as a super-sized version of the MAKE Learn to Solder robot pin. It's got huge traces, but people also use this method to make fine traces. (vol 33, pp. 130-132)
		How did you learn your fabrication skills? When I was a kid, my grandfather often told me that you can learn anything anyone anywhere knows from a book. I spent a lot of time in the library back then. Nowadays, the same thing can be said about the internet. Just about anything you could want to know can be found somewhere online, but it can also be easy to get discouraged. The trick is to find inspiration and ideas without allowing yourself to be overwhelmed by the volume of other folks out there who have already done what you're thinking of trying. (Vol. 32, pp. 29-32)
Hack & Repurpose	Harnessing and salvaging component parts of the made world to modify, enhance, or create a product or process.	A few years ago I got interested in the idea of making my own cigar box ukulele. I had a nice box and the wood to make the neck but I needed a lot of other parts, like frets and a slotted fretboard and tuners and strings, that I had to order and wait for them to arrive. But I wanted it done right then! So while I waited, I thought about how those parts functioned and what I could substitute. I remembered someone using toothpicks for frets on cigar box guitars, and while I was wary of steel strings cutting into the wooden frets, I thought a ukulele's nylon strings should be fine. Toothpicks for frets: check. I'd also seen a lot of instruments built with cookie tins for the body, so I headed to the local resale shop to look for one. No tins, but what I did find was even better. Nice, rigid aluminum cake pans, in two sizes. "Resophonic instruments use aluminum cones, don't they?" I thought. Cake pans for the body: check. I brought my treasures home and found a nice piece of hardwood for the neck. Luckily, I had a set of tuners and strings on hand. I got to work and a few days later, I had a cake pan uke! The name? Early in ukulele history, Alvin D. Keech introduced a banjo ukulele that eventually got the name banjolele. Looking like it does, it seemed natural to call my instrument a Cake Pan-jolele, or Panjolele for short (Vol. 33, p. 76).
		I really think there's massive value in building from scratch, but there's also another larger series of benefits that come from taking apart something and repurposing it. We could just have people make electric go-karts and dump as much money in them as possible and call it a day. To me,

		that's boring, and reserved for a more legitimate racing series. I want people to take something that was never intended to be modified in this way and use a minimal budget to make it happen. Some of the best bouts of creativity come from constraints, and we live in a world full of constraints! We should just condition ourselves to try and fail and then learn. Hacking apart stuff is pretty much the easiest and cheapest way to do this. It's something we all need. (Vol. 33, pp. 24-31)
		It's easy to build up a "junk box" of items you can use to build projects seen in MAKE — or just about anything you can imagine. Many of my articles for MAKE (makezine.com/go/arey) take advantage of found components, often picked out of trash bins. Just because an electronic device has failed at its original task doesn't mean it can't perform other tasks. Castoffs can be recovered and the parts repurposed in countless ways. Recently, my trash-picking adventures turned up a discarded laser printer. I set about finding what wonders were waiting beneath the plastic covers (Vol. 32, pp. 108-109).
Combine & Complexify	Developing skilled fluency with diverse tools and materials in order to reconfigure existing pieces and processes and make new meaning.	GEEKED OUT GARDENING What do you get when you mix Arduino and an indoor garden? Garduino, of course. Luke Iseman was interested in gardening but knew he couldn't keep up with the daily watering and lighting requirements, so he put his tech to work. Combining an Arduino and a series of inexpensive sensors (photocell, thermistor, and galvanized nails), his system ensures the plants get watered when they're thirsty and get light when they need it, and it alerts him when temperatures drop. (Vol. 30. pp. 76-81)
		But stick an Arduino in a wooden box, along with a finger-operated sensor and small motor, and you've made a 21st-century treasure chest that's suitable for a daily diary, petty cash, or even those special Rice Krispies recipes that your snoopy neighbor wants to steal (Vol. 32. pp. 110-117).
Customize	Tailoring the features and functions of a technology to better suit and personal interests and express identity.	There's lots of room for customization. Make the body profile realistic or more abstract. Give the car a front and back, or make it symmetrical. Play with the wheel size and the distance between the front and back wheels. Stain or paint can liven your car up, as well as extra details such as names or stickers. Make your car what you want it to be! (Vol. 32. pp. 147)
		The console employs a combination of readymade and custom circuits to achieve various lighting and sound effects. Ours is used for world domination, but the same basic panel would work equally well for tracking the migration of a swarm of monarch butterflies, or detecting unicorns, if that's what you need. Here's how I built it. (Vol. 32. pp. 134-138)
		The designs themselves leave a lot to the imagination. "Every bicycle is different; every body is different; every disability is different. You don't have to show them exactly how to do it, just that it can be done. The first time they see this chair go across the grass, they go, 'Aha!' So I just give them enough information to get them started down the right path. They get some skin in the game, get it exactly how they need it, and come up with their own good ideas." (Vol. 30. p. 25)
Share	Making information, products, methods and modes of participation accessible and usable by members of the community.	It would be hard to overstate the importance of the internet in the lives of Hellfritsch, Saxon, and Rabinovitch. "We're self-taught in every possible area," says Saxon. "We grew up in a generation in which internet search was entirely native. Search is all about self-directed education, and all of us are extremely keen at searching and finding what we need out there to get things done. To go

		from complete ignorance on a subject to execution of a project within a week is pretty normal here." Says Hellfritsch: "I probably spend 50 percent of my time on the internet reading forums. Being on a forum and trying to connect with someone or search for the stored history of that forum has been really key. I've used it a lot — even in the middle of a project." (Vol. 30, pp. 30-35)
		After you build something cool, please tell us about it on the XIG project website (code.google.com/p/xig). For schematics, breadboard instructions, and video, see makeprojects.com/v/30. For parts lists, troubleshooting, and source code for the web browser interface, see jordan.husney.com/xbee_garage_door. (Vol. 30. pp. 66-71)

TABLE A2 CODING CATEGORIES FOR FAMILY ENACTMENT OF MAKER COMMUNITY LEARNING PRACTICES

Maker Community Practice	Definition	Example
Explore & Question	Interrogation of the material properties of the context in order to find inspiration or to determine intention for a process or project.	Boy investigates the material properties of the component, making connections and explaining the imagined workings of the device to himself through his investigation (Electronics Family 3). Girl pushes needle through the fabric with right hand, pulls it out the other side with her left hand, and asks, "Is it [the needle] making holes in the cloth?" (Sewing Family 1)
Tinker, Test & Iterate	Purposeful play, experimentation, evaluation and refinement of the context.	Boy taps the clip on the tab several times, and exclaims, "Ooo, that's how you do that." He turns, letting go of the green wire and picks up another component from the bin. "Now do you want to hook up this?" (Electronics Family 3) Father says, "Oh!" as he stands the project up, "here you go, man." They look at it but it is wobbly. Father sits down next to boy on his own stool on boy's left. Boy says, "we need another" and father says, "oh, no, it's still falling over. What are we going to do?" Father is holding project upright. Boy leans onto table, reaching for another new piece of wood, and says "another piece" and brings it towards the project, on the opposite side of the piece they had just attached to help stabilize it. Father asks, "where are we going to put it?" Boy holds new piece in place. Father says "right there?" and helps hold project as boy positions the new piece and looks for a nail with which to attach it (Woodworking Family 5)
Hack & Repurpose	Harnessing and salvaging component parts of the made world to modify, enhance, or create a product or process.	"I made this out of old parts," she says, touching a wire to the nail to make the fan run (Electronics Family 3). Mother reaches over to pick up some small fabric scraps, "You gotta stuff it with stuffing. See these guys here? You gotta stuff it." Mom places some fabric scraps on the table in front of girl (Sewing Family 1). Girl says, "We started out with this cool fabric that I think was curtains, and now we are going to make it into a skirt" (Sewing Family 4).

Combine & Complexify	Developing skilled fluency with diverse tools and materials in order to reconfigure existing pieces and processes and make new meaning.	Family advances from practice sewing boards (prior experience in maker space) to intently making a pillow with cotton fabric, metal needles and thread (Sewing Family 1). Boy selects and investigates a more complicated circuit block to investigate. The new block component has two working motors and four points of electrical connections, as opposed to one motor and two points of connections on the previous block (Electronics Family 3).
Seek out Resources	Identifying and pursuing the distributed expertise of others, includes recognition of one's own not-knowing and desire to learn.	"Hey, you want to connect this one?" boy says as he shows educator the component (Electronics Family 3). Boy speaks and stops hammering, looks at father, father looks at him, boy says, "I need help" (Woodworking Family 5). Dad says, "Do you need more thread? Do you want me to tie it off and get you more thread?" She agrees, is looking at her piece, pointing the needle at the area where she intends to sew next. Dad says, "Do you want to do mine while I get you more thread?" She nods, then looks back to her project. He hands the fabric over to her place, laying it on the table in front of her, and says, "Run it through. Can you do that for me? And I'll get you more thread." He takes her project and puts it on the table in front of him. "Do you want more red thread?" (Sewing Family 3)
Customize	Tailoring the features and functions of a technology to better suit and personal interests and express identity.	Girl is determined to add button as eyes to her pillow project (Sewing Family 1). Father asks, "Is it finished?" Boy responds, "nah…" and shakes his head. Father picks up a new piece of wood (round shape), and holds it in two hands in front of boy's face. Father says, "where should I put it? Should I put it right here?" Father places the round shape on the top of the structure. Boy reaches towards the new piece, pushing father's hand away, picks up the piece with both hands, and says, "no." Boy moves new round piece off the structure, puts it on the table, near the bottom of the structure. Father takes round piece out of boy's hand and holds it up to the structure on the side, and asks, "do you want to put the spinner on the side?" Boy takes piece out of father's hand and says, "wheels!" and holds it to the structure towards the bottom again, "We need another one to make wheels" (Woodworking Family 5). "And I want red thread now, not orange thread" (Sewing Family 3)
Share	Making information, products, methods and modes of participation accessible and usable by members of the community.	"Hey Owen," she says, placing her fan circuit on the table near his compact disk player circuit, look what I made…you want to try it?" (Electronics Family 3) "Pillow, pillow, pillow! Guys watch out! There's a pillow monster coming your way!" (Sewing Family 1)

TABLE A3 CODING CATEGORIES FOR ADULT ROLES IN FAMILY ENGAGEMENT IN MAKING

Adult Role	Definition	Example
Technical Advisor	Telling or showing how to do or improve technical skill	Mother: "Put the needle through," and pushes the needle part way through the fabric. "Now push it through," pointing in the direction the needle is going, "push it. Now take it on the other side," motioning how to grasp the needle with her fingers. "Pull it all the way through" (Sewing Family 1) Educator explains content through analogy: "Imagine these are like a train station" pointing to the nails on the battery component, "and they send out the electricity on the train line," indicates electricity moving along the wire by gesturing with his arms, "they send it out on the red one," points to the nail with the small red wire connecting it to the battery, "and it comes back on the black one" (Electronics Family 3). Father places his hands on boy's hands and re-positions boy's hands, "hold it closer to the head, it will be easier" (Woodworking Family 5).
Technical Support	Creating conditions for others' consequential activity	Father holds wood steady as child hammers (Woodworking Family 5) Mother holds fabric taunt and steady while child stitches (Sewing Family 1). Educator chunks information and verbalizes steps in making sequence (Electronics Family 3).
Technical Facilitator	Does activity solo in order to make progress and/or enable child's feeling of accomplishment.	Mother ties a knot for child in the thread for her child (Sewing Family 3). Father hammers the nail into wood just enough to secure it for the boy to hammer the nail into the wood the rest of the way (Woodworking Family 5). Father threads the needle, readying it for child to sew (Sewing Family 3) Educator opens and attaches clips to wire leads of the components as child instructs where to place them (Electronics Family 3).
Collaborator	Doing consequential activity together	Father and son hammering together, hands intertwined (Woodworking Family 5). Father sorts through button box looking for a button to match the one his daughter has already chosen and is working to place on her quilt (Sewing Family 3).
Emotional Coach	Providing encouragement and coping	Boy starts hammering as father holds nail, father says "Oh, that's great." Father says again,

	mechanisms for child	"doing great, keep going" (Woodworking Family 5) Mother gently rubs girls back as she stitches (Sewing Family 1).
Unengaged	Not focused on consequential activity	Father removes himself from the child's making experience, steps back, and looks away (Recycled Construction Family 4). Mother turns to personal cell-phone and begins texting (Recycled Construction Family 4).

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