The Maker Movement, the Promise of Higher Education, and the Future of Work

by

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ABSTRACT

The 21st century will be the site of numerous changes in education systems in response to a rapidly evolving technological environment where existing skill sets and career structures may cease to exist or, at the very least, change dramatically. Likewise, the nature of work will also change to become more automated and more technologically intensive across all sectors, from food service to scientific research. Simply having technical expertise or the ability to process and retain facts will in no way guarantee success in higher education or a satisfying career. Instead, the future will value those educated in a way that encourages collaboration with technology, critical thinking, creativity, clear communication skills, and strong lifelong learning strategies. These changes pose a challenge for higher education's promise of employability and success post-graduation. Addressing how to prepare students for a technologically uncertain future is challenging. One possible model for education to prepare students for the future of work can be found within the Maker Movement. However, it is not fully understood what parts of this movement are most meaningful to implement in education more broadly, and higher education in particular. Through the qualitative analysis of nearly 160 interviews of adult makers, young makers and young makers' parents, this dissertation unpacks how makers are learning, what they are learning, and how these qualities are applicable to education goals and the future of work in the 21st century. This research demonstrates that makers are learning valuable skills to prepare them for the future of work in the 21st century. Makers are learning communication skills, technical skills in fabrication and design, and developing lifelong learning strategies that will help prepare them for life in an increasingly technologically integrated future. This work discusses what aspects of the Maker Movement are most important for integration into higher education.

DEDICATION

For Sharlissa, without the perfect partner, none of this would be possible.

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This dissertation would not be possible without the ASU Maker Research team. To Micah Lande, Shawn Jordan, Chrissy Foster, and all our undergraduate researchers, thank you. My committee members have each helped me immensely in this process. Micah, you've been amazing to work with. Brad, you've been the single greatest influence I've had when it comes to teaching. It's no stretch to suggest that my success as an instructor will be entirely due to working for you as a TA. Finally, Ira, without meeting you, I wouldn't have even known about the HSD program, much less that I'd find my place there. Thank you all.

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PREFACE

This dissertation is based primarily on data collected under two NSF grants, "Should Makers be the Engineers of the Future?" and "Might Young Makers be the Engineers of the Future?" (Grant Nos. 1232772 and 1329321) by Dr. Micah Lande, Dr. Shawn Jordan, undergraduate and graduate research assistants, and myself at Arizona State University. Additional data was collected through my own participant observations at makerspaces and Maker Faires.

Parts of this paper are based on coauthored conference papers presented at the American Society of Engineering Education (ASEE). The section on maker education pathways is drawn from the following. Foster, C. H., Wigner, A., Lande, M., & Jordan, S. S. (2015). Welcome to the maker movement. In *2015 122nd ASEE Annual Conference and Exposition*. American Society for Engineering Education. For this paper, I served as the main co-author and contributed to writing, analysis, and data presentation. The section on making and ABET accreditation was likewise presented as follows. Wigner, A**.**, Lande, M., Jordan, S. (2016). How Can Maker Skills Fit in with Accreditation Demands for Engineering Programs?. ASEE 2016 Annual Conference, New Orleans, LA. On this paper, I was the primary author.

The remainder of the dissertation and analysis are original work that has not been published elsewhere.

CHAPTER 1

INTRODUCTION

Higher education has historically promised to prepare students for both the workforce and to operate as better informed citizens and critical thinkers, but it is uncertain how successful the current model may be in the 21st century. The near future will be the site of numerous changes in education systems in response to a rapidly evolving technological environment where existing skill sets and career structures may cease to exist or, at the very least, change dramatically. Likewise, the nature of work will also change to become more automated and more technologically intensive across all sectors, from food service to scientific research. The most likely scenarios paint a picture where simply having technical expertise or the ability to process and retain facts will in no way guarantee either success in higher education or a satisfying career. Instead, the future will likely value those educated in a manner that encourages collaboration with others and with technology, critical thinking, creativity, clear communication skills, and strong lifelong learning strategies. The great challenge for higher education will be a question of how to best prepare students for this future, how to prepare them to be flexible lifelong learners who are unafraid of interacting and engaging with complex rapidly evolving technological systems. Universities will have to address this issue from a pedagogical perspective within the classroom as well as in terms of how makerspaces are created and integrated with the university more broadly. Preparing students for the future of work will require fundamental changes in both education systems and education policy at both institutional and governmental levels.

Inspiration for a form of education to prepare students for the future of work can be found within the Maker Movement. Makers, as will be shown in the empirical chapters, excel at communication skills, critical thinking, technological adaptability, and lifelong learning strategies. The research in this dissertation indicates that makers are developing the skills and attitudes that will prepare them for work and life in the 21st century, whether that work occurs in engineering or less technical domains. By laying the groundwork of showing what and how makers are learning, this work will enable future studies to bridge making and higher education to better prepare students.

The Maker Movement encompasses millions of Do-It-Yourself, and Do-It-Together, enthusiasts, has been lauded by the Obama administration, inspired university presidents to commit to enhancing maker culture on their campuses (OSTP, 2014), and led to the creation of thousands of spaces for technological tinkering and innovation (hackerspaces.org, 2016). Makers exhibit a combination of technical savvy and lifelong learning skills that could be very helpful in reframing education for the future (ASEE, 2016). However, it is not fully understood what parts of this movement are most meaningful to implement in education more broadly, and higher education in particular. As described by Halverson and Sheridan, "*Learning* in making is, emphatically, not interchangeable with *schooling*." (2014). Teasing out the learning in making that is applicable for schooling, in this case specifically for higher education, is the goal of this dissertation.

To situate the value of the Maker Movement in higher education it is important to have a clear image of what the future of work may be and what skills will be needed to thrive in that future. One of the primary visions of making is that it represents a new form of innovation based on individuals operating in spheres previously left to large scale industry (Hatch, 2014). Similarly, among education visioning documents such as the National Academy of Engineering's (NAE) Engineer of 2020, the Equinox Blueprint for Learning 2030, scholarly literature on the future of work and education and existing educational standards all point towards a future in which creativity, communication skills, and the ability to work across disciplines as vital for today's students.

Creativity, communication skills, and the ability to engage in complex analysis across disciplines are examples of areas that rapidly developing Information and Computing Technologies (ICT) and automation perform poorly at. This tie between the traits seen as valuable for future education and the traits ICT systems perform poorly at is no coincidence. While automation has historically been viewed as a technological trend that displaces repetitive manual tasks, automation is now creeping into even highly trained, though often routine, intellectual tasks like those found in law and medicine (Kim, 2016; Turner, 2016). This trend towards automation shows no sign of slowing down and some studies go so far as to suggest nearly 50% of U.S. jobs are at "high risk" of automation in the early 21st century (Frey & Osborne, 2017). However, while given tasks may be automated and displaced within a job, this displacement often leads to a shift in what an employee may do, rather than the robotic replacement of an employee. For example, Automated Teller Machines (ATMs) seemed to represent the end of a job for bank tellers around the U.S. While jobs as tellers did decrease after the introduction of ATMs, banks also hired significantly more employees to work in sales and services (The Economist, 2016). The routine task of dispensing money was replaced; the employment of a human being was not. Outside of the dystopian scenarios of mass unemployment and replacement, or utopian scenarios where robots support a human leisure class, there lies a techno-realist perspective which critically analyses the tasks likely to be automated in the future and the skills that will remain valuable and uniquely human. Two sources will be primarily drawn from in the literature review to frame this techno-realist mentality. First, *Race Against the Machine: how the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming* *employment and the economy* will be used to provide an in broad view of the types of tasks human excel at and how technology may augment, rather than supplant, these tasks (Brynjolfsson & McAfee, 2011). A second source for understanding the relationship between automation and employment is a 2017 report by the McKinsey Global Institute, *A Future That Works: Automation, Employment, and Productivity*, which carefully breaks down the tasks involved in a given job to understand what parts of what careers are at risk in the 21st century (2017).

Taken together these documents point us towards an education system where students need to learn how to operate symbiotically with technology, each bolstering the area the other is weak at, to succeed. I argue that the Maker Movement, and specifically the mindset encountered among makers and the technological skills they are learning, is an example educators might embrace to "future proof" students' education to prepare them as they move forward in the 21st century.

To lay the groundwork for understanding the Maker Movement in the context of education and 21st century technological systems, I first introduce a broad overview of the movement through the lens of Science and Technology Studies (STS). Using STS as a lens for storytelling allows for the focus on the people and organizations involved in the movement, rather than focus solely on the technological artifacts, tools, and spaces that are used by members of the movement. This background is not an in depth theoretical analysis of the Maker Movement, such an analysis would be a dissertation in its own right. Instead, it seeks to use some of the tools of STS to provide some social perspective on the Maker Movement and how it came to be. It further situates the Maker Movement in its relation to the internet and with pre-internet digital communities to exemplify the movement's connection, and reliance, on modern communications technology. Previous work has already quite handily discussed the technologies and spaces associated with the movement (Gershenfeld, 2008; Hlubinka et al., 2013; Sheridan et al., 2014; Weinmann, 2014), albeit with a lack of depth in the social context in which those technologies are deployed and engaged with in the larger context of society, education, and the future of work.

Making, the future of work, and higher education in the 21st century are connected by one more common trait, the Maker Mindset. Understanding how makers think and learn can offer insight into plans for reimagining higher education. In chapter Two, I explain what traits form the Maker Mindset and why educators view it as important. Showing how the Maker Mindset connects to our educational structures in an empirical manner is addressed later chapters.

To guide the data analysis portion of this dissertation, three primary research questions are asked.

- **Research Question 1** – What can we learn about adult maker's life pathways to illuminate how they learn?
- **Research Question 2** – How do the skills learned by young and adult makers map to current education goals, as represented by ABET accreditation standards?
- **Research Question 3** – How do the attitudes and skills learned by makers relate to the goals of visioning documents related to education and workforce preparation in the 21st century?

These questions originated out of research focused on engineering as a site of making found in higher education, but have since been expanded to consider education more broadly. To answer these questions, I chose to use qualitative methods, thematic analysis, participant observation, and constructivist theory, to explore the deeper stories of what makers are learning and how they are engaging with their own learning processes. While much of this work relies on the descriptions makers give of their work, the goal was not to illuminate how the Maker Movement ticks, but rather to explore in practical terms how the mentality seen in makers might be replicated for use in higher education.

The data for this work is based on a series of interviews with young makers and their parents and adult makers collected over a four-year period. In total, 52 young makers, 32 parents of young makers, and 42 adult makers were interviewed. The makers were all interviewed at one of two national Maker Faires, one in California and the other in New York, about an artifact they had brought to share with attendees of the faire. In depth follow-up interviews were performed remotely afterwards. The focus of these interviews was originally to understand how engineering and the Maker Movement intersect, but the analysis of the interviews has been expanded to offer a broader view of how the Maker Movement and higher education relate.

This document focuses on three of the primary findings from those interviews. One discusses the life and education pathways taken by adult makers. The second looks at how the skills and knowledges makers are acquiring fit into higher education in terms of accreditation standards. Lastly, the mindset makers are building is analyzed to see how makers' experiences with technology, tinkering, and building relate to preparing them for the future of work. While much of this case study is based on engineering education, it is important to note that the sciences, business, medicine, art, and law all face similar challenges as we dive deeper into the 21st century.

Finally, the conclusion presents a discussion on how the pedagogical methods of the Maker Movement might be deployed in a university setting. These methods come in the form of integrating making into courses and extracurricular experiences. An example syllabus for an interdisciplinary making course is included in Appendix A.

CHAPTER 2

LITERATURE REVIEW

The goal of this dissertation is to provide insight into how the qualities of the Maker Movement can be used to improve education and better prepare students for their futures. To understand the Maker Movement, education, and the future of work in sufficient depth, it is necessary to take a system of systems approach to their analysis. While a variety of works have addressed making and its impact on, for example, K-12 education (Sousa, 2013), critical making in design (Somerson, Hermano, & Maeda, 2013), how to set up makerspaces (Cavalcanti, 2013b; Doorley & Witthoft, 2012; Hlubinka et al., 2013), or making and entrepreneurship (C. Anderson, 2012; Hatch, 2014), few studies have examined how the different actors incorporate and react to aspects of making in the context of education and work in the 21st century.

In this literature review, I present the background on a variety of connected systems that exist in the realm of making, education, and work. In the first, and by far longest section, I present the background of the Maker Movement, how it formed, who the primary actors are, what tools and spaces have meaning within it, some of the social challenges it faces, and how it connects with the technologies of the 21st century. The background section provides a starting point for understanding the Maker Movement as a nexus of technologies and social groups that emerged from pre-internet digital groups, online communities, the do-it-yourself community, and the early personal computer movement. While much of this section will be familiar to those involved with the Maker Movement, many of the details and connections between making and pre-internet digital communities are new territory that has not, to my knowledge, been discusses elsewhere.

A second section addresses the Maker Mindset, an underdeveloped component for understanding the Maker Movement that will be useful for understanding both how makers think and how the lessons of making may be applied to education. Then, the current state of education as critiqued and framed by visioning documents and accreditation standards will be presented along with recommendations for the future of education. Finally, literature that discusses the future, or at least one possible future, of work in the 21^{st} century will be addressed to frame the challenges students graduating in the early part of the century may face later in their lives.

What is the Maker Movement?

In this section the Maker Movement was analyzed both as a historical social construct, as well as the convergence of technologies in the personal manufacturing field with online do-it-yourself (DIY) groups to form physical spaces for hands on innovation. Background and historical information on the DIY and Maker Movements are depicted in order to provide context for social analysis. This background information, combined with news articles, academic works, and webpages forms the basis for how the Maker Movement is analyzed in the rest of this dissertation. This presentation of makerspaces and their possible precursors sheds some light on who the subculture is comprised of, what technologies are definitive for the group, and how these groups physically and socially manifest in shared workspaces.

As a sociotechnical system, or perhaps a system of systems due to the number of technologies and variety of makerspaces involved, the story of Makerspaces and the Maker Movement could be told in many ways. For this section, the movement and spaces will be looked at through a Social Construction of Technology (SCOT) framing to tell the story with the focus on the groups that work and interact in Makerspaces and participate in the broader Maker Movement. The Maker Movement is composed of many kinds of spaces, social groups, and technologies which lend themselves to being described in a similar manner to the technologies of bicycles and early automobiles (Kline & Pinch, 1996; Pinch & Bijker, 1984). Unlike Kline, Pinch, and Bijker's examples, the Maker Movement interacts with a wide range of technologies, from the internet to microcontrollers to sewing machines and industrial fabrication. However, the focus on how user groups interact with these technologies can give us insight into the functioning of the broader community and its interplay with the transformation of the technologies the community uses.

It is worth noting, and will be discussed in future work, that the rise of the Maker Movement could be discussed as a response to public policy failures, such as the removal of hands on projects in the form of high school shop classes, by using Public Value Mapping (PVM) (Bozeman & Sarewitz, 2005, 2011). In this framing, PVM would be used to assess education programs instead of scientific research programs. Discussing the Maker Movement in policy terms is important to the present day portion of the story where the White House, during the Obama administration, held a yearly Maker Faire and where making was seriously discussed as a way for to maintain global competitiveness through innovation (OSTP, 2014).

Background on the Maker Movement. To begin the discussion around the Maker Movement, it is first necessary to explore what the physical portion of the movement has created, makerspaces and hackerspaces. For the purpose of this dissertation, makerspaces and hackerspaces will be treated by and large as interchangeable, though there are certainly nuances which could be explored to differentiate them. For example, the term 'hackerspace' was used earlier chronologically to describe workshops focused on electronics and computer hardware and software. Initially, the term 'makerspace' applied to workshops focused on personal manufacturing capabilities. However, the two terms have since merged and become largely synonymous. In either case these are community spaces, often funded by membership fees, where people can access shared tools and classes on how to use them. Both types of spaces usually have an assortment of electronics, computers, and a variety of tools for building technology, whether in the form of soldering irons and sewing machines, or 3d printers and laser cutters. In addition to having the previously mentioned items, these spaces often include resident experts who run classes on how to operate the computers and machinery in the space. It should be emphasized that in most cases these resident experts are also members in the makerspace or hackerspace. They are not generally professionals selling their time, but are instead community members interested in sharing their knowledge and expertise. In chronological terms, the first of these community spaces were opened in the early 1990's as hackerspaces, which focused on electronics and computers but were not focused on personal manufacturing. Some of these community spaces have embraced the idea of personal manufacturing since the early 2000's and have been identified as "makerspaces", though for the most part that moniker has only been applied since around 2010.

One example of this sort of space is HeatSync Labs, a makerspace in Mesa Arizona. HeatSync started in 2009 and offers members 24 hour a day access to their shop in Mesa. HeatSync is also open to the public from 7pm to 10pm Monday through Friday and whenever a member is in the shop and has the doors open (HeatSync, 2013). Unlike some makerspaces which have full time staff and require membership for access, HeatSync is a volunteer community and run only on donations. As such, they are very focused on public accessibility and the community workshop aspect of makerspaces. HeatSync is part of a larger community of makerspaces and regularly communicates, collaborates, and competes with the Xerocraft hackerspace in Tuscon Arizona and other spaces in surrounding states. A typical monthly class offering might include 3d Printer training, laser cutter use, knitting, and electronics programming. Classes are run by members, so what is offered on a given month varies dramatically with who has the time and skillset to teach a class and what the demand is for learning a given technique. Below, I will go into greater depth on makerspaces, but this example should serve as an introduction to the concept.

The Groups and Technologies Behind the Maker Movement. While determining with certainty how the Maker Movement began would require a separate dissertation in its own right, we can look at some of the social groups involved in a chronological order to see how it might have evolved. The Maker Movement as we see it today is intrinsically linked to the internet. While makerspaces are physical places, they embody communication methods and technologies which are decidedly linked to the internet. The Maker Movement can be tracked to groups, both physical and virtual, that predate the internet. Below, I introduce and explore some of these groups.

The initial intersection of fabrication and digital methods came about in 1952 when the Massachusetts Institute of Technology (MIT), patented a method for "Numerical Control Servo-System", which first linked the previously analog, handmade activity of machining to digital punch card systems. Over the following decades, computerization when become more and more entwined with machining systems. As David Noble discusses in his article, Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools, and a Challenge for Labor, CNC was neither the only option available nor the most socially just (Noble, 1978). However, it is the design choice which is now used on all computerized machine tools. While at the time expensive CNC machines displaced human labor, or at least the power structure of labor, today the same machines are allowing a wide range of actors access to the power to create their own objects (Gershenfeld, 2008). Today, computerized designs can be rendered and visualized in 3d before feeding the design to other machines for production. As prices and educational barriers to entry have fallen for both the software to design models and control machine tools as well as the tools themselves, they have become more accessible to smaller groups. These tools and the method for controlling them will remain an important detail in the following discussion of groups involved in the Maker Movement. Likewise, the physical location of the institution responsible for CNC, MIT, will remain central to the story as well.

The Hacker community, which began forming in 60s and 70s at MIT, was a loose collection of programmers, pranksters, and technologists. They were focused more on the computer and electronics, but applied what we would very much call a do it yourself approach to their work. In Hackers: Heroes of the Computer Revolution, a book by Steven Levy about hacker culture and the original MIT hackers in particularly, Levy discusses what he calls the Hacker Ethic, which contains many of the same values of today's Maker Movement (Levy, 2010). Though, makers would likely consider access to a wide range of tools, both low-tech and high-tech, rather than focus narrowly on computers if they wrote a Maker Ethic.

1. Access to computers—and anything which might teach you something about the way the world works—should be unlimited and total. Always yield to the Hands-on Imperative!
2. All information should be free.
3. Mistrust authority—promote decentralization.
4. Hackers should be judged by their hacking, not bogus criteria such as degrees, age, race or position.

5. You can create art and beauty on a computer.

6. Computers can change your life for the better.

This group provided much of the ideological basis for the Maker Movement. Early hackers focused on learning, on doing, and on sharing knowledge, which is very much in line with the Maker Movement's vision. Likewise, there was great breadth in Hacker areas of interest, from lock picking, to phone phreaking, to building custom electronic devices. This breadth of interest is well represented in current makerspaces as well. To make the comparison clearer, here is the philosophy behind HeatSync Labs in Arizona.

"We are a community workshop that makes workspace, tools, and other resources available to students and hobbyists, artists, engineers and entrepreneurs to build their projects, prototypes, and art. We believe in creating a community of collaboration and learning-by-doing."

-HeatSync Homepage (HeatSync, 2013)

Similarly, Mark Hatch, the former CEO of TechShop, breaks down the maker ethos into nine components in his Maker Manifesto (Hatch, 2014).

1. Make – Making is fundamental to being human,
2. Share – Wholeness is achieved via sharing.
3. Give – What you make is instilled with your essence, giving that item away is satisfying.
4. Learn – Lifelong learning ensures a rewarding life.
5. Tool Up – Have the right tools for the job.
6. Play – Learning and making are joyful activities, enjoy them.
7. Participate – Join the Maker Movement, become part of a community.
8. Support – Movements require emotional, intellectual, financial, political, and institutional support.
9. Change – Embrace change on your journey as a maker.

Much like the Hacker Ethic, the Maker Manifesto focuses on how an individual can grow through learning and utilizing technology in a hands on manner. Unlike the Hacker Ethic however, the Maker Manifesto also focuses on community building and makes no explicit mention of distrusting authority or requiring that information be free.

During the late 70’s computer clubs came into being. These clubs were informal groups of electronics enthusiasts who would meet up to discuss computer and electronics plans, swap parts, and generally get a chance to chat those who had similar hobbies. While most companies and members of the public viewed computers as large mainframes that were the domain of governments, big businesses, and academia, hobbyists were interested in computers as personal tools. In SCOT terms, they were displaying the interpretative flexibility of the computer. While at the time, there was precisely one choice for a personal computer, the Altair 8800, hobbyists could modify it to do a variety of things. Even with the Altair, home computers were not something you bought, prepackaged and preloaded with software; instead, hobbyists would buy hardware components and design programs for them. The Homebrew Computer Club, perhaps the most famous of the computer clubs, ran from 1975 to 1986 in Silicon Valley and counted among its members one of the founders of Apple, Steve Wozniak. Wozniak was a member and when Steve Jobs joined him, they tested out their designs for early Apple computers with their computer club friends (Wozniak, 1984). Many of the hardware and software designs that defined the personal computer revolution were designed in clubs like the Homebrew Computer Club. Personal computers such as the Apple and Apple II were designed with the ideals of computer club members in mind. They were to be tools of personal empowerment, things that expanded one's creative options and which were available to individual consumers, not just large corporations. In no small part, through computer hobbyists’ work, and the work of their companies, the computer was transitioned from the mainframe of yesteryear to the PC of today. While their appeared to be rhetorical closure of the issue through the definition of the PC and the ubiquity of personal computers, one could easily argue the interpretive flexibility of what defines a computer is continuing today with the shift towards tablets and smartphones.

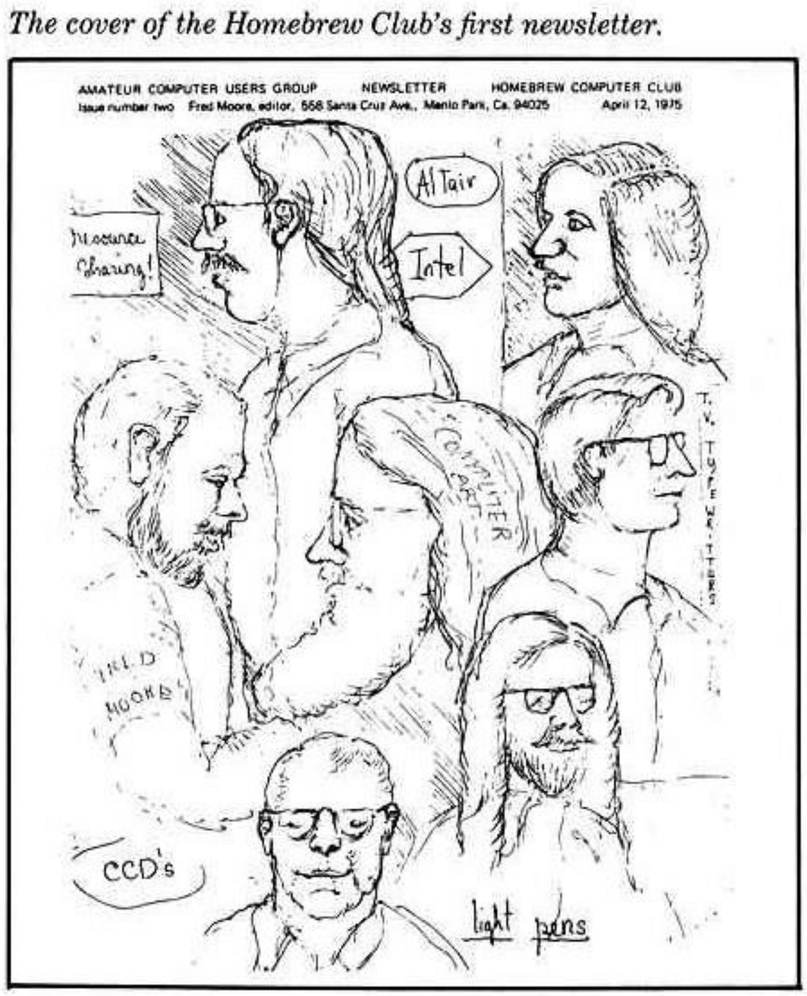

Figure 1. Homebrew Computer Club Cover 1975

Once PCs became common, they started being used as nodes for inter-user communication. One of the first digital expressions of DIY ideology was likely in the form of the Computer Bulletin Board System, commonly referred to as BBSs. Inspired by physical bulletin boards, a BBS was originally used to facilitate communications between people with similar interests, much like a physical bulletin board in a supermarket could allow people to post their interests and find likeminded individuals. A typical BBS consisted of a computer connected to one or more phone lines, a modem to allow computer to computer communications, software to interface with, and a systems operator (SYSOP). Much like modern day websites and forums, BBSs allowed multiple users to access data, upload and download files, play games, and communicate with one another. Unlike the internet, a BBS was limited to how many simultaneous users could be present by the number of phone lines connected to the computer and how much data was available. In most cases, this amounted to one user at a time accessing a given BBS and that user only had access to the information stored on the hosting computer (Wikipedia, 2013). BBS's also tended to be geographically centered. In order to call in to the modem without incurring long distance fees, you had to possess a phone number within the same area code. Since BBS members tended to be geographically close to one another individuals could meet up in person or organize group gatherings with much greater ease than members of a modern global internet forum.

One DIY specific BBS was HouseNet, which started in 1991 as a subscription service for the home improvement DIY community. HouseNet's roots began in 1987 as a news column, Do It Yourself or Not, which provided the initial user base for HouseNet BBS. HouseNet acted as a central location for contractors, homebuilders, and Do It Yourselfers to share experiences and advice. As the owners describe it, the hub of their BBS, a personal computer, was located in a guest bedroom with a maze of phone lines and modems connected to it. In 1993, they also created an internet site, HouseNet, which was a popular clearinghouse for real world advice and cost estimates. HouseNet eventually morphed into diyornot.com, the current incarnation of this home improvement community (Hamilton, 2013). HouseNet was one of the few BBSs that a clear line of history and data is still available on. Sadly, as with much of the BBS and early internet history, the sites, comments, discussions, and information exchanged on them are largely lost to us. While this example is focused more on the home improvement side of the DIY movement, it acts as an example of how other groups could have transitioned from digital communities on BBSs to internet entities which engage with a wide variety of physical entities.

Other BBSs were far less specific in their focus, but nonetheless contributed to the formation of the Maker Movement through the distribution of text files on a wide range of topics, from relatively harmless guides to electronics, programming, and telephony, to potentially illegal how to guides such as the infamous Anarchist's Cookbook, a paranoid how to guide which was created as a protest to the US involvement in the Vietnam War. One of the most well-known BBSs for the distribution of documents was Totse, an acronym for the original BBS's name, "& the Temple of The Screaming Electron". Totse acted as a popular clearinghouse for all sorts of random information, from how to guides on a truly ridiculous number of topics, to fan submitted pornographic writings, to conspiracy theories and random musings. Totse in many ways embraced the Hacker ideal of information being free, whether the information was good, bad, harmful, misleading, useless, or mistaken, it had a place to be viewed and downloaded (Various, 2013). Totse, in its numerous and maze like forums, also provided a place to explore ideas, ask for advice, and chat with others. Even during the BBS days though, communications were not entirely digital. As with physical bulletin boards, you could also post information on a meet, a gathering for BBS members. While I was unable to find any records of meets specifically for the purpose of a DIY project, it seems likely that such meets did occur. Much like Do It Yourself or Not, Totse moved to the internet in 1998. Archived versions of the site are still available today. In the case of BBS technology, the closure came not so much as a result of user groups guiding new technologies, but instead by the introduction of a technology that redefined the problem. With the arrival of the internet, it was no longer an issue of how to communicate with local communities, one user at a time on a BBS, but instead how to make these same communities available everywhere via the World Wide Web. In the example of HouseNet, as shown above, users simply migrated from local BBS's to international internet spaces.

A central player in the Maker Movement is MIT and, more specifically, the Center for Bits and Atoms. The Center for Bits and Atoms was originally funded by an NSF grant in 2001 and is focused on exploring the boundary between computer science and physical science. One of the earliest classes taught at the Center was How to Make (Almost) Anything, a class focused on introducing graduate students to the tools of prototyping and fabrication (Chuang & Gershenfeld, 2002). The space where this class took place was referred to as the fabrication lab. During this class students would learn how to turn their ideas into physical objects made from wood, plastic, metal, electronics, etc. The professor for this class, Dr. Neil Gershenfeld, realized that "the killer app in digital fabrication, as in computing, is personalization, producing products for a market of just one person" (Gershenfeld, 2012). Graduate students in the class, and at MIT more broadly, redefined the space from that of a place to do class work into a space to build whatever their imagined or required for projects which were often unrelated to coursework or classes. Artifacts ranging from pieces of art to coat hooks were being fabricated there. The students were interpreting the space in a light wholly unexpected by the creators of the fabrication lab. Recognizing that the fabrication lab had become a space for innovation and exploration, the Center for Bits and Atoms collaborated with the Grassroots Invention Group, an MIT group focused on interdisciplinary outreach and education, and formed the first FabLab (short for fabrication lab, or fabulous lab) in inner-city Boston using funding from the NSF. A FabLab is a workshop containing a standardized set of tools for digital fabrication. This set includes subtractive machining tools, such as a laser cutter or a CNC mill, a 3d printer, electronics workspace, and internet access. These labs are ideally open in some way to the public and participate with each other on a global scale (Center for Bits and Atoms, 2013a). The space was redefined once more as one open to the public instead of merely students at a university. Since then over 300 FabLabs have opened or are in the planning stages all over the world, from Afghanistan to Norway (Center for Bits and Atoms, 2013b). Since 2009, it has also become possible to earn a certification from them by attending the Fab Academy. The Fab Academy is a distributed learning platform directed by Dr. Gershenfeld. During the 5 month, $5,000 course, students who participate remotely from participating FabLabs, learn how to build almost anything with the wide range of digital fabrication tools available at the FabLab (FabAcademy, 2013). A diploma is offered for the course and there are numerous opportunities for scholarships or volunteer work to offset the cost of the program at any of the 14 FabLabs currently participating in the Fab Academy.

In addition to the numerous FabLabs which have been set up as education and outreach projects, there are also many participants which are independent of MIT. The majority of FabLabs in the network are currently owned by individuals, small groups, and institutions outside of MIT. One of the ways these labs are funded is through membership dues from those that do work there or in some cases external grants from companies or institutions (Wiki.Fablab.is, 2013). The movement from education space to play space to public space to education certification space will likely continue as FabLabs change in terms of purpose. They haven't closed yet on what services or form they will fall into, but are instead still in the process of stabilizing.

Figure 2. Fab Labs Globally (http://wiki.fablab.is/wiki/Portal:Labs)

The Center for Bits and Atoms has acted as the mother for a wide range of groups currently involved in the Maker Movement. Among their spinoffs are Formlabs, a 3d printer company and Instructables, an online site for posting how to guides. Instructables motto is "Let's Make..." and they currently have posted over 100,000 how to instructables (also the noun for a how-to guide). Instructables was purchased in 2011 by Autodesk, a company which makes much of the popular software for 3D modeling, both for amateurs and professionals. As a community forming site, users are able to upvote useful instructables, give commentary to the original designer, and make spin offs from any given design. The whole site is open and available to anyone free of charge, though there are perks for paying subscribers ("Instructables," 2013). The Instructables community differs from previous DIY communities in several ways. First off, there is not an overarching theme to the projects. Unlike HouseNet, where the focus is on home improvement, the focus on Instructables is on making, making anything. Some instructables are recipes for food, some are simple art projects, others are intense how to guides on doing industrial processes at home. The only common thread is that something is being built, cooked, remixed, or altered and that there is a step by step way to do it.

While MIT and the Center for Bits and Atoms were distributing the idea of personal manufacturing as an educational model, another group was starting the open source 3d printer movement that led to the low cost models we see today. On February 2nd of 2004, Adrian Bowyer, a British Engineer and professor, suggested replicating rapid prototyping machines as a source of 'Wealth without money' and began a project at Bath University to design an open source 3d printer which was capable of printing its own parts (minus electronics, bushings, screws, and motors) (Bowyer, 2004). His concept led to multiple iterations of extremely low cost 3d printers that could print most of their own components. Much like early personal computers, these started out as tools only usable by tech savvy individuals who were willing to play with sometimes expensive and always finicky tools. While the open source RepRap project continues to innovate in 3d printer design, one of the founding members of RepRap, Zach Smith, formed his own company, Makerbot, in 2009 with Bre Pettis and Adam Mayer. Makerbot started out offering kits using open source designs. Makerbot also launched an online community at the same time called Thingiverse. Thingiverse operated as a central sharing hub for 3d printer designs. Thingiverse at first was a place for 3d printer owners to share designs on how to optimize their 3d printers. This worked well with Makerbots original vision as an open source company. Now, Thingiverse acts as a general repository for 3d object designs, with the focus no longer being just on 3d printer designs. Makerbot's current flagship printer is the Replicator II, which ships fully assembled and whose designs are not open source. The Replicator II is a premade 3d printer which can build just about any shape out of PLA, a common and environmentally friendly plastic, for about $2,200, a considerably lower price tag than many early PCs. Unlike many of its hobbyist precursors, which required assembly and access to rapid prototyping machines, printers like the Replicator II are designed to be user friendly and usable right out of the box. My personal experiences with the machines have shown that they aren't nearly as user friendly or out of the box ready as you might think. However, the newer 3d printers are indeed orders of magnitude easier to use and maintain than their predecessors. Truly user friendly ones are certainly on the near term horizon. In SCOT terms, the 3d printer, at least the extrusion plastic style, consumer grade, 3d printer, is perhaps one of the best examples of interpretive flexibility followed by closure and stabilization(Pinch & Bijker, 1984). Initially, dozens of different 3d printers were in use by hobbyists and designers. Groups included contributors to reprap.org, 3D Systems (a huge 3d printer manufacturer), and often groups at individual makerspaces. Some, like RepRap's, were focused on 3d printers that could print 3d printers, others, the Ultimaker for example, were focused on speed and precision, and finally the Makerbot, and some of the more recent 3d printers, are designed for out of the box use by non-tech savvy consumers. Popular designs currently seem to be moving away from the DIY 3d printer kits to the factory calibrated and user friendly pre-built models. This shift seems to be in no small part due to user groups getting frustrated with the lack of consistency, and difficulty of use, associated with DIY kits.

While Makerbots and Reprap were busily exploring the arena of home 3d printing, a variety of organizations were popping up online to support 3d printing for companies, professional designers, and DIYers who don't have access to their own printers. Services such as iMaterialise and Shapeways, which started in 2012 and 2007 respectively, offer average consumers the ability to upload their designs and get mailed back 3d prints. Alternately, designers can post their 3d designs on either website for resale to other customers. Since the objects are 3d printed on demand, there is no physical inventory to maintain, just a digital inventory of files which are printed and shipped as items sell. While Shapeways was from its inception designed as a source for consumer objects, iMaterialise spun off from Materialise, a Belgian company which has offered 3d prints to academic, medical, and industrial consumers since 1990.

MAKE Magazine is likely responsible for rebranding hackers and hobbyists into makers and was first published in January of 2005. MAKE Magazine was founded by Dale Dougherty who is the co-founder of O'Reilly Media, a publisher who created what many consider the best series of technical books for programming ever made. Initially, Dale pitched the idea to his daughter as HACK magazine. However, she thought that sounded sinister and suggested the word MAKE instead, because "everyone likes making things" (Cavalcanti, 2013a). The goal of MAKE Magazine is to make do it yourself projects, and the associated mindset, approachable for the average person. The magazine focuses not only on the how to guides themselves, but also the people and places behind the design (MAKE Media, 2013a). Its digital presence at Makerzine.com is a combination of articles, a store for purchasing high tech parts, and a central link to Maker Media’s other endeavors, such as the Maker Faire, which will be discussed below.

While MAKE may have provided some of the terminology used in the modern DIY community, the most commonly used computer hardware can be tied directly to two companies, Arduino and Raspberry Pi. Arduino began producing open source hardware board designs in 2005. Initially, the boards were designed as tools for Massimo Banzi's students at the Interaction Design Institute Ivrea, in Italy. The initial versions were the result of a Master's thesis project, called Wiring, by one of his students, Hernando Barragán (Barragán, 2016). Massimo re-designed the board in response to his students' (the Relevant Social Group in this case) requirements for easily programmable, low power computers to link into sensors, lights, etc, for class projects (Kushner, 2011). Through a contact of his at MIT, the boards and their programming language were further developed and then mass marketed in an open source manner. Their explicit purpose was to provide the inexpensive, easy to program, highly accessible hardware tools needed for a do it yourself community of artists, designers, and hobbyists ("Arduino - HomePage," 2013). Arduino's early success in this area has made them one of the most commonly used hardware types throughout the Maker Movement. MAKE Magazine has a section devoted to their use, Arizona State University uses them throughout their fabrication and design labs, and many open source 3d printer designs use Arduino boards as the brains. A similar device called the Raspberry Pi was being designed at the University of Cambridge in their Computer Laboratory from 2006-2008 with the audience in mind being kids who wanted to learn programming rather than design students (Raspberry Pi, 2014). While the Arduino focuses on being a controller for sensors, motors, and other hardware components, the Raspberry Pi is a full-fledged mini-computer, capable of connecting to a monitor and other normal peripherals. Additionally, the Raspberry Pi is built on a closed hardware platform rather than an open hardware platform. The hardware differences are explained below.

The Arduino and Raspberry Pi are used throughout the maker community for projects requiring electronics. In this case, both technologies co-exist despite their similar properties and usages. The Arduino and Raspberry Pi are being continually reinvented as users develop new requirements for mini-computers. However, the modes in which social groups influence the two products development are very different. The Raspberry Pi, with six current versions, has been designed by the Raspberry Pi Foundation who handles the details of manufacturing and designing (Raspberry PI, 2016). While it certainly takes input from its users, the product is at the end of the day the work of a single organization. In contrast, the Arduino is built on an entirely open hardware platform. This means anyone who desires can design or build a fully Arduino compatible board. Non-brand name Arduinos are available in much the same way generic versions of drugs are available. Both have exactly the same structure and function, but are produced by different manufacturers with no license fee. One example of a custom Arduino is the Qduino Mini. A young maker created his own, fully compatible, mini Arduino board with a built in battery circuit to use for his projects. After that, he ran a crowd funded campaign and partnered with Sparkfun, an electronics company in Colorado, to produce and sell his mini-Arduino (MAKE Magazine, 2015). This is one example of how user groups can have a strong impact on open-source hardware aspects of the Maker Movement by creating, funding, and producing their own electronic building blocks.

Close on the heels of MAKE magazine, another part of the maker puzzle came into being in 2005, YouTube. YouTube began in February of 2005 and offered an outlet for people to publish homemade, as well as copied, videos. While previous DIY videos were produced, in general, by professionals, YouTube offered a service for sharing individual making experiences. Currently, YouTube is an amazing resource for DIY enthusiasts. If you are curious how to use a 3d printer, program an Arduino, or build almost anything, there is almost certainly a YouTube video detailing how. As of the writing of this dissertation, there are over four million videos with "Do it yourself" in the title and millions more that are how to guides or include the phrase "DIY". The figure below demonstrates this explosion of Do-it-Yourself guides online. Currently, over a half million new videos are added per year with "Do it yourself" in the title or description. DIY, MAKE:, hack, and other search terms yield millions more videos catering to every type of project.

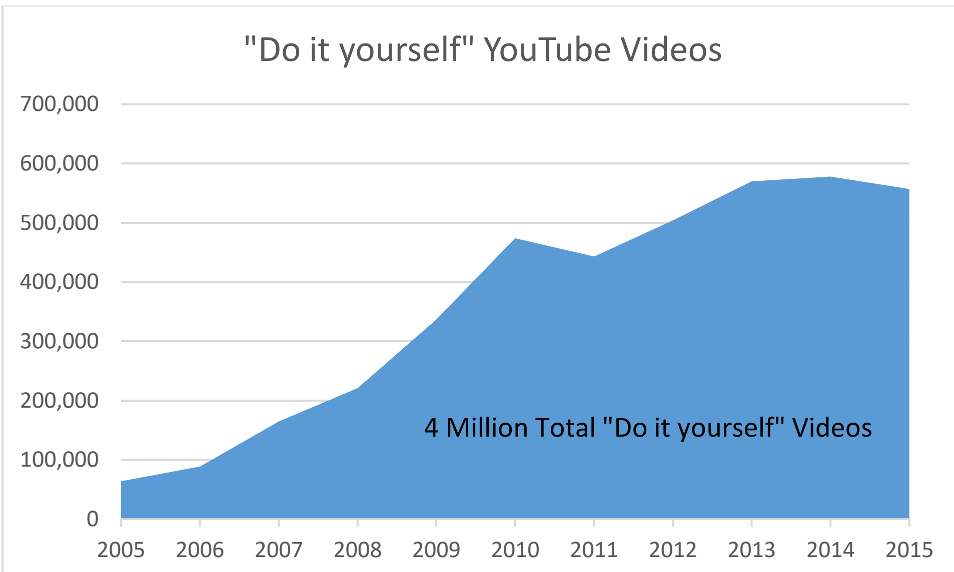

Figure 3. YouTube Videos with "Do it yourself"

In sharp contrast to the idea of Doing-it-Yourself or interacting in digital communities, the Maker Movement also has a collaborative and festive side in the physical world. Beginning in 2006, MAKE Magazine sponsored its first Maker Faire. The Maker Faire is a gathering of makers, tinkerers, artists, educators, machinists, and hobbyists who present their creation in a festival like atmosphere. As MAKE describes it, the Maker Faire is " Part science fair, part county fair, and part something entirely new" (MAKE Media, 2013b). There are sponsored educational tents where kids can learn how to build with electronics and 3d printers, art displays, and, of course, food and drink. Since the original Maker Faire in 2006 the attending crowd has grown dramatically with over 165,000 people attending the two Maker Faires in 2012. In addition to the Makerfairs, groups of makerspaces often engage in Hackathons, day or multiday contests surrounding a given technology or idea, and then present their work to each other in a friendly competition. Sometimes these Hackathons are competitions for prize money by interested sponsors. Sponsors for Hackathons include organizations as wide ranging as DARPA, universities, and Amazon. Perhaps more frequently however, the prize is in the form of bragging rights and the goal is community building rather than taking home a fist full of cash or a corporate sponsorship.

Currently, makerspaces and hackerspaces are springing up around the globe. Some are community ventures, others are commercial, academic, or a combination of the two. In the Phoenix metro area, all three types of makerspaces exist. For example, Heatsync, as previously mentioned, is a community owned, managed, and operated space. Open to all and funded by members and donations. The Startup Lab on the ASU Polytechnic campus is a makerspace open to all of Polytechnic's engineering students which offers classes, workspace, materials, tools, and expert help to aid with student projects, both class related and personal (ASU, 2014). Outside of the realms of academia, makerspaces have also found a place in the commercial world. In 2006 Jim Newton and Ridge McGhee opened the first TechShop in Menlo Park, California. Since many of the tools used for rapid prototyping are prohibitively expensive for your average consumer, TechShop was opened on a membership model. Instead of individually purchasing expensive machinery, members instead pay around $100 per month to have access to everything from CNC milling and routing machines to 3d printers and laser cutters as well as welding machines, hand tools, and just about everything else you could possibly want for tinkering (TechShop, 2014). Since then, nine more TechShop locations around the US have opened, with several more in the planning stages.

Currently, hackerspaces.org lists 1238 active hackerspaces and makerspaces worldwide (hackerspaces.org, 2016). Clearly, this is a phenomenon that, while likely born from digital groups and given a technological push by the open source movement and decreasing costs of personal fabricators, is firmly entrenched in the physical world and a part of life for many thousands of people. Over 300,000 Arduino units have been sold, thousands of Makerbots and their many competitors have entered into homes and communities, Youtube is full of DIY channels, and many thousands of people are going to Maker Faires just to see what it's all about. As Cory Doctorow, author of the book Makers, describes them, makers are " people who hack hardware, business-models, and living arrangements to discover ways of staying alive and happy even when the economy is falling down the toilet" (Doctorow, 2013).

Makerspaces and the Maker Movement seem to be producing something new. While it may not turn out to " herald a new industrial revolution" as the Economist magazine suggested in 2011, it does represent a new social movement focused on creativity and the power of personal fabrication technologies (The Economist, 2011). In addition to the positive press the movement has received so far, it is also raising questions about the legality and ethics of people having access to the ability to print their own firearms, make their own weapons, and bypass copyright and patent laws. For our society, this movement raises questions of how we value items produced in a one off manner that can be shared digitally and for free. Makerspaces also currently display many hidden themes of discrimination and the gendering of tool spaces (Davies, 2017). How they proceed, whether through the explicit designation of some makerspaces as saferspaces or through the rollout of women-centered makerspaces remains to be seen (Henry, 2014; Toupin, 2013).

What is the Maker Mindset?

The Maker Mindset is a working definition of the attitude that makers apply to learning and problem solving. Before diving further into empirical data collection and analysis, it is useful to see what how the Maker Mindset is defined by members of the movement and academics studying the movement. Dale Dougherty, the founder of MAKE: Magazine, sums up the Maker Mindset as “what can you do with what you know?” a simple description for a much more elaborate process of iteratively building on projects, interactively learning within a community, and sharing work and expertise (2013). Dougherty sees a Maker Mindset as a means to empower learners to grow their skills and understanding through playful interaction with the physical world. Core components of Dougherty’s description are drawn from the work of a Stanford psychology professor, Dr. Carol Dweck. Her work involves the exploration of a growth mindset, one in which a learner views their intelligence as a trait that can be developed through hard work, grows through failure, and is not a fixed trait (Dweck, 2006). Dweck’s core premise of a growth mindset has been expanded on to focus more specifically on mindsets to promote academic achievement. In addition to viewing one’s intelligence as a malleable trait, a successful academic mindset also includes a sense that one belongs in their learning environment (Rattan, Savani, Chugh, & Dweck, 2015). These ideas coalesce in the academic literature on education to identify four primary traits of the Maker Mindset; playful, growth-oriented, failure-positive, and collaborative (Martin, 2015).

Table 1. Qualities of the Maker Mindset

Quality	Effect
Playfulness	Learning is pursued to support intrinsic interest, process is part of the goal
Growth-oriented	Learner expects to discover new information and advance skills through work
Failure-positive	Setbacks are seen as opportunities for advancement through iterations
Collaborative	Learning occurs through participation (physically or virtually) in learning communities

While the Maker Mindset describes how individual makers approach learning, it is also important to discuss how makers learn within a community. One way makers learn within groups is through additive innovation, a process wherein community members learn through project sharing and iteration one their own, and others', ideas (Jordan & Lande, 2016). In a system of additive innovation, individuals can learn and grow through others' playfulness and failure-positive experiences. Importantly, additive innovation can occur either with fellow makers within physical spaces, such as makerspaces or maker faires, or through purely digital interactions, whether through posting how-to videos on YouTube or through more interactive forums.

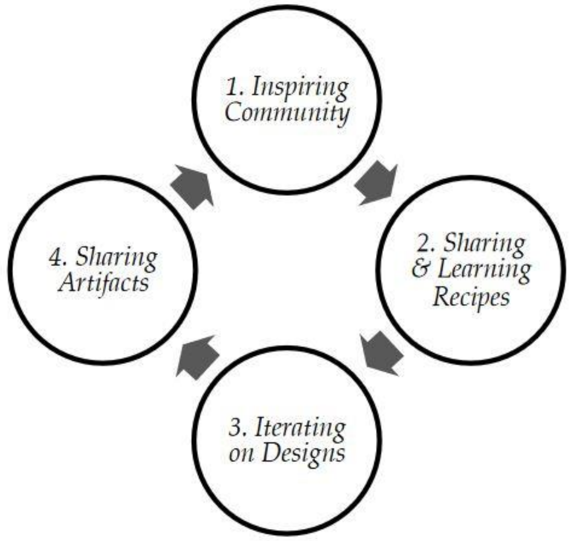

Figure 4. Additive Innovation (Jordan & Lande, 2016)

Making and Learning

Two critical parts of the Maker Mindset are that the learner themselves decide on which project to pursue based on what inspires them, and second makers engage directly with the tools and materials used in a given project. These two facets, learner led projects and engagement with materials, have a long history in education studies. While the Maker Movement is a new take on how people share ideas and get inspired, the core pedagogical lessons we can draw from making have been discussed in education literature for some time. One of the more common approaches to understanding what learners learn is through Bloom's Taxonomy of Learning (Bloom, 1956) and the taxonomy's 2001 revision (L. W. Anderson, Krathwohl, & Bloom, 2001). The original taxonomy viewed learning as a building up of the following stages of understanding.

1. Knowledge – The recalling previously learned material.
2. Comprehension – The ability to grasp the meaning of recalled knowledge.
3. Application – The ability to use learned material in new situations.

4. Analysis – The ability to break down learned material into component parts.
5. Synthesis – The ability to resolve contradictions in learned material and to put parts of learned material together to form a new whole.
6. Evaluation – The ability to judge the value of synthesized material for a given purpose.

For the revised vision of Bloom's Taxonomy, creation (synthesis) was moved to the top of a learning pyramid to represent the accumulation of evaluations required to synthesize new information and the language was reframed to be more active (Armstrong, 2016).

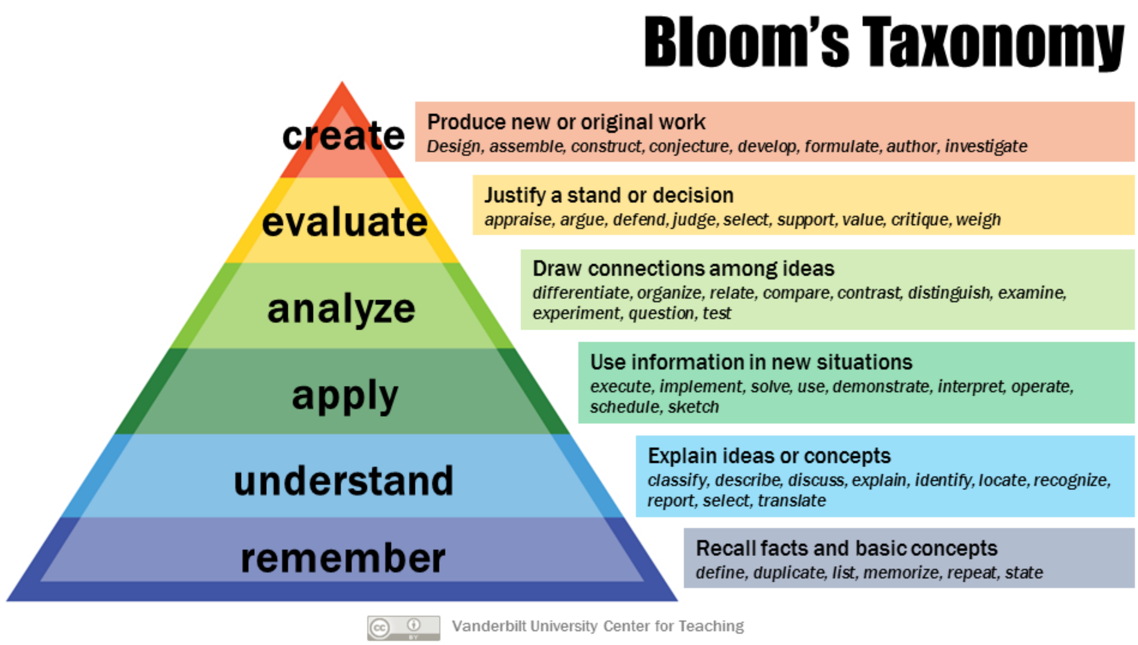

Figure 5. Bloom's Revised Taxonomy

One of the strong cases made through Bloom's Taxonomy is that learning facts alone, and even applying those facts to solve defined problems, fail to fully engage with the entire learning process. In the case of engineering, one can imagine learning facts about the physical world, understanding those facts through math, applying those understandings to solve problems presented in class, and eventually analyzing existing systems, evaluating them to discover new problems, and finally synthesizing new answers to open ended problems. For makers, the process is similar, though, as will be discussed in research findings, makers often begin with a specific problem they would like to solve or thing they wish to create and then proceed to figure out what knowledge they need to gain and what skills they need to apply that knowledge to create a thing they have already imagined. Through the creation of an object, or as will often be referred to in this document an artifact, the maker engages with the full spectrum of learning under Bloom's Taxonomy. From the accumulation of factual knowledge to the application of knowledge and analysis of iterative problems in the design process to the final creation of an artifact.

Despite the hype surrounding making as a new way of learning, creating artifacts as a means of learning is not a new concept in education and has been discussed across disciplines for decades (Halverson & Sheridan, 2014). This is perhaps unsurprising in the worlds of art and design, where intimate knowledge of materials and methods for shaping them are the cornerstone for understanding how to create objects of meaning and/or usefulness. The Rhode Island School of Design, for example, often refers to this process of creation through careful understanding of material, methods, and goals as "critical making" (Somerson et al., 2013). While not generally referred to as critical making, engineering has its own well established brand of project based learning in the form of senior project or capstone courses (Dutson, Todd, Magleby, & Sorensen, 1997). What is new about making as an educational tool is the potential for engaging new audiences with technology, the related possibility for democratizing technology in a manner beyond simple access to technology, and the inclusion of creativity and communication skills with technical knowledge.

Education Visions for the 21^{st} Century

> By 2030, simply knowing facts will have little value. Education will need to equip learners to think creatively, independently, rigorously, and collaboratively in full awareness of themselves and their social context.
>
> - Equinox Blueprint, Learning 2030

Education, and how we educate, have long lasting impacts on students' futures. Here, I examined the recent literature on how education needs to change to adequately prepare students for living and working in the 21^{st} century. After introducing and discussing three documents that look towards the future of education, the Framework for 21^{st} Century Skills (rebranded to 21^{st} Century Learning), the National Academies' Engineer of 2020, and the Equinox Blueprint for Learning 2030, I will introduce a specific example of education in the present, through ABET's accreditation standards for engineers. ABET accreditation will be used later in the dissertation as a basis for coding maker skills to existing standards. Finally, I will discuss visions of work in the future through the lens of recent scholarship and articles about technological innovation. These documents were chosen to provide a scaffold for understanding education goals in the 21^{st} century.

The Equinox Blueprint for Learning is an education visioning document by the Waterloo Global Science Initiative (WGSI), a non-profit partnership which produces biennial gatherings of experts to discuss science challenges. For this document, it represents an international view of education by education experts within and surrounding academia. 21^{st} Century Learning provides a similar visioning framework, but is a combination of education and industry experts and is based solidly in the US.

Finally, the Engineer of 2020 is a product of the National Academy of Engineering and provides a much narrower view of education focused specifically on college engineering. These viewpoints, international, national, and college degree specific combine to provide a solid vision of what experts believe education should look like in the 21st century and will form a framework for an empirical analysis of interview data. These views will be valuable to keep in mind when examining ABET standards to see differences between present day requirements and future visions for education.

In 2013, the Waterloo Global Science Initiative gathered a diverse group of education specialists from around the globe to suggest best practices for improving high school education. While their focus was on high school education practices to enable students to pursue a variety of post high school pathways, their findings on skills and traits that are useful education outcomes for thriving in the 21st century are equally applicable in university settings. They identify two core concepts as vital for the successful education of students. First is the concept of a "T-Shaped Learner" also often referred to by its result, the "T-Shaped Professional", one who is both adept at a single core expertise, the depth of the stem of the 'T', and one who has broad knowledge of topics and skills, the horizontal bar of the 'T' (Brooks & Holmes, 2014). The goal of a T-Shaped professional is to have a trained person who is also capable of engaging broadly with the topics and situations which surround any technical or specialized problem. The capability to engage with the problem areas surrounding a core difficulty allows for solutions that help address real world problems. This form of professional has been seen as desirable among engineering as well as other fields, such as medicine (Donofrio, Spohrer, & Zadeh, 2010; Lee & Hanifin, 2015; Oskam, 2009; Tranquillo, 2013). The second trait they identify is "Habits of Mind", the underlying traits or mindset which allows for success in education. These habits include the following, presented in an abridged format (Brooks & Holmes, 2014).

Table 2. Learning 2030, Habits of Mind

Persisting	knowing how to keep pressing on when your inclination is otherwise
Managing impulsivity	acquiring patience to wait for optimal moments
Listening with understanding and empathy	skillful conversation tactics and teamwork
Thinking flexibly	knowing how to consider other's perspectives
Thinking about our thinking	understanding one self's and other's thought processes
Striving for accuracy and precision	strategies for reducing error
Questioning and posing problems	how to probe for deeper understanding
Applying past knowledge in new situations	lessons of experience from self or others
Thinking and communicating with clarity and precision	Clarity in thought, speech, and writing
Gathering data through all senses	using all sources for learning
Creating, imagining and innovating	thinking with few boundaries
Responding with wonderment and awe	personal passion for learning
Taking responsible risks	embrace and analyze failures
Finding humor	improve communications and sharing experiences
Thinking independently	Co-creating programs and experiences to develop skills
Learning continuously	appreciate learning occurring at anytime, anywhere

These "Habits of Mind" identified by WGSI have a great deal in common with Dr. Carol Dweck's concept of a "growth mindset". Dweck suggests that individuals are most successful at learning when they view their intelligence not as a fixed quality, but as something that can be developed over time. Intelligence develops in though a mindset which embraces failure, is self-reflexive, and approaches learning in a curious, flexible, and questioning manner (Dweck, 2006). Dweck also discusses that to foster a growth mindset, the process of learning should be praised rather than the learner's innate intelligence (Dweck, 2009). Often, as will be seen in later sections discussing interviews with makers, they engage with each other within a community that praises the processes they use to make, rather than to suggest that it requires innate intelligence to be successful as a maker. The implications for a growth mindset for education have been explored across many disciplines in recent scholarly work including computer science and engineering as well as for policy recommendations on how to change education as a whole (Martin, 2015; Murphy & Thomas, 2008; Rattan et al., 2015).

The Partnership for 21st Century Skills (P21) is a US based cross sector non-profit with education, government, and industry partners that focuses on leading conversations about the nature of learning in the 21st century, supporting educators in aligning their curricula with innovations in education, and showcasing examples of strategies and policies to enhance education outcomes (P21, 2016). Initially, their work focused on K-12 education, however their current models discuss education as a lifelong pathway, from K-12 through college and into one's professional life. While it may be vitally important to impart 21st century skills training in K-12, training in those skill areas continues throughout college. P21 makes two key claims about the skills needed by students as we progress into the 21st century; core academic competence is important and that core academic competence is by no means all there is to a successful education system. They are not suggesting that facts or the core understanding imparted in our current system is unnecessary (P21, 2009). Instead, they frame core academic understanding as one component of a successful education system. P21 identifies what they refer to as the 4Cs, critical thinking, communication, collaboration, and creativity, as an additional area of educational importance along with Life and Career Skills and Information, Media, and Technology Skills, see Figure 6 below.

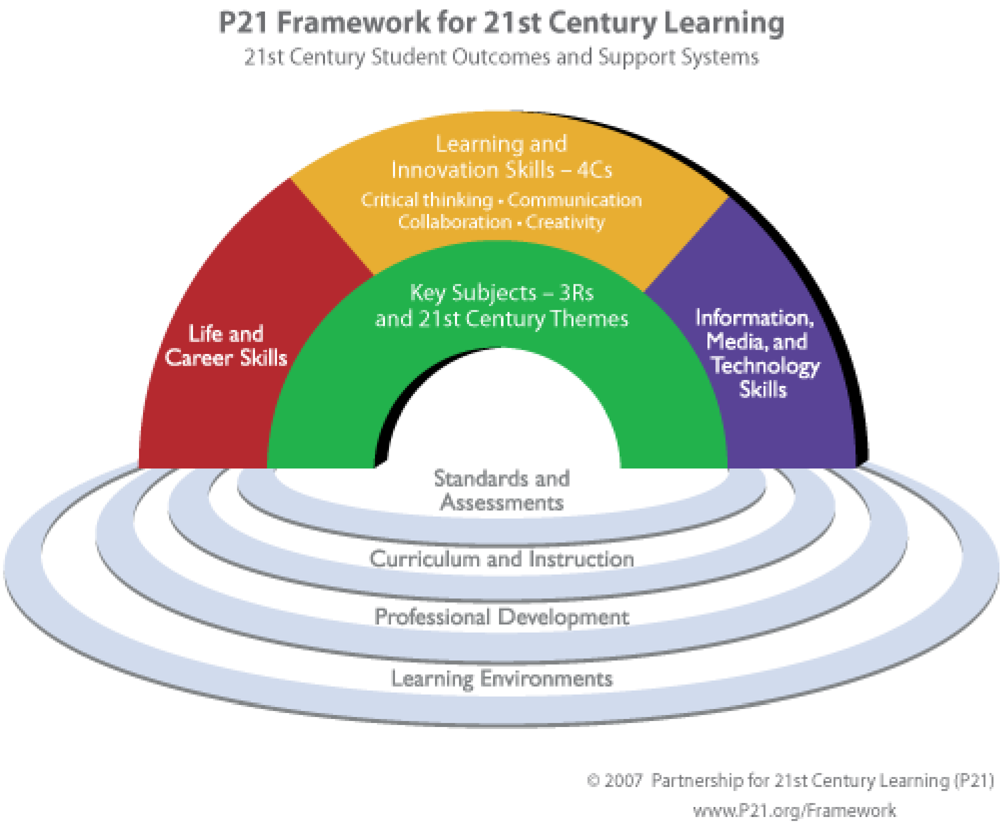

Figure 6. Partnership for 21st Century Learning Framework

The P21 Framework for 21st Century Learning, much like the Equinox blueprint or the concept of a T-Shaped professional, emphasizes the value of learner's who are engaged critical thinkers with core competencies as well as broad knowledge bases. Furthermore, P21 makes it clear that they view learning as a lifelong endeavor which uses traditional schooling, K-12 and university, as a foundation for understanding how to learn in a rapidly changing technological society. A further breakdown of P21's vision of modern learning outcomes can be seen below in ***Table 3*****,** a combination of their Learning and Innovation Skills; 21st Century Themes; and Information, Media, and Technology Skills (P21, 2009).

Table 3. P21 Learning Goals

Learning and Innovation Skills
○ Creativity and Innovation *
▪ Think Creatively
▪ Work Creatively with Others
▪ Implement Innovations
○ Critical Thinking and Problem Solving *
▪ Reason Effectively
▪ Use Systems Thinking
▪ Make Judgements and Decisions
▪ Solve Problems
○ Communication and Collaboration *
▪ Communicate Clearly
▪ Collaborate with Others
21st Century Themes
○ Global Awareness
○ Financial, Economic, Business and Entrepreneurial Literacy *
○ Civic Literacy
○ Health Literacy
○ Environmental Literacy
Information, Media, and Technology Skills
○ Information Literacy *
▪ Access and Evaluate Information
▪ Use and Manage Information
○ Media Literacy
▪ Analyze Media
▪ Create Media
○ ICT (Information, Communication, and Technology) Literacy *
▪ Apply Technology Effectively
* topics reflected in the Maker Movement

These categories will be used later, combined with the Equinox Blueprint for Learning and accreditation requirements for engineers, to provide an overview of what skill interviewed makers are learning that apply to these learning goals for the 21st century.

While the Equinox document focuses on the educational groundwork needed from high school into college and P21 provides a broad overview of educational needs based on industry/government/educational input, the National Academy of Engineering's *The Engineer of 2020: Visions of Engineering in the New Century* and its companion piece, *Educating the Engineer of 2020: Adapting Engineering Education to* *the New Century*, offer a narrow and discipline specific lens on educational goals needed for the future of the engineering profession (National Academy of Engineering, 2004, 2005). The core question both documents attempt to answer is how engineering as a discipline and profession will advance into a new century of increasing technological change across a geographically broader landscape, both literally and figuratively. The reports recognize the global nature of engineering and the need to prepare students for a technological future that may be quite different from the technological present the students are trained in. In the words of the report's authors "The comfortable notion that a person learns all that he or she needs to know in a four-year engineering program is just not true and never was (2004)." Ten traits are identified that tie the education practices of present day engineering to the practices needed for the future (National Academy of Engineering, 2004).

- Strong analytical skills
- Practical ingenuity
- Creativity
- Communication
- Business and management
- Leadership
- High ethical standards
- Strong sense of professionalism
- Dynamism, agility, resilience, flexibility
- Lifelong learners

The education goals outlined above from the Engineer of 2020 are strikingly similar to the education desires for high school students as outlined in the Learning 2030 report as well as the much broader requirements for success shown in the Partnership for 21st Century Learning, albeit with a much stronger focus on analytical skills and a strong science basis for the Engineer of 2020.

The above-mentioned documents are designed to provide a vision for the education needs of the future. Taken as a whole, they provide an idea of what current experts think will be most useful for education in the future. In contrast, ABET is the organization responsible for accrediting applied science, engineering, and engineering technology programs in higher education (ABET, 2017a). The goal of ABET accreditation is to ensure that a given program meets the minimum curricular standards for engineering programs. Furthermore, graduation from an accredited organization is a requirement for becoming a licensed professional engineer (NSPE, 2017). As a result of licensure and standards of quality engineering institutions take ABET accreditation standards very seriously. To understand how making is situated within the specific discipline of engineering, it is worthwhile to consider ABET accreditation documents as educational visioning documents for the present and near future. For this dissertation, two components of ABET standards are particularly relevant. The most important section in terms of making as a learning tool is the Student Outcomes section. In this section, ABET describes the abilities students of all engineering programs will need to have learned through the course of their education to succeed in careers in engineering. These Student Outcomes are by necessity vague, describing desired traits rather than specific testable qualities. In contrast to the present, early in ABET's history, from its precursor organization in 1932 until 1997, it provided specific curricula, faulty, and facility guidelines to describe engineering education minimums. However, the over specified guidelines were seen as counterproductive to the broadening field of engineering. The current Student Outcomes, also often referred to as Criteria 3, a-k, or outcomes a-k, are listed below (ABET, 2015).

a) an ability to apply knowledge of mathematics, science, and engineering
b) an ability to design and conduct experiments, as well as to analyze and interpret data
c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d) an ability to function on multidisciplinary teams
e) an ability to identify, formulate, and solve engineering problems
f) an understanding of professional and ethical responsibility
g) an ability to communicate effectively
h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i) a recognition of the need for, and an ability to engage in life-long learning
j) a knowledge of contemporary issues
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Much like the previous visioning documents, ABET identifies a clear need for lifelong learning skills, ethics, interdisciplinary, critical thought, and clear communication skills. These broad criteria will form the basis for a coding scheme applied to maker interviews to determine how "Maker Outcomes" might map to the Student Outcomes of engineering. Additionally, the Student Outcomes section is currently under review by ABET and may be changed starting in the 2017-2018 academic year. To offer a complete view of ABET Student Outcomes as a vision of the future of education, the revised outcomes are listed below and also used in the Findings and Analysis chapters as coding criteria. It is worth noting that these revisions face strong resistance from parts of the engineering education community and may, or may not, end up being adopted.

1. An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet desired needs.
3. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
4. An ability to communicate effectively with a range of audiences.
5. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
6. An ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.
7. An ability to function effectively on teams that establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty.

The second part of ABET accreditation that is valuable to understand as it relates to making is the program specific criteria found in ABET accreditation workbooks (ABET, 2017b). Depending on the discipline, these workbooks may be highly specific in their requirements, such as descriptions of program languages and specific fields in computer science programs, to very vague displaying only a mention of acquiring the skills needed to perform as a professional in a given field and leaving the decision up to the individual doing the accreditation for a given institution. Parts of these workbooks are used in greater detail in the Findings and Analysis chapters to describe what skills makers are learning. Where available, the information in these workbooks also provide the basis for determining what technical skills fall under a given engineering discipline.

Taken together, these reports offer a clear vision of what experts in education, industry, government, and engineering see as vital traits to instill in tomorrow's students. Whether the education focal point is high school, higher education broadly, or engineering specifically, lifelong learning habits, creativity, communication skills, the ability to engage in critical thinking, and the ability to perform across disciplines are seen as absolutely necessary.

On the Future of Work

The cross-disciplinary and cross-scholastic level convergence of education goals seen in the above visioning documents can be connected to techno-realist visions of the world today's students may find themselves in later in the 21st century. While many imagined visions of the future end in dystopian apocalypses or utopian victories, most of these seem to require political, technological, and social changes to happen on a level that seems unlikely given society's tendency for incremental change in these spheres. Barring a Kurzweilian machine singularity (Kurzweil, 2005), worldwide ecological disaster, or drastic change in governments across the globe, the most likely scenarios for the future of work involve not a revolution in the way people work and interact with technology, but instead an evolution of existing structures.

One of the most compelling examples of a middle of the road vision of the future of work comes from *Race Against the Machine*, a book where the authors look at current technology and extrapolate how automation and ICT might change the way people interact with the economy in the future (Brynjolfsson & McAfee, 2011). As they correctly point out, technology is rapidly automating tasks that were seen as impossible for computers at the end of the 20th century. Complex tasks like beating human opponents in chess, driving a car, playing winning go strategies, and translating languages in real time have all been accomplished since 2010 (Brynjolfsson & McAfee, 2011; Koch, 2016). However, the story of humans and computers is more complex than a simple case of one competing with the other for a given job. Whether in manufacturing, chess, law, finance, retailing, or the pursuit of science, the combination of human actors working with expert and automated systems is more effective than either element functioning alone (2011). Professionals in the medical field for example find expert systems incredibly useful for enhancing their effectiveness as doctors in diagnosing rare diseases (Kim, 2016). These examples of human performing tasks more effectively with the help of automated systems leads to a conclusion that technological familiarity will be vital for workers in the future. To work well with expert systems, it is helpful to understand how they work and how they can be changed to better suite a given task. One of the main prescriptions found in *Race Against the Machine* is the suggestion that education undergo a radical change away from a stagnant lecture model. The author's see online courses and a focus on leadership, team building, and creativity as the most important, and least likely to automated skills. Furthermore, for STEM practitioners, the inclusion of the arts, turning STEM to STEAM, seems vital to ensure that scientists and technologists also hone the creative skills that will help them work with automated systems in the future (Brynjolfsson & McAfee, 2011).

In 2017 the McKinsey Global Institute released *A Future That Works: Automation, Employment, and Productivity,* a report on automation in the 21st century. Their goal was to gauge today's automation potential in the workforce, including the use of robots, expert systems, and artificial intelligence. By understanding what jobs could be automated with today's technology, forming an accurate vision of the skills that will remain useful in tomorrow's job market become much more feasible. While previous studies often looked at the possibility of automating entire jobs (Frey & Osborne, 2017), and thus displacing 50% of workers entirely, the McKinsey study breaks down more than 2000 work tasks and looks at how those tasks are applied in 800 occupations in the US, which allows for a clearer vision of what parts of what jobs might be automated (Manyika et al., 2017). Under this more nuanced analysis they determined that less than 5% of jobs in the US could be completely automated. Jobs in this area include sewing machine operators and agricultural sorters. Those jobs that are entirely physical and routine can be replaced entirely with machine elements. However, more than 60% of jobs had at least 30% of their tasks that could be automated (Manyika et al., 2017). The most susceptible categories of automatable work fell were either physical and predictable, involved processing data, or involved collecting data. Management tasks; applying expertise to decisions making, planning, and creative tasks; interfacing with stakeholders, and performing unpredictable physical tasks were all seen as unlikely to be easily automated in the near future. Additionally, they note that high automatability is not seen only in low wage jobs, but exists across the spectrum of wages. Landscapers for example are seen as only having 10% of their work in automatable tasks, while CEOs have 25% of their work that could be done by machines. Across the board however, they see automation as having a positive effect on the economy. When part of a job is automated, the worker can focus more on the non-routine tasks that demand human input. In terms of education, they see STEM skills with a renewed focus on creativity, critical thinking, and systems thinking as vital in a time period where "everybody's job is likely to change to some degree (Manyika et al., 2017)."

Summary of Literature Review

Education visioning documents, reports and books investigating automation and the future of work, and current engineering accreditation standards all point to a future where creativity, communication skills, critical thinking, complex systems thinking, and technical knowhow will be vital to individual's success education and in the work force. In this chapter, the Maker Movement was introduced as a conglomeration of technologies and social groups, the Maker Mindset was introduced to show how makers learn within existing education frameworks, three visioning documents for the future of education were introduced, and phenomenon of automation and the future of work were presented. However, from the standpoint of education, the question remains "How can these traits be instilled in future learner?" The Maker Movement is an example of a group that intersects with these qualities in many ways and this intersection between education goals, the maker movement, and the future of work is explored in the chapters to come.

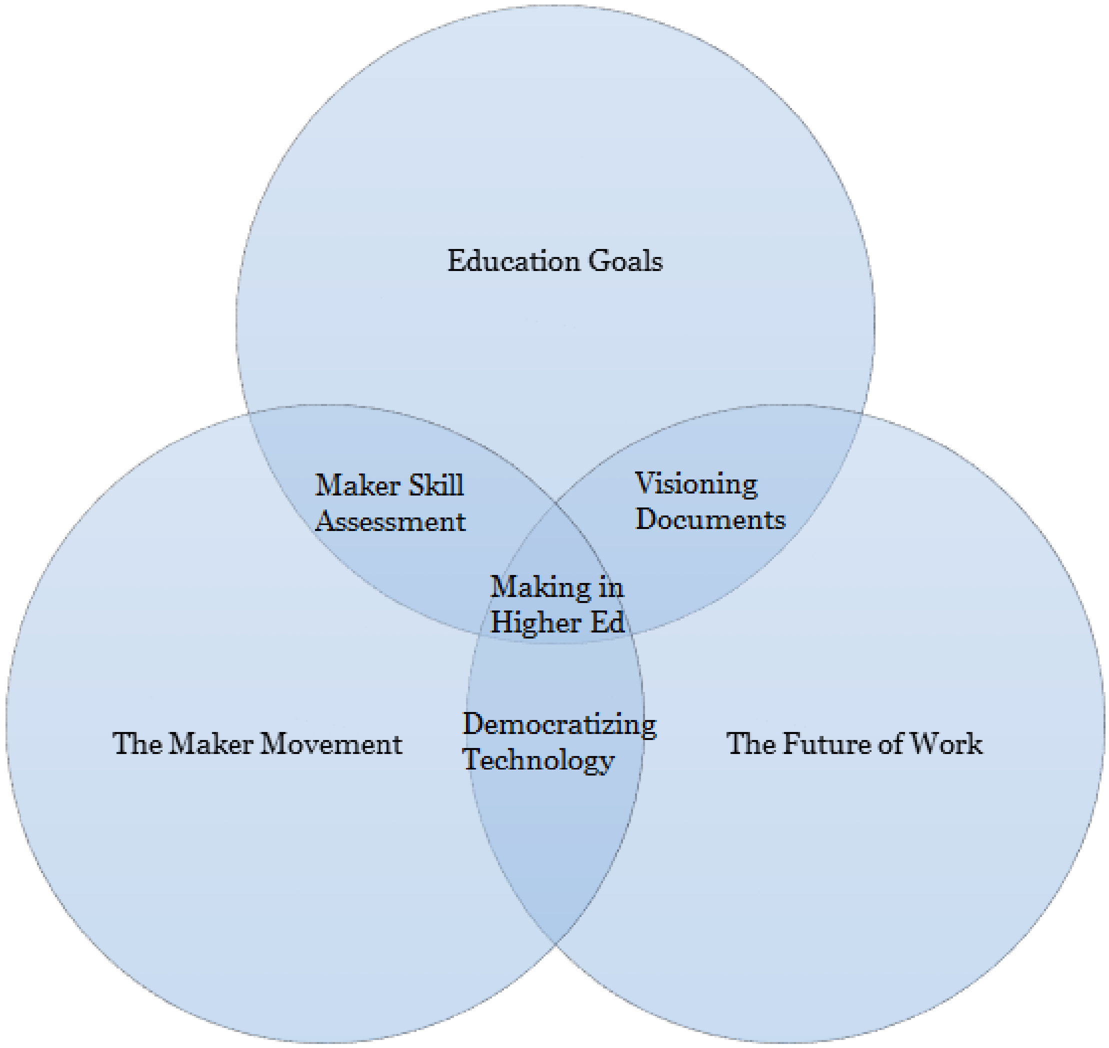

Figure 7. Intersections between Education, Making, and the Future of Work

CHAPTER 3

RESEARCH METHODOLOGY

Research Question and Methodology Overview

This dissertation presents multiple studies to allow for the exploration of how makers learn, what the maker mindset is, and, ultimately, how the learning outcomes experienced by makers can be integrated into higher education to prepare students for the future of work and life in the 21st century. To this end, three questions are explored in three separate studies based on one data set.

- **Research Question 1** – What can we learn about adult maker's life pathways to illuminate how they learn?
- **Research Question 2** – How do the skills learned by young and adult makers map to current education goals, as represented by ABET accreditation standards?
- **Research Question 3** – How do the attitudes and skills learned by makers relate to the goals of visioning documents related to education and workforce preparation in the 21st century?

The answers to these questions provide a multi-dimensional vision of maker's learning experiences by exploring the individual learning and work experiences of adult makers, the overall skill acquisition of adults and young makers in the narrow context of current ABET standards for engineering education, and finally how these traits relate to broader visioning documents that explore the future of education.

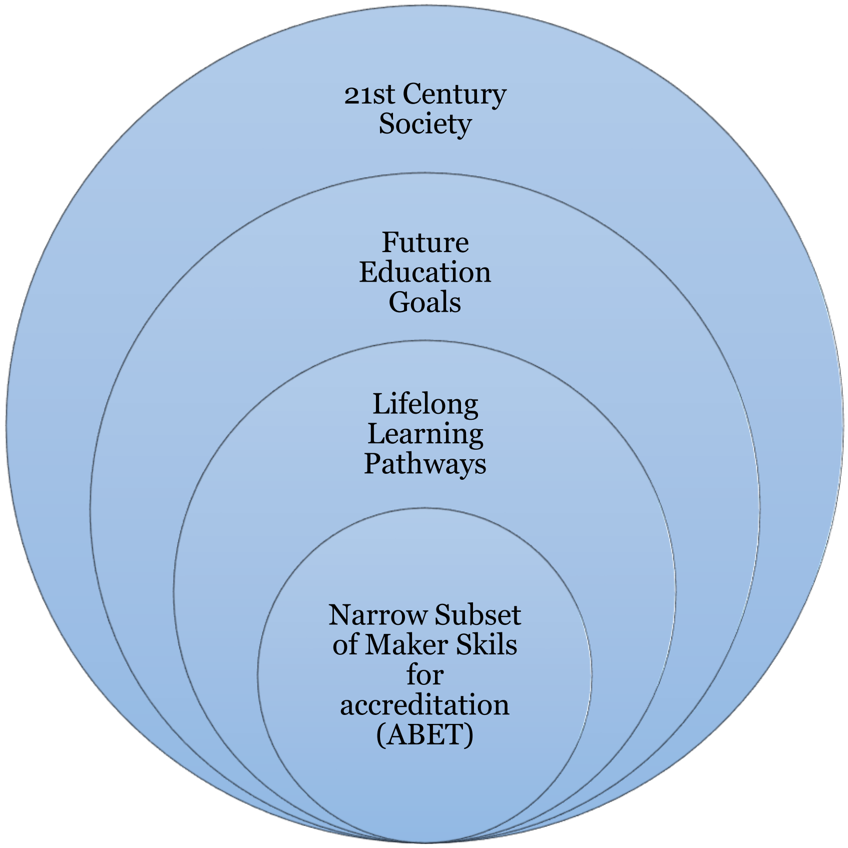

Figure 8. Scope of Dissertation Research

This project has evolved over time from a narrow focus on making as it relates to engineering education to higher education more broadly and to the future of work. As a result, the methods for each of the analysis sections vary slightly, though in each case they are based on constructivist qualitative thematic analysis. The overall study is designed with Crotty's (1998) four elements of research study (epistemology, theoretical perspective, methodology, and methods) in mind. Below, the process for this project is visualized in a linear flow chart model with dotted lines indicating iterative processes within the research design. Additionally, a table outlining the elements of the research study is included. Several of these tables and figures are repeated in the research findings chapter.

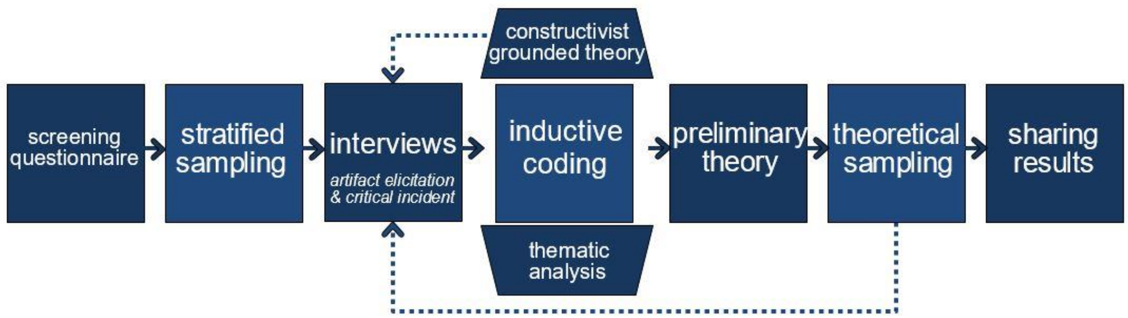

Figure 9. Research Process Flow

Table 4. Elements of a Research Study by Crotty (1998)

	Definition	**Selected**	**Rationale**
Epistemology *informs:*	Theory of knowledge	*Constructivism* Knowledge is constructed through human-world interaction (Piaget, 1996)	To understand how and what makers learn through their creations
Theoretical Perspective *informs:*	Philosophy that informs methodology	*Constructionism* Meaning is created through constructing & sharing artifacts (Papert & Harel, 1991)	To understand how makers create meaning through the design and sharing of their creations
Methodology *informs:*	Design connecting methods to outcomes	*Constructivist Grounded Theory* Researcher is the author of participant's voice and meaning (Charmaz, 2006)	Little is known (Corbin & Strauss, 2014a) about what makers know and their pathways. Methods must be sensitive to study objectives.
Methods	Implementation of methodology	Screening questionnaire Artifact elicitation interviews Critical incident technique interviews Participant observation	To screen potential participants To understand makers' skills learned by creating To understand maker life pathways To gain further insight into maker culture

Built into this research design is a clear intent for iterative understanding, not only of makers and how they learn, but also of the *questions* that should be asked about makers. This iterative process resulted in the three above mentioned research questions that this dissertation explores.

Research sampling. To gain a representative sampling of makers, data collection was performed where makers gather in large numbers, at two national Maker Faires, one in New York City and one in the Bay Area in California. Each year both Maker Faires were attended for a total of eight collection periods. At each of the Maker Faires an average of 1000 makers presented their creations to 100,000+ attendees (MAKE Media, 2016). Over a four-year period, a total of 42 adult makers (ages 18+), 52 young makers (ages 12-17), and 32 parents of young makers were interviewed. Initially, adult makers were interviewed under an NSF grant to determine "Should Makers be the Engineers of the Future?". During interviews the research team noticed numerous young makers presenting their work at Maker Faires. As a result, a second study was performed under the NSF grant "Might Young Makers be the Engineers of the Future?". After an iteration of young maker interviews, the study was expanded to include the parents of young makers as well, as the sampling team often noticed side conversations with the parents revealed a great deal about what and how the young maker was learning.

A stratified, purposeful sampling strategy was used for initial selection of participants (Patton, 2002). This strategy focused on maximizing sampling variation, with an oversampling of underrepresented groups, to ensure the widest possible range of maker viewpoints and experiences. This set of makers was appropriate for answering questions on broad perspectives on learning through making experiences whereas a more statistically representative sample based on demographics seen at maker faire would have served to exclude many viewpoints. In Table 5 the primary and secondary strata for sampling are displayed.

Table 5. Maker Sampling Stratification

Primary Strata	**Secondary Strata**
▪ Self-identified maker ▪ With/without formal engineering education experience (e.g., engineering degree) ▪ With/without informal engineering education experience (e.g., robotics team, hacker space) ▪ Member of an underrepresented group based on ethnicity or gender	▪ With/without a STEM career ▪ With/without a STEM hobby ▪ Years of experience as a maker ▪ Age

In all cases, interviewees were sampled primarily on the basis of their self-identification as makers. For the adult population members with and without formal engineering backgrounds were interviewed in order to explore the different life pathways that led to participation in Maker Faires and making more broadly. Likewise, informal engineering experiences were of interest in both adult and young maker populations to understand the impact such experiences had on their learning and life paths. As mentioned above, careful iterative sampling was done to insure diversity based on ethnicity and gender. The end result of the study, at the time of this dissertation, a sample of over 120 participants composed of roughly 47% female interviewees and 41% minority interviewees. While this number of participants does not allow for a rigorous quantitative analysis of makers, a smaller N is appropriate (Pawley, 2013) for the characterization of identity traits and an overview of the maker learning landscape. With over 120 participants and ~160 interviews there is more than enough "thick description" for the research on maker mindsets, learning pathways, and skills.

Data collection methods. The study began with administering a screening questionnaire to potential participants to inform the stratified purposeful sampling strategy for maximum variation in participant backgrounds. Fifteen-minute artifact elicitation interviews (based on the method of photo elicitation (Clark-Ibáñez, 2004; Harper, 2002) were then conducted in person at Maker Faires with each study participant. A longer, one hour, critical incident technique interview (Flanagan, 1954) was conducted with each participant in the months following Maker Faire. Additional data was collected in the form of participant observations at Maker Faire and two local makerspaces in Arizona, Heat Synch and TechShop.

Screening questionnaire. Prior to each Maker Faire, all makers with information publicly available online were contacted through email and asked to complete a short online screening questionnaire. The questionnaire consisted of short answer questions (see Table 4) and requested contact information and their exhibit location at the Maker Faire. The results were collected in a spreadsheet that was used to select initial participants using the stratified purposeful sampling strategy described above, and was also used to contextualize the artifact elicitation and critical incident technique interview questions. Makers without publically available information were approached at Maker Faire and invited to be interviewed based primarily on age and ethnicity.

Table 6. Screening Questionnaire Examples

Are you a Maker?	Primary Strata
How many years are you a Maker?	Secondary Strata
As a Maker, what do you Make?	Theoretical Sampling
Why are you attracted to Making?	Theoretical Sampling
Have you been involved with any group Maker activities?	Primary Strata
Have you taken any engineering classes or have an engineering degree?	Primary Strata
Do you have an engineering related job/career?	Secondary Strata
Ethnicity, Gender	Primary Strata
Age	Secondary Strata

Artifact elicitation interviews. Semi-structured artifact elicitation interviews (Douglas, Jordan, Lande, & Bumbaco, 2015), based on the research method of photo elicitation (Clark-Ibáñez, 2004; Harper, 2002), were used to elicit "thick description" from participants (Geertz, 1973). Interviews were conducted in person with the maker participant to examine how and what the maker had learned that led to the creation of the artifact on display. Each participant was located at their exhibit booth at the Maker Faire where they were typically interacting with Maker Faire attendees and showing/demonstrating their creation. Following obtaining research consent, approximately fifteen minutes was spent with each maker participant, asking them to describe their artifact, show how their artifact works, describe their process for making, and describe the knowledge, skills, and attitudes they learned or gained from making (see Table 5). We asked probing questions about the artifact to elicit "thick description" (Geertz, 1973). Questions evolved after each round of data collection based on emergent themes that were discovered during early analysis.

Table 7. Sample Artifact Elicitation Questions

Can you tell me about what you brought to the Maker Faire? ▪ What technology does it use? ▪ Can you show me how it works?	Knowledge and skills
What knowledge and skills did you have to learn to make this [insert name of artifact]?	Knowledge, skills
Where did you learn these things?	Lifelong learning
How did you come up with the idea for this [insert name of artifact]? ▪ What could you improve in your [insert name of artifact]?	Attitudes

Constructivist critical incident technique interviews. Semi-structured constructivist critical incident technique interviews (Flanagan, 1954; G. A. Klein, 1999; G. Klein, Calderwood, & Macgregor, 1989) were used to examine the educational and career pathways of makers and how they intersect with formal engineering education and careers in engineering. Klein used critical incident technique interviews to study decision making in a variety of fields, and the method have been used very successfully in engineering education research (Adams et al., 2007; Adams, Daly, Mann, & Dall'Alba, 2011; Adams, Forin, Srinivasan, & Mann, 2010; Adams, Mann, Forin, & Jordan, 2009; Pears, Fincher, Adams, & Daniels, 2008; Walther & Radcliffe, 2007). This technique aligns well with this study to understand decision points contributing to the various pathways in a maker's education. Following each Maker Faire, all participants who completed an artifact elicitation interview asked to participate in the semi-structured constructivist critical incident technique interview via email. All maker participants who were willing to complete the critical incident interview were contacted via Skype or by phone. Critical incident interviews typically lasted between 45minutes to 1 ½ hours. The semi-structured interview was guided by questions (see examples, Table 6) designed to examine decision points in their educational pathway. Questions evolved after each round of data collection based on emergent themes that were discovered during early analysis.

Table 8. Sample Critical Incident Interview Questions

What would you say "Making" is for you?	Attitudes
Tell me the story of how you became a Maker.	Pathways
How did your educational experience prepare you for the Making you are doing now? ▪ Have you found any gaps in your knowledge (e.g., things you wish you would have learned or things you did not learn well enough)?	Lifelong learning/ Pathways
What is your job? ▪ Why did you/did you not pursue an engineering career?	Pathways
Where do you see yourself in 5-10 years?	Pathways

Data Analysis and Synthesis

The data analysis for this dissertation falls overall into constructivist applied thematic analysis, but the individual sections were each analyzed using different specific methods. Applied thematic analysis is primarily designed for exploratory research, where the researcher enters into the process with a goal of developing, rather than verifying, hypotheses about the subject matter (Guest, MacQueen, & Namey, 2011). As can be seen in the research questions, the goals of this study are primarily exploratory; what are makers learning, how are they learning, etc. Additional research goals are, however, more pragmatic seeking to map the developed hypotheses about how making applies to existing accreditation standards and may apply to future education goals. The specific methods used in each portion of this work are described below.

Analysis for learning pathways. For the portion analyzing the learning pathways of adult makers, interview transcriptions were analyzed inductively. Open coding (Corbin & Strauss, 2014b), theoretical memoing (Glaser, 1978), and sorting were used to identify key influences in the participants' pathways identified within their artifact elicitation and critical incident interviews. Sorting and theoretical coding were also used to connect the resultant themes into the larger work on making and education.

Characterizing makers and their pathways is a challenging endeavor. Most makers do not as a rule follow traditional pathways, i.e. education followed by a career in their field; instead, they cross between disciplines, make major career changes, learn diverse skills and knowledge, and so on – often for the purpose of realizing their goals as makers. This breadth of education and work experiences will be further illuminated in chapters 4 and 5. Part of the diversity of experience found in makers is due to how the maker community is built. The community is based on a culture of acceptance and supporting one another in individual and group interests and pursuits. As making goes mainstream, it continues to be a place where people from all backgrounds can gather and showcase their artifacts, whether it be a transformative innovation or an offbeat artifact. The maker showcase events (including flagship Maker Faires, mini Maker Faires, and other features events) have seen their total attendance grow 24 times since the first Maker Faire; this translates to approximately 22,000 exhibitors and attendees in 2006 to 530,000 exhibitors and attendees in 2014 (Maker Media Inc., 2015). With this growth comes an increase in the diversity of artifacts being showcased and people from different pathways. Browsing by topic on the Maker Faire website will lead to 70 exhibit topics to explore (see Table 7). The Maker Movement is a place for people of all sorts; this type of diversity makes analyzing their life pathways a challenge. Data were analyzed inductively using NVivo in several iterations. First for broad themes and then narrowing as themes emerged from the data. Major milestones and key influences during the maker's life pathway were also coded to see what decision points may have led to identifying as makers.

Table 9. Exhibits at the Maker Faire (Maker Media Inc., 2014)

< 18 YO	Computers	Fun & Games	Kinetic Art	Scratch
3D Imaging	Computers & Mobile	Gadgets	Make; Believe	Small Business
Alternative Energy	Craft	Gaming	Makerspaces	Solar
Arduino	Culture	Getting Started	Media	Space
Art Cars	DIY Projects	GPS	Microcontrollers	Start Up
Art & Design	Drones	Hacks	Music	Steam Punk
Beaglebone	Education	Ham Radio	Performances	Sustainability
Bicycles	Electric Vehicles	Hands On	Photography & Video	Tesla Coils
Biology	Electronics	Health	Physics	Toys
Biotech	Engineering	Home	Raspberry Pi	Up-cycling
Boards	Fabrication	Invention	Robotics	Wearables
Chemistry	Fine Arts	Kids < 5 yo	Rockets	Woodworking
Circuit Bending	Flying	Kids & Family	Science	Writing

Analysis for maker skills and ABET accreditation criteria. In contrast to the inductive coding used to understand maker learning pathways, this portion of the research was conducted using deductive coding of interview transcripts using ABET accreditation standards as a theme for analysis. This portion of the research only used the artifact elicitation interviews as a data source in order to maintain a clear "apples to apples" comparison of what each maker was learning through the creation of the artifact shared at Maker Faire. Including the longer critical incident interviews would have skewed the data to display skills learned outside of the creation of a single artifact and only apply to the 25% of young maker interviewees who also participated in the critical incident follow-up interview compared to the 60% who participated in the adult critical incident interviews. For this portion of the study, a total of 36 self-identified Young Makers, age 12-17, and 40 Adult Makers, age 18-60+, were interviewed (the total interviewees at the time of analysis). The interviewees include both adult makers as well as pre-college makers. Allowing for a clear view of adults post-college as well as those entering college in upcoming years.

The 76 artifact elicitation interviews were coded in NVivo mixed methods analysis software for the following ABET student outcome and program criteria categories (ABET, 2014).

Table 10. ABET Criteria 3 - Student Outcomes (a-k) Codes

a)	an ability to apply knowledge of mathematics, science, and engineering
b)	an ability to design and conduct experiments, as well as to analyze and interpret data
c)	an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d)	an ability to function on multidisciplinary teams
e)	an ability to identify, formulate, and solve engineering problems
f)	an understanding of professional and ethical responsibility
g)	an ability to communicate effectively
h)	the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i)	a recognition of the need for, and an ability to engage in life-long learning
j)	a knowledge of contemporary issues
k)	an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Table 11. ABET Program Specific Criteria Codes

1)	Broadly applicable to engineering programs
	a) science fundamentals
	b) high level math (calculus, differential equations, etc)
	c) computer aided design (CAD)
2)	Biomedical engineering programs – solve biomedical problems, interaction between living and non-living systems, realize biomedical devices, measure and interpret data from living systems.
3)	Electrical, computer, communications, and telecommunications engineering programs – analyze and design complex electrical and electronic devices, software, and systems containing hardware and software components.
4)	Manufacturing engineering programs – understand materials and manufacturing processes, process assembly and product engineering.
5)	Mechanical Engineering – model, analyze, design, and realize physical systems, components or processes.
6)	Computer Science - Programming without electronic or hardware components.

Program specific criteria are drawn from ABET Accreditation Workbooks, which themselves leave quite a bit up to the subjective understanding of the individual reviewer. Some of the program specific workbooks go into great detail on specific skills, such as computer science, while others are notably lacking in specific suggestions. From the workbooks, main thematic knowledge areas were chosen rather than focus on over specific criteria. For example, all engineering programs require knowledge of science fundamentals and higher level math, which led to the creation of a coded category for "Broadly applicable" skills. CAD skills, while not required explicitly by most programs, are useful in most forms of engineering and are an example that shows the use of modern engineering tools. Furthermore, CAD skills are often used by makers when designing and producing artifacts which require 3d printing or laser cutting. Computer science is listed as a separate category to distinguish the very few maker projects which were solely app based rather than those which required both hardware and software components. Finally, Manufacturing Engineering was taken to include prototype fabrication as well as designs that were meant to be broadly distributed and used by a wide audience.

Table 12. Engineering Experience Codes

1) Has an engineering degree or worked professionally as an engineer (adult)
2) Wants to pursue education in engineering (young)

For engineering experience, I drew from both the artifact elicitation interviews as well as the initial background survey.

Mapping data to proposed future ABET student outcomes. The student outcomes section of ABET criteria was undergoing proposed changes in 2016-2017, the results of which are still not finalized as of the writing of this dissertation (ABET, 2016). As a result, it was useful to compare existing student outcomes with proposed student outcomes to see how maker skills might apply to ABET in the future. After initially coding the interviews based on existing a-k standards, interviews were then mapped to proposed changes in ABET Student Outcomes. Each interview was counted only once per category, regardless of the number of a-k categories present. For example, if a given interview was coded with both (a) and (e), it would be counted as one example of category (1) and one example for category (3). It is worth noting that the proposed changes to Student Outcomes are easier to map to than the previous a-k standard. While in a-k there is some ambiguity as to whether a given individual, for example, applied knowledge of engineering (a) to build something or identified and solved a problem using engineering (e), in the proposed standard it is much easier to simply identify that as applying to (1), or to (3) if they explicitly collected and interpreted data.

Table 13. ABET proposed student outcomes Mapped to Existing a-k

Proposed Student Outcome	Equivalent to Existing Student Outcome(s)
1. An ability to identify, formulate, and solve engineering problems by applying principles of engineering, science, and mathematics.	a. apply knowledge of mathematics, science, and engineering e. identify, formulate, and solve engineering problems
2. An ability to apply both analysis and synthesis in the engineering design process, resulting in designs that meet desired needs.	b. design and conduct experiments/analyze and interpret data c. design a system with realistic constraints k. use modern engineering techniques
3. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	b. design and conduct experiments/analyze and interpret data e. identify, formulate, and solve engineering problems
4. An ability to communicate effectively with a range of audiences.	g. an ability to communicate effectively
5. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.	h. broad education to understand engineering in context f. professional and ethical responsibility
6. An ability to recognize the ongoing need for additional knowledge and locate, evaluate, integrate, and apply this knowledge appropriately.	i. lifelong learning
7. An ability to function effectively on teams that establish goals, plan tasks, meet deadlines, and analyze risk and uncertainty.	d. function on multi-disciplinary teams

These proposed changes are highly controversial in the engineering education community and the mapping of maker learning outcomes to the proposed student outcomes is in no way a promotion of the revised outcomes on the part of the author. While the smaller number of student outcomes provides some simplification from an accreditation perspective, the removal of lifelong learning and the focus on multidisciplinarily runs contrary to the ideals, as presented above, of the Maker Movement and educational visioning documents.

Ethical Considerations

All research on this project was conducted with Arizona State University IRB approval and designed to protect the identities of the interviewees. Interviewees signed consent forms, as well as parental assent forms for young makers, which explained the nature of the study, the protections placed on their identities, and that the only benefit to them would be in the form of a gift card as a thank you for participating in the critical incident interviews after Maker Faire. No part of the interview data or protocols represented a threat to participants and participants were informed of their right to end the interview at any time and to ignore any question they did not wish to answer. Audio and video recordings were transcribed and anonymized using identifiers based on the year and location of the interview. All digital data was maintained on password secured devices and all physical data was stored securely as per university policies. In the analysis and presentation of this data, pseudonyms were used for all participants. A copy of the consent and assent forms are presented in Appendix A.

Limitations of Study

As with any study, limitations exist within this one as well. The primary limitation in the case of this study is in the realm of data collection. In terms of data collection, the primary limiting factor is that all interviews were taken from makers presenting their artifacts at one of two national Maker Faires. This subset of makers may not be completely representative of the larger making community. While many our interviewees came from a wide geographical range, the majority were from the immediate area surrounding the two faires, that is from New York and the surrounding area or from the Bay Area in California. This geographical constraint may lead to a representation of makers that is not entirely accurate when compared to makers in the Midwest or southern regions in the US and with makers internationally. Furthermore, this study, despite its strong focus on inclusion through stratified sampling, has a disproportionately underrepresented number of African Americans, despite being composed of 41% minority interviewees. Outside of geographical and demographical concerns, this study only represents makers who are interested in sharing and participating with the Maker Movement in a festival like atmosphere, and who have the freedom of mobility to attend a weekend-long event. Finally, the research team had a much better response rate among adult makers for critical incident follow-up interviews than young makers and their parents. This lack of additional data on top of the artifact elicitation interviews common to all interviewees made it difficult to provide direct comparisons between adult and young makers in a rigorous fashion. Given these limitations however, I found the makers interviewed at Maker Faire were very similar in their attitudes towards learning, their love of sharing, and their desire to explore making in a community atmosphere to their counterparts at local makerspaces in Arizona and with makers described in other academic literature. While universal claims are challenging from this dataset, conclusions on general trends among makers seem reasonable.

Summary of Research Methods

This dissertation explores interviews of makers and their parents using the qualitative method of applied thematic analysis. Interviewees were included using purposeful sampling to insure a broad range of diverse range of views were represented with respect to both age, gender, and ethnicity. Data was collected in three parts, a screening questionnaire, an artifact elicitation interview where the maker was asked at Maker Faire about the object they created to display, and in a follow-up critical incident interview to delve deeper into their educational and career history as a maker. Analysis was performed in two ways. First, the interview transcripts were open coded in an inductive manner to discover important details and similarities between interviewees. This revealed details on how adult participants viewed their journeys as makers. Secondly, ABET accreditation requirements were used to form deductive codes, which were applied to the artifact elicitation interviews of young and adult makers. This coding process was designed to determine how the skills and attitudes learned by makers fit in with existing requirements for engineering education. All research was performed ethically with no perceived risk to the interviewees after obtaining IRB approval.

CHAPTER 4

PRESENTATION OF FINDINGS

The purpose of this dissertation is to present what makers are learning and how they are learning within the context of higher education. In this chapter the data supporting my conclusions and recommendations is presented in two formats reflecting the research methods described in the previous chapter. First the data was organized via inductive coding based on maker life experiences and secondly deductively by applying ABET accreditation standards and student outcomes as discrete codes.

First, the results of the inductive investigation into adult makers learning pathways is presented. First the data is presented as an overview of coding results from the artifact elicitation and critical incident interviews conducted with adult participants. Following the overall analysis, two groupings of three adult makers each are presented in much greater detail. These groupings are based on the makers' creation of similar artifacts and presented to show the variety seen within the maker community in terms of skill acquisition and lifelong learning pathways. Here, the goal is to present the descriptive data collected in a clear manner. The meaning of the data will be described in much greater detail in Chapter 5.

Similarly, the data that resulted from deductive coding of the specific skills and attitudes makers are learning as described by ABET accreditation standards is also presented. The deductive coding results are then graphed and analyzed in a mixed methods approach to show in numbers what young and adult makers have learned relating to engineering accreditation. Unlike the pathway cases, this section presents the data as a statistically significant sample of makers presenting at maker faires, albeit a sample chosen to maximize variation instead of a randomized one.

Sampling Demographics

Table 14. Demographics of Interviewees

Category	Adult Maker	Young Maker	Parent of Maker
Gender			
Female	17 (40%)	22 (42%)	20 (61%)
Male	25 (60%)	29 (58%)	13 (39%)
Age			
7-10		5	
11-14		26	
15-17		18	
18-25	4	2 (18 yr/olds)	
26-30	7		
31-40	11		
41-59	9		
60+	1		
No Response	10		
Ethnicity			
African American		1	
Asian	8	15	10
Hispanic	3	6	3
Jewish		4	2
White	14	25	16
No Response	17		2
Percent Minority	26%	52%	45%

Learning Pathways Findings for Adult Makers

During the inductive open coding period of the adult maker data review several themes emerged. First, adult makers had an astoundingly wide range of backgrounds, both professionally and educationally. Furthermore, these backgrounds were not varied merely between interviewees, but for many interviewees within their own lives as well. For example, a maker might have pursued an undergraduate degree in engineering, changed careers to science outreach at a museum, and then pursued artistic pursuits later in life. A second finding was that makers who worked on artifacts in the same domain (music, 3d printing, large scale interactive art, etc.) often had very different backgrounds, both educationally and professionally. Below, the data on education and professional backgrounds of adult makers, the types of artifacts created by makers, and six in depth examples of maker pathways in two domains of artifacts, are presented. What this data means in the broader context of making, education, and the future of work will be discussed in the next chapter.

Screening questionnaire results for adult makers. The screening questionnaire data provides a snapshot of the makers' reported educational backgrounds and careers (see ***Table 15*** and ***Table 16***). Makers often move between multiple careers through the course of their lives. Of the 42 participants, including those who reported having more than one career, 25 have formal engineering education experience, 13 have an engineering degree or are currently studying toward an engineering degree, and 21 have informal engineering education experience (e.g., robotics clubs). Of the same participant pool, 22 reported having an engineering-related career and 7 reported *not* having an engineering-related career. (Participants often reported multiple careers. A given participant might have been a machinist, engineer and artist, for example.) Consolidating the responses for educational backgrounds and careers into like categories reveals that the frequency of educational background and career for the art and STEM categories are somewhat proportional. Additionally, most makers have STEM and/or art education backgrounds and careers, in addition to being involved with entrepreneurship in their career. From this vantage point, it seems as though the makers' pathways are mostly linear (e.g., an individual who has an educational background in STEM has a career in STEM). Looking across the educational background to career for the individual participants reveals that 34 pathways are linear, with 16 including entrepreneurship in the career. Two pathways show cross over between art and STEM and four show cross over between multiple categories (e.g., tradesman, professional, business). Twenty-four of the 42 interviewees had careers or education experiences bridging across multiple categories. This leads to the graphic representation shown in ***Figure 10***.

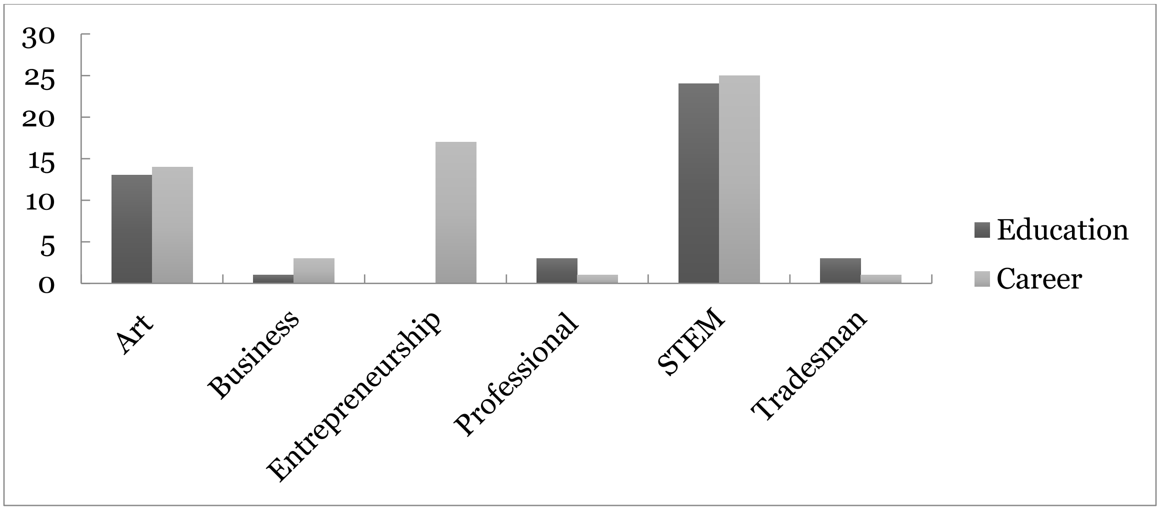

Figure 10. Education and Career Backgrounds of Adult Makers

Table 15. Educational Backgrounds as Reported by Adult Makers

Agricultural Engineering	Design
Apprentice; Artist, Machinist, or Herbalist	Drafting
Architecture B.S., and/or M.S.	Electrical Engineering, B.S., M.S., and/or Ph.D.
Art Experience	Environmental Engineering B.S., and/or M.S.
Art School	Formal Art Training
Arts and Humanities	Game Design
Auto Shop Classes	Horticulture
Bioengineering	Journalism
Carpentry and Woodworking Classes	Manufacturing Engineering
Chemical Biology Ph.D.	Mechanical Engineering, B.S., M.S., and/or Ph.D.
Computer Science and Electrical Engineering Classes	Minor in Civil Engineering
Costume Design	Naval Science Degree
Creative Writing	New Media Design, B.F.A.
Dance	Science, education and professional work

Table 16. Professions as Reported by Adult Makers

Accountant	Game Producer
Advertiser	Graduate Student in Digital Arts and New Media
Art Professor	Graduate Student in Geoscience
Artist	Machinist
Belly Dance Performer, Costume Designer, etc.	Master Woodworker
Bioengineer - R&D Director	Pilot
Business Manager	Police Officer
Community Manager at a 3D printing start-up	Postdoc - Biomedical engineering
Craftsperson	Product Developer
Design Engineer at an oil company	Research Engineer
Designer of Prototypes at a start-up	Retiree
Dress Designer	Scientist - Medical Therapeutics
Electronics Worker	Senior Equipment Engineer
Entrepreneur	Teacher at community makerspace
Freelance Electronics Engineer	Video Game Design

Similar artifacts, divergent pathways. Throughout the collection of interviews with makers and inductive analysis, a theme emerged where makers from different educational backgrounds and with different careers (e.g., art, STEM, business) were making artifacts that had similar purpose. These groupings of makers, based upon the artifacts they made, became an interesting technique to study the complexity of makers' pathways. This process for comparison is intended to prompt new questions, uncover new dimensions, and produce alternatives (Khan & VanWynsberghe, 2008). This is important when studying pathways to consider the multiplicity of ways that makers arrive at making and how it intersects with engineering. With this new direction, artifacts produced by the makers were grouped based upon similarity (see ***Table 17***). The focus for analysis within each case was on the events, activities, and processes they were key to the makers' pathways (Khan & VanWynsberghe, 2008). While the data from screening questionnaires provides an interesting view at the major milestones along the makers' life pathways, it tells us little about the specifics events that occurred in their pathway and the skills that they gained through the activities and events.

Table 17. Artifact Cases and the Makers That Comprise Them

Case	**Educational Background**	**Career**
3D Printing		
3D Printer	Machinist	Community Manager
3D Printer	Computer Science & Electrical Engineering	Teacher - Makerspace
3D Printer	Design	Entrepreneur
3D Printer	Drafting, art, electronics, auto shop	Entrepreneur
Biofeedback Devices		
Biofeedback tent	Electrical Engineering & Creative Writing	Freelance
Biosensing chair	Electrical Engineering	Bioengineer
Common Materials		
Toothpick structures	Journalism	Self-Employed
Tape structures	Fine art history	Artist
Costumes		
Sculptures, props, toys	Naval Science	Artist
Electronic devices	Biomedical Engineering	Post Doc – BME
Dresses	Costume design	Entrepreneur
Toys		
Electronic		
E-textiles	BS, ME, and PhD in Mechanical Engineering	Research Engineer
Games	Fine Art	Masters Student in Games Research
Science toys/ jewelry	PhD in Chemical Biology	Scientist
Machine art/kinetics	Electrical Engineering	Retired
Building/Circuits	BS, MS in Electrical Engineering	Entrepreneur
Interactive		
Interactive coding	New Media	Advertising, Engineering Freelance
Augmented 3D games	Games Design	Entrepreneur
Large-scale		
Articulated mannequins	Mechanical Engineering	Mechanical Engineering
Carnival	Fine Art	Masters Student in Art
Athletic Activity	Game Design	Game Designer
Physical		
Puppets	Pilot, Police Officer, Apprentice	Entrepreneur
Paper fractal activity	Science	Masters Student in Science
Music		
Speakers	Manufacturing Engineering	Entrepreneur
Noise band	Art, Sculpture - BFA	Art Professor
Robotic symphony	ME and Electronics	IT Director + Entrepreneur
Paint		
Paints dreams	Art	Self-Employed
Ancient technology	Art	Art Professor
Sensors		
Wireless home sensors	Electronics and Software	Designer of Prototypes
Aircraft sensors	Electrical Engineering in Progress	Entrepreneur + Student
Smart Watering		
Biosensing garden	Art, Economics, New Media	Masters Student
Hydroponics	Horticulture	Horticulture, Entrepreneur
Smart irrigation	Mechanical Engineering	Entrepreneur
Travel		
Electronic		
Skateboard map	Structural Engineering, Architecture	Student
Racing cars	Accounting	Business
Non-electronic		
Wooden bicycles	Wood working	Small Business
Origami Kayaks	Engineering, Architecture	Entrepreneur

Two cases of parallel pathways, (1) musical artifacts and (2) large-scale interactive artifacts, are presented here to demonstrate the multiple, parallel pathways that makers take to making their artifacts and the contextual events and activities that are critical to the direction of these pathways. These cases were selected as illustrative examples for this dissertation because the makers within each case have different educational backgrounds and different careers, despite making artifacts of similar engineering sophistication. Examining the similarities and differences in the pathways within each case illustrates how making intersects with education with a specific focus on how engineering pathways might be broadened. The findings in this section are highly contextual, dependent upon thick descriptions, and have not undergone comparative analysis across the cases.

Case 1: Musical Artifacts. Alejandro, Cane, and Stephen *(pseudonyms)* make musical artifacts (see Figure 3). Cane makes musical speakers from up-cycled products (e.g., soda cans and lunch boxes) for his growing business. Stephen makes musical instruments from discarded products (e.g., children's toys) for hobbyist, improvisational performances with an organized group. Alejandro makes robots that dance to micro symphonies. Each of these makers used technical knowledge and skills to bring their artifacts to fruition; however, each of their pathways to technical activities is different. Through three stages of data collection (screening questionnaire, artifact elicitation interview, and critical incident interview), new dimensions of their individual pathways were uncovered (see *Figure 11)*.

Figure 11. Musical Artifacts of Adult Makers

Alejandro's pathway seems somewhat standard for engineering; he had six years of engineering schooling, which allowed him to obtain a Mechanical Engineering degree with a major in Mechatronics. He attributes his theory-heavy formal engineering education experiences to enabling him to "look for things and figure out things." However, he wished his formal engineering education had more lab experiences and contests because "it's also frustration that teaches you a lot". Like many engaged engineering students, he sought out informal engineering education experiences by participating in an engineering society; specifically, for Alejandro, he would build and present Rube Goldberg devices at science fairs. Alejandro became familiar with the label "Maker" when he was invited to present his robots at the Maker Faire. His drive for making came from the ability to go "against the socially accepted project in engineering school". He pursued the intersection between art and engineering through his making, allowing dance and music to inspire the creation of his robots. When his peers in engineering school tried to label him as an artist for making non-traditional engineering devices, he would respond to them saying, "I'm not an artist. I'm just an engineer that creates moving things." When asked what his future aspirations are, Alejandro reminds us that his artifact at the Maker Faire was the first performance for his dancing robots and that he has four more performances to make to represent different forms of dance (e.g., Bolero). While working a technical day job, he has launched a robotics start-up to pursue his interests in dancing and musical robots. Alejandro's pathway reflects one of a traditional engineer inspired and informed by his art.

Cane's pathway is another example of one that seems standard for engineering; he has an engineering degree in manufacturing engineering and is working as a consultant using the knowledge he gained from his engineering education while also running a business that relies upon manufacturing and electrical engineering knowledge and skills to make musical artifacts (e.g., modeling, casting, using Solid Works). Like Alejandro, Cane participated in informal engineering education experiences; however, Cane's focus was on his interest in teaching, so he sought out experiences in this vein (e.g., being a mentor for FIRST Robotics). His passion for the arts also led him to experiences outside of engineering (e.g., teaching ceramics and woodworking). A defining life event for Cane was growing up with a dad who was an electrical engineer and working on projects with him while learning technical and non-technical skills (e.g., soldering and wood working). He also attributed engineering projects in the science classroom as shaping his pursuit of an engineering degree. Cane's identity as an "inventor" drove him to manufacturing engineering whereby he learned "how to make things". Once again, his passion for the arts led him to launch a business where he could combine his engineering knowledge and skills with music. Unlike Alejandro, he did not see a disconnect with engineering and the work that he is doing; rather, he wishes that his formal engineering education could have been extended to include developing interpersonal skills and business skills to enable people to leverage their ideas and pursue their goals. According to Cane, his future will include continuing to make the things he is making, to expand his business to other products, and to get involved with teaching again. Cane's pathway reflects one that was driven by early childhood experiences and a pursuit to use his engineering education to implement his art.

Stephen's pathway is dissimilar to that of Cane and Alejandro in that he is trained as an artist and works as a professor of art at a school of art design. Stephen points to positive experiences with art from an early age and how art "engaged" him. To Stephen, interacting with the world around him and learning new skills and knowledge is critical. He pursued the arts because "it's an excuse to learn everything". His knowledge and skills span a wide array (e.g., wood working, modeling, casting, materials, and drawing). Through his formal education in sculpture and ceramics, he became interested in technology. "I've always been interested in technology and oddly I got into sound as an art form from sculpture". Through this interest, he began to learn about electronics and made "boxes that make noise". He became involved with informal education activities that support technical activities, including a group dedicated to doing things with electronics. From his musical artifacts, he formed a group that mimics that of jazz improvisation, where the members "have a relationship with each other even before they get on stage and have a relationship with the instruments". When asked how he learned to make his musical artifacts, he points to his formal art education and self-directed learning. He points out that he is interested in engineering and that he would have pursued had it been available to him. "If I had had actually somebody advising me when I was getting out of high school and going to college and I knew engineering as a career, I might have been an engineer to be honest, because I love engineering as a concept of being aware of your world and being in your world." To Cane, engineering is "taking that knowledge of the world and creating because it is a very creative endeavor, creating something new that exists in that world that changes how people interface with that world." Recognizing the similarity with art, he says, "that's what art is all about at a certain level." His future aspirations are to keep making, specifically electronics, and to continue being an "academic artist" that enables him to pursue making with technology. Although his pathway differs from that of an engineering pathway, he has overlap in the knowledge and skills he has obtained and his purpose for making.

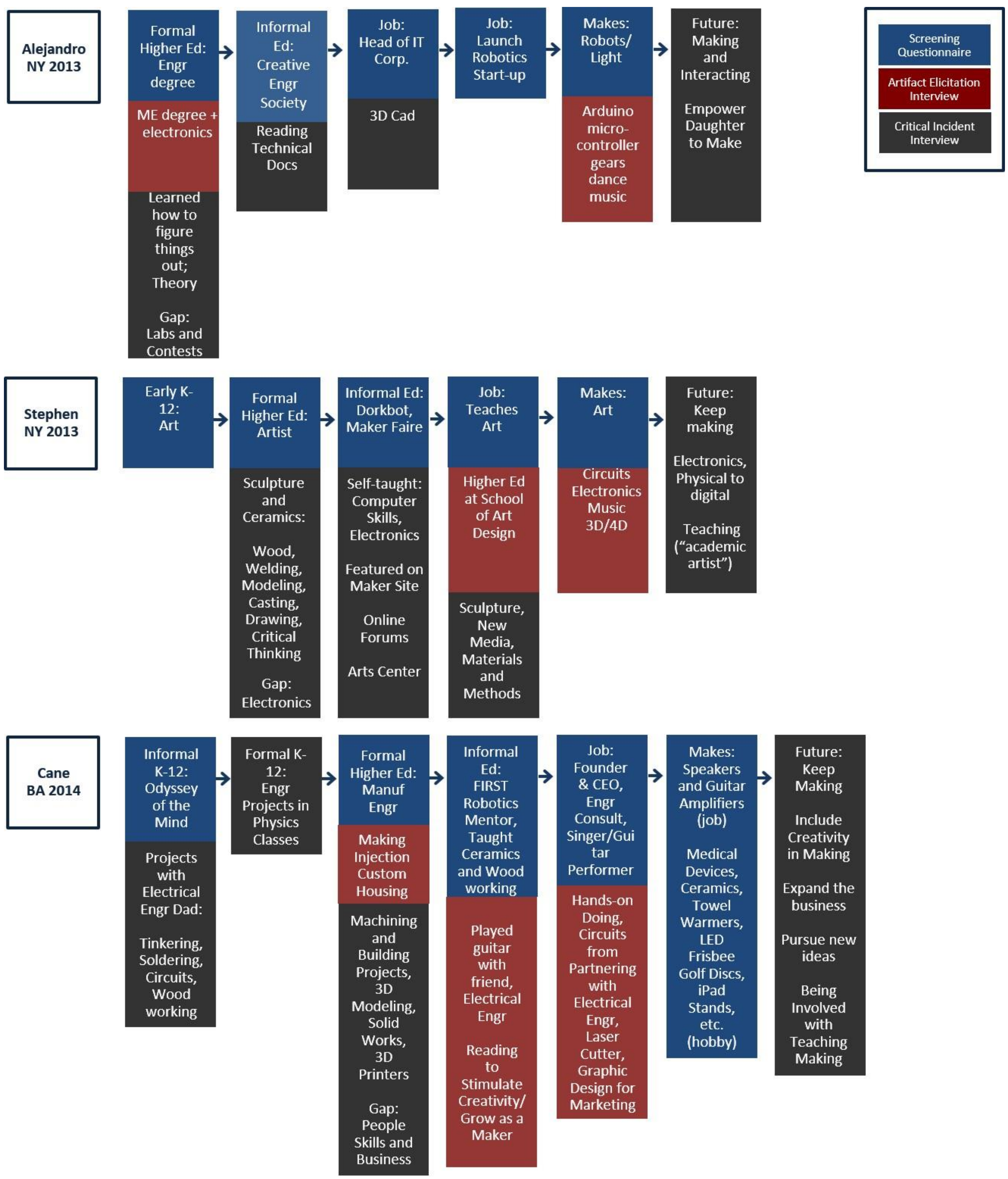

Figure 12. Parallel Pathways - Musical Artifacts

Case 2: Large-Scale Interactive Artifacts. Heather, Jack, and Mark *(pseudonyms)* made large-scale interactive artifacts to exhibit at the Maker Faire. Heather made a human-powered arm wrestling activity, whereby two mechanical arms are powered by human energy (e.g., bicycles and turn cranks). Jack made a large-scale, high-five activity where Maker Faire attendees can experiment with how high they can jump. Mark made articulated, life-size, stick-figure mannequins with hinged joints that Maker Faire attendees can position to create poses and stories. Each of the makers collaborated with like-minded individuals to bring the artifact to fruition. Heather worked with fellow graduate students, while Jack and Mark worked with friends of the same discipline. All three of these makers' artifacts were created in the spirit of fun and to showcase at the Maker Faire; the artifacts were outside of the makers' normal realm of making. Like in the first case, each of these makers used technical knowledge and skills to bring their artifacts to fruition; however, each of their pathways to technical activities is different. Through three stages of data collection (screening questionnaire, artifact elicitation interview, and critical incident interview), new dimensions of their individual pathways were uncovered (see Figure 6).

Figure 13. Large Scale Interactive Artifacts of Adult Makers

Heather's pathway is intertwined with art and technical activity. Heather grew up in a do-it-yourself environment, where all members of her family made things with their hands (e.g., her father was a welder and her mother made the family's clothes and grew the food). She encountered difficulties in her life after graduating high school, but art rescued her. She entered into an undergraduate program for fine art and became trained as a painter. She pursued her painting career for ten years. As she worked in art galleries, she became dissatisfied with painting because to her it seemed "outmoded and, technologically speaking, it had died a long time ago". She was drawn to interactive work because of its "engaging and thought-provoking" characteristics. This prompted a path of self-directed learning to adopt new skills in technology; she took courses at local Hacker spaces to learn Arduino, robotics, and kinetics. During this shift in her pathway, she never forgot the role that art has in her life. "I owed my life to my art because it got me out of situations that my peers are still embroiled in. No matter what I do, I always owe my art my best." With this dedication to art, she began to plan how she could appropriate her developing skills with Arduino, robotics, and kinetics to be "a better artist". During her self-directed learning, she found the local programs lacking for an individual like herself who had no technical foundation. She entered into a graduate program at an interactive arts school. During this formal education experience, for which she was still enrolled in during the time of the Maker Faire, she acquired the skills and knowledge needed to know to propel her forward (e.g., mechanics, electronics, fabrication, and production). Preparing to graduate, she recognized "so now I know what to ask and how to ask". She gives credit to her graduate program for "getting her over that bump" and exposing her to like-minded individuals who can participate and contribute in her making. To Heather, making is "a verb; it's finishing something". She sees the Maker Movement as a place that brings together different sects, from "those that just want to build" to those that want to engineer and "make sure all the technical components are there." She sees herself as the jock. When asked about her future aspirations, she says she would like to (1) "be an advocate for artists with art knowledge and purpose and intent", (2) "guide more traditional institutions of fine art into this idea to give artists digital tools", and (3) "for my own selfish intent, I want to make things that are awesome, things that I see in my head and make them happen".

Jack's pathway represents a blend of technical training, making, and design. He has a degree in computer science and psychology and works as a video game producer. He focuses his responses to the interview questions on design, creativity, and implementing ideas. He credits his dual degree with enabling him to know "how things work programmatically and how people might interact with the [artifacts and games]". When asked about the specific knowledge and skills he learned from his formal education, he cannot recollect specific examples and discloses that the field of computer science has changed so much since he went through his degree program. He identifies as always being a maker and references early childhood experiences with being "creative" and taking "whatever is in my head and make into something real". As a child, he would take things a part and put them together again. He uses making as a creative outlet to work with physical processes and to use his hands; this balances his computer-heavy work with game design. "When I'm building it, I'm working with a lot, you know, I'm working with tools and actually like getting calluses on my hands as opposed to when I'm making video games it's all virtual." Through making interactive artifacts, he learns about materials, like conduit, and processes. He purposefully selects projects for making that are less time intensive to allow for time for his young son and work, but relies upon making to "push creativity in a different direction". He also tries to keep his making separate from his job as a game producer, but acknowledges that they inform one another, specifically with "creativity and having to create access to tools". He identifies himself as "more of a designer and a visionary and about user experience." Recognizing how making has shifted his mindset, he now considers himself an artist. Before making became mainstream and he became familiar with the label, he considered himself "as a creative, but not necessarily an artist". He now feels like he is an artist because he has a "skill set" and is making ideas "into real things". In the future, Jack hopes to be a leader at work, raise his family, and continue to make new things. His views of art and technical work influence his directions in life; this is interesting to compare to Heather, whose pathway has also been influenced by her views of art and technical work.

Of all the pathways presented, Mark's pathway might seem the most traditional for engineering; he has mechanical engineering degrees (B.S., M.S., and Ph.D.) with experiences in Mechatronics and is a practicing mechanical engineer with a career in robotics. His father was also a mechanical engineer and liked to do hands-on projects together, such as radio-controlled airplanes, submarines, solar-powered mobiles, and building things from Erector sets. From an early age, he had foundational experiences with engineering, like working for a local inventor who "had invented a machine that watered automatically trays of alfalfa sprouts". When it was time to select a university, his dad flew with him to reputable engineering universities for tours. During graduate school, he worked in a biomechanics lab where he was "introduced to human anatomy" and learned how the joints and muscles work. During his masters program for engineering, he extended his knowledge of robotics and controls and during his Ph.D. program in engineering, he studied electronics, robotics, and programming. He uses his knowledge and skills for his job, designing devices for robotic assisted surgeries. He credits the blend of his knowledge and his interest in "combining engineering and art" for the reasons he makes the articulated mannequins and animatronics features. The artifact initially began as a hobby: “I have had a career in robotics, and I’ve had kids, and I enjoy entertaining kids particularly at Halloween time”. However, “sharing it with other people” drove him and his friend to bringing the artifacts to the Maker Faire. He has been showcasing these artifacts for eight years, each time making them better. “People loved them; they tore them a part; they broke all the wires in them, so we figured we would make them better. Each year we have improved the mechanical design of them.” In addition to his recreational making and his engineering career work, he mentors high school students to promote “hands-on learning through robotics”. When asked about gaps in his education experiences with engineering, he references a list of technical topics that he wished he had more exposure to, including statistics, programming language, and digital electrons. When asked if there are any other gaps, he refers to his “artistic talent” and that he never pursued art courses, but learned it on his own. In the future, Mark aspires to continue to improve the things he makes, makes new things, and teach at local tech shops. His pathway is familiar to engineering. It is starkly different than that of Heather’s and overlaps with Jack’s in his dedication to make physical artifacts.

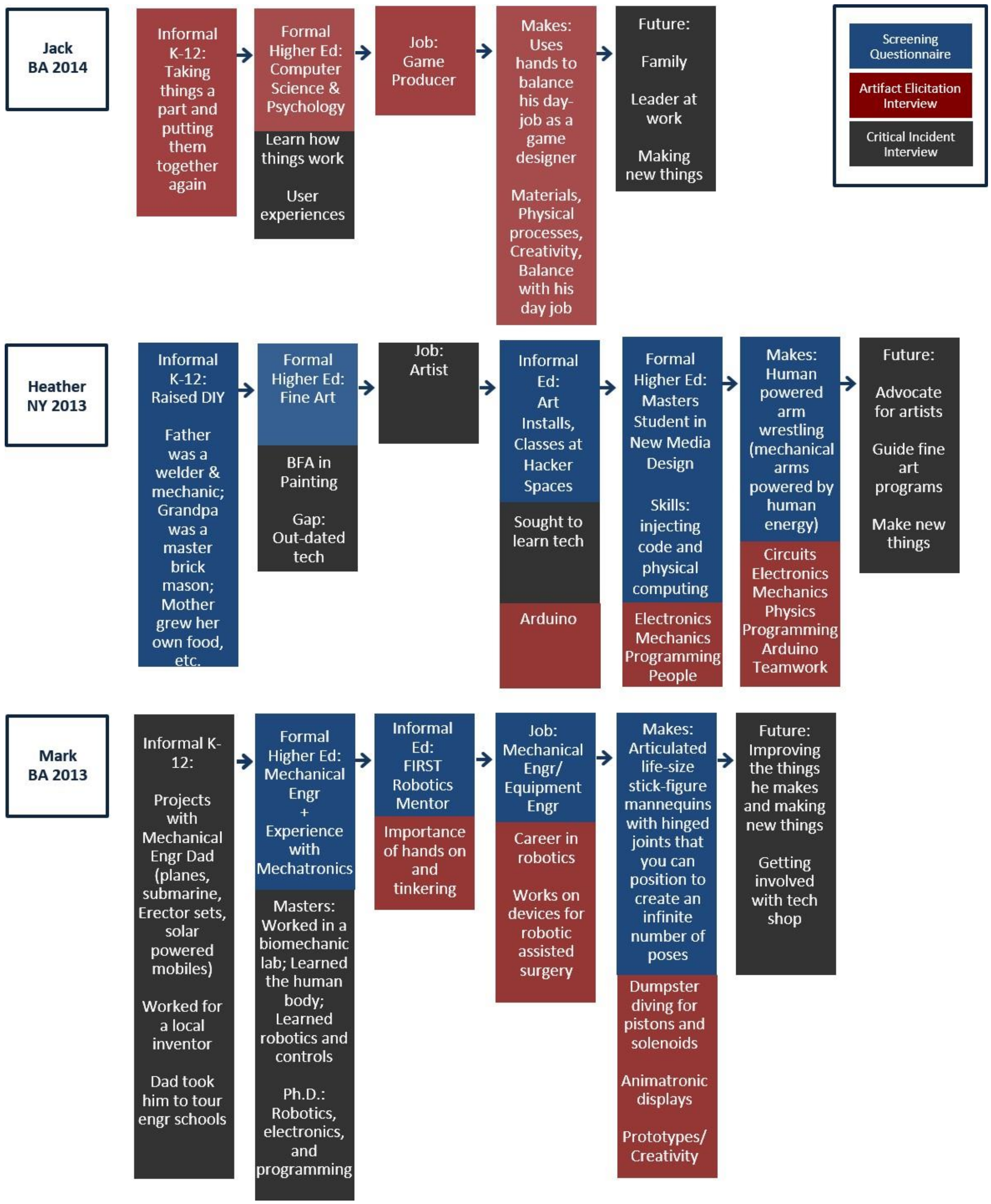

Figure 14. Parallel Pathways - Large Scale Interactive Artifacts

Maker Skills and ABET Results

Through the exploration of both young and adult maker interviews, it was seen that there was a substantial crossover between what the makers reported learning, or displayed as having learned for their artifacts, and engineering skills and education outcomes. These skills and outcomes are most clearly described by ABET Student Outcomes a-k, as well as ABET program specific skills. Understanding what knowledge makers are acquiring is relevant to understanding how the growth of makerspaces in universities can be leveraged to meet existing and future accreditation standards. To more clearly see how makers are meeting specific criteria important to ABET, the artifact elicitation interviews of adult makers and young makers were coded according to ABET Criteria 3 (Student Outcomes), the proposed changes to ABET Criteria 3 (to provide continuity should those proposals become permanent), and ABET Program Specific skills (those described for specific engineering disciplines) are discussed along with examples of coded interviews to provide a thicker context for the results.

The raw numerical results are shown below in *Table 18* to give the context in which the visualizations that follow are sited. The raw results are shown in separate columns for all makers combined, adult makers alone, and young makers alone.

Table 18. Raw Results of ABET Coding

ABET a-k	Total Sources	Adult	Young	Percent	CI
(a) Apply sci, eng, math knowledge	33	19	14	43%	11%
(b) Design and conduct experiments	8	6	2	11%	6%
(c) System design with constraints	29	14	15	38%	11%
(d) Function on multidisciplinary teams	20	13	7	26%	10%
(e) Identify and solve eng problems	22	12	10	29%	10%
(f) Professional and ethical responsibility	12	4	8	16%	8%
(g) Communicate effectively	60	32	28	79%	9%
(h) Broad education	35	22	13	46%	11%
(i) Lifelong learning	42	26	16	55%	11%
(j) Contemporary issues	9	4	5	12%	7%
(k) Use engineering tools	13	8	5	17%	8%
Engineering Experience					
Is an engineer (adult)	14	14	0	35%	14%
Wants to be an engineer (young)	18	0	18	50%	15%
Program Specific Criteria					
Electrical and Computer Engineering	43	19	24	57%	11%
Manufacturing Engineering	37	22	15	49%	11%
Mechanical Engineering	21	11	10	28%	10%
All - Science Fundamentals	20	10	10	26%	10%
All - CAD Skills	18	5	13	24%	9%
Computer Science Only	3	1	2	4%	4%
Biomedical Engineering	3	1	2	4%	4%
All - High Level Math Skills	2	0	2	3%	3%
N = 76, 40 adult makers, 36 young makers, population = 1000, 95% confidence level					

Below, these raw results are graphed and presented with the context of ABET accreditation criteria. Examples of individual young and adult makers' experiences are also included to provide a more in depth view of what and how makers are learning related to ABET criteria.

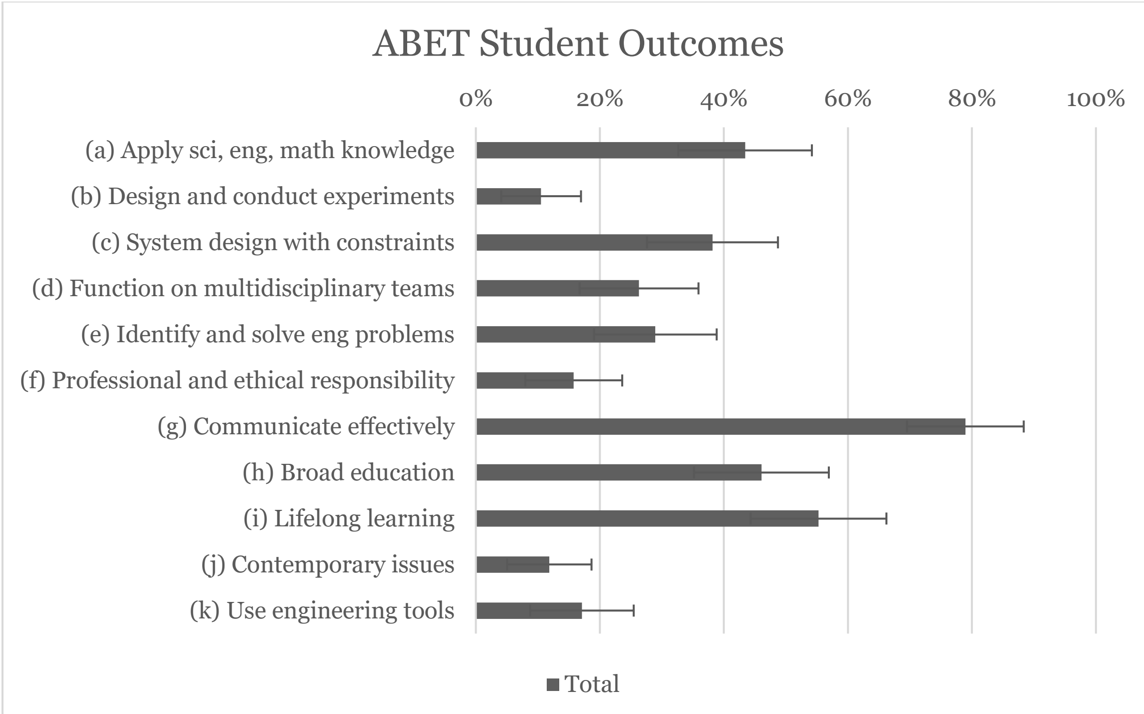

Figure 15. Student Outcomes – Combined Adult and Young

In Figure *15*, we can see that most makers exhibited effective communications skills. Almost 80% were able to clearly explain their technical project to a wider audience and/or mentioned specific cases where they effectively communicated in other situations. For example, one young maker designed a PowerPoint presentation and pitched an idea for a makerspace to his local school board. Another young maker produces a YouTube channel describing various science and engineering projects, has published a series of making books, and speaks regularly at maker faires on making and education. An example among adult makers is a group which communicate physics principles to an audience using a gigantic Rube Goldberg machine based on a children's game. Additional areas which makers are acquiring skills are lifelong learning, designing systems or projects within realistic constraints, and the application of science and engineering to solve problems. In the category of lifelong learning, most makers are highly adept at finding out how to solve problems by using internet searches, forming collaborative groups, and digging through existing literature to find solutions to help build their specific projects. The methods used by makers for finding project focused solutions are performed in a just-in-time fashion. When a project requires a solution, the maker finds out how to do it, applies the solution and moves on with the project. This ad-hoc method of contacting fellow makers, reviewing online sources, or forming groups to tackle a problem mirrors problem solving in a real-world environment. If makers were imagined as employees in a technology firm rather than hobbyists, this ability to solve problems outside of the baseline knowledge acquired in university would be strongly valued. This willingness and drive to learn and expand their knowledge is an example of the Maker Mindset's focus on growth through experience.

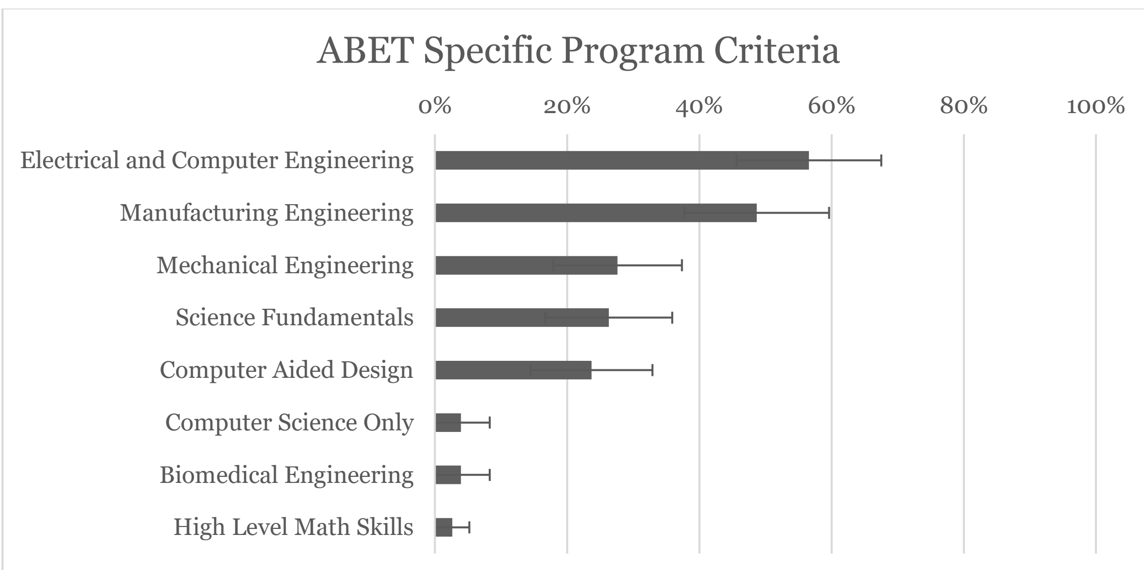

Figure 16. Program Specific Criteria – Combined Adult and Young

In terms of program specific ABET criteria, it is clear that makers are primarily learning the skills associated with building systems with hardware and software components, such as robots, drones, interactive games, and with fabrication techniques. It is worth noting that an area makers are strongly lacking in terms of engineering education is higher math skills. While our data collection methods did not specifically ask interviewees if they used higher level math in the creation of their artifact, only one interviewee mentioned calculus and polar coordinates as skills learned for their project. This suggests that to effectively use making as an educational tool, explicit mathematical elements may be needed during project creation or evaluation. Methods for doing so are further elaborated on in the conclusion and discussion sections of this dissertation.

In contrast to higher math, makers are learning a great deal about the integration of hardware and software components to form complex systems. Tony (pseudonym), a 14-year-old maker needed to identify and create a prototype solution for his final middle school project. He identified firefighting as a dangerous job which could be performed by robots. He then designed a prototype firefighting robot. This robot used a laptop running Linux to run pathing functions, which were then sent via WiFi to his foot-tall robot. The programs to drive the robot were written by him using Python and C. The robot itself was a combination of 3D printed and laser cut components with an Arduino board acting as the local brain for the robot. Mechanically, the robot used four two way wheels so it could navigate corners in a maze without turning. Finally, the robot had a fan attached which it would use to blow out a candle once it had been navigated to the "fire". Tony had analyzed his system and recognized weaknesses in his design; seeing what the robot saw on the laptop had a 30 second delay, stairs would be a problem for the robot, and a fan wouldn't work well on an actual fire. However, as a prototype, he considered it a successful starting point. To take his project to the next level, Tony recognized he would have to learn more about both programming and hardware. Two of our team's assistants, both juniors in electrical engineering, remarked on how this was a more impressive project than many of their classmates would create for a senior project. While Tony's artifact was particularly impressive, even for Maker Faire, and represented examples applicable to almost all of the a-k Student Outcomes and skills applicable to electrical engineering, it demonstrates how allowing a student to choose a problem they're passionate about, and then create a prototype solution can lead to an immense amount of learning.

It is worth noting that more than half of the makers interviewed built systems using software and hardware components, many used fabrication methods associated with mechanical and manufacturing engineering, and around ¼ of makers used CAD programs to design their artifact in 3D prior to creating it. This seems in no small part to be due to the increased accessibility of electronics and fabrication tools. Desktop 3D printers, laser cutters, and cheap, easy to program microcomputers such as Raspberry Pi and Arduino featured prominently in many artifacts.

With regards to pure computer science and biomedical engineering, it is either very uncommon for makers to engage exclusively in these categories or our sample size is insufficient to show a reliable estimate for what makers are learning in these areas.

In most cases, young and adult makers learned skills and behaviors applicable to ABET standards in roughly similar percentages. Though, adult makers, particularly those with engineering degrees, often displayed a greater technical depth of learning. This difference in depth however was more akin to what one would expect comparing first and second year engineering students to graduate students rather than comparing adults to children. Both populations showed high levels of technical prowess. However, there were a few notable exceptions where the two populations differed in percentage by more than the confidence interval of the combined data. These areas of major deviation are shown below in Figure 17.

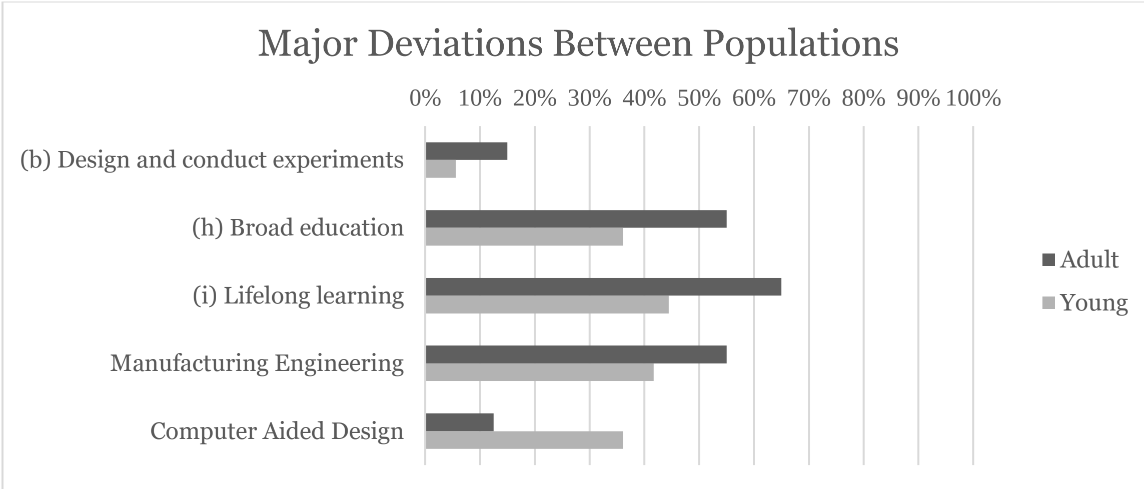

Figure 17. Statistically Significant Deviations Between Young and Adult Makers

Some of these differences, like broad educational experiences and lifelong learning, are unsurprising. Adult makers have, during the course of their lives, been exposed to more levels of education and greater variety in terms of career and experiences than makers 30 years their junior. Two areas of importance however are found in designing and conducting experiments and computer aided design. Older makers were much more likely to see themselves as conducting experiments through their iterative design process than young makers. I hypothesize that this is due to the more formal exposure to the scientific method that adults would have received in college. This finding could also be interpreted as suggesting that making could be a form of scientific inquiry in the classroom if students were guided in the process. Finally, more than twice as many young makers explicitly mentioned using computer aided design tools in their projects. In many cases, this seemed to be due to being formally introduced to tools such as SketchUp or TinkerCAD in the classroom. The early introduction of CAD software to young makers could set them up for success when they are introduced to such programs again in a college setting.

The Maker Mindset and maker skills are equally applicable to the proposed ABET Criteria for Student Outcomes. For the purposes of this study, as discussed above, the proposed revisions for ABET Student Outcomes can be seen as a combination of existing a-k standards. Where makers appear to shine under the revised Student Outcomes are communications skills (4), the application of technology to solve problems in a social context (1, 2, and 5), and their ability to engage in self-directed learning (6). When taken as a whole, makers are learning to identify and solve problems they care about using technology.

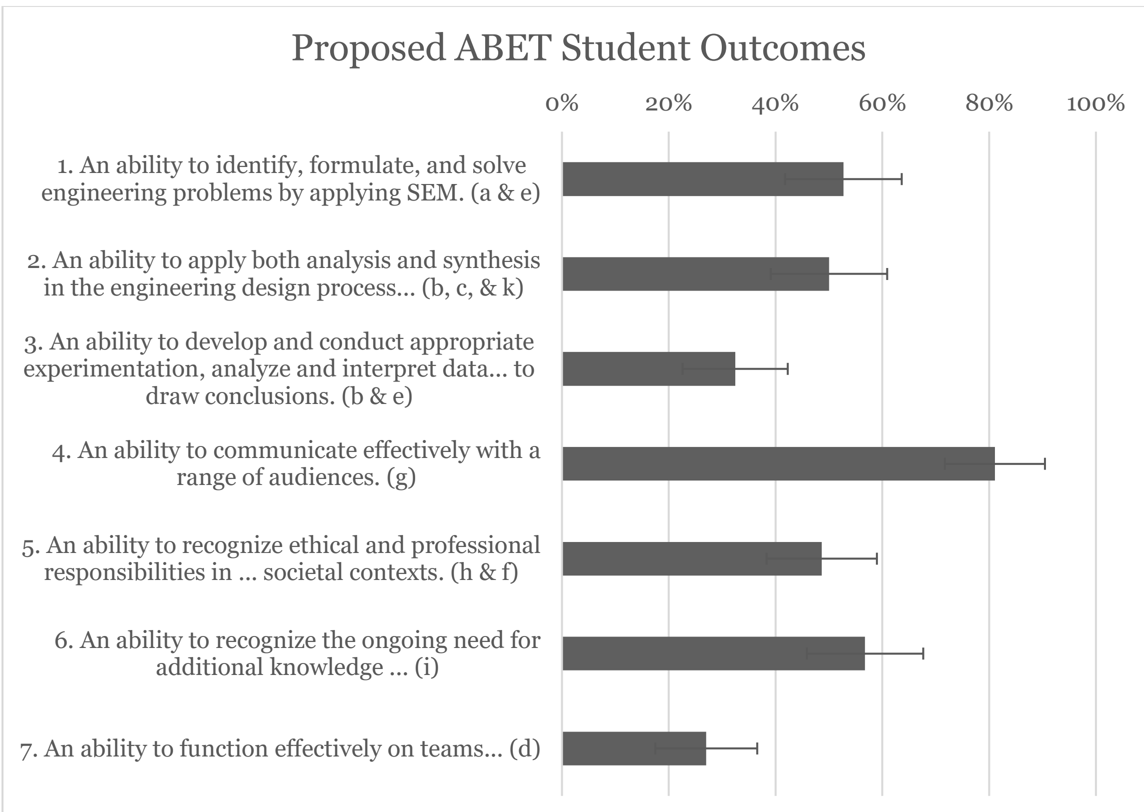

Figure 18. Results for Proposed ABET Student Outcomes

Finally, the maker community is formed of many current engineers as well as future engineers. Nearly half of our adult participants either had been trained as engineers or are currently working in an engineering field. Some of the participants identified making as the hobby that allowed them to renew their love of engineering or inspired them to learn additional engineering skills outside of their original area of training. For example, after retiring from an electrical engineering career, Matt learned 3D design and prototyping to create a Rube Goldberg style amusement park for plastic frogs. Ray on the other hand was trained as a mechanical engineer, but learned about fluids, programming, and web interfaces to create a web-based watering system for his garden. Furthermore, this large percentage of adult engineers in the making community provides a social mentorship network which young makers are able to tap. Fifty percent of young makers identified engineering or computer science specifically as their major of choice going forward into college. These pre-engineering makers will likely enter their programs with an expectation that project based learning will be part of their education.

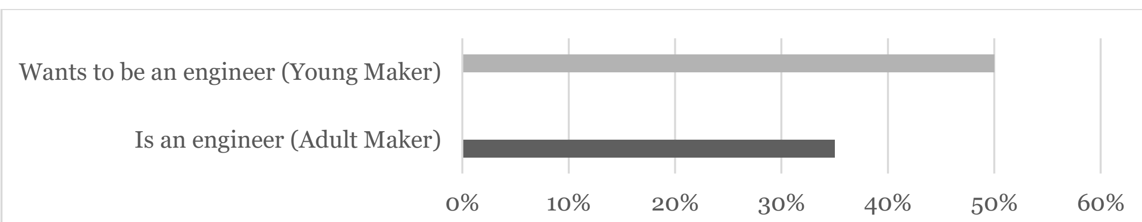

Figure 19. Engineering Training Responses

Summary of Findings

A total of 42 adult makers, 51 young makers, and 33 parents of makers participated in this research. Their ages ranged from 7 to over 60, 40% of makers were female with a similar percentage of minority participants. During the open coding portion of this research several broad trends emerged about adult makers. First, they come from a very wide range of backgrounds, both in terms of careers and education, with art (~15%) and STEM (~25%) backgrounds being the most prevalent. A high degree of entrepreneurial activity was also seen with almost 20% engaged in entrepreneurial ventures. The artifacts created by adult makers ranged from 3D printers to toothpick sculptures. Two categories, musical artifacts and large scale interactive artifacts, were explored in greater depth to present the life and education pathways taken by each of the six makers in these two categories. Each maker displayed a unique pathway of education and career experience.

Young and adult maker interviews were sorted using ABET accreditation student outcomes and program specific skills as codes. For ABET student outcomes, based on each makers' experience creating a single artifact for presentation at Maker Faire, it was found that 79% learned effective communication skills, 55% demonstrated strong lifelong learning skills, 46% displayed a broad basis of education including technical and non-technical fields, 43% applied STEM knowledge for problem solving, and 37% engaged in system design with constraints. Participants also showed experience with identifying and solving engineering problems, 29%, and functioning on multidisciplinary teams, 26%. In terms of program specific knowledge, 57% used skills associated with electrical and computer engineering, 49% used skills related to manufacturing engineering, and 28% utilized mechanical engineering knowledge in the creation of their artifacts. Finally, 50% of young makers were interested in becoming engineers and 35% of adult makers interviewed either were, or had trained as, engineers.

These findings will be referenced and discussed further in the next chapter. There, the findings will be placed in the broader context of higher education and the future of work.

CHAPTER 5

ANALYSIS AND INTERPRETATION OF FINDINGS

In this chapter the findings presented in chapter 4 are given meaning and context both as individual units of analysis and with each other. Both the explorations, the maker learning pathways and ABET accreditation and maker skills, provide a wide range of details about makers, the maker movement, and education for the future. Each section of analysis will first be discussed in terms of what it means individually and then at the end of this chapter in context with one another and the visioning documents introduced in the literature review.

Pathways Analysis and Interpretation

The maker pathways portion of this dissertation's data lends itself to several forms of analysis. First, it presents a guideline for how to conduct further research on learning pathways that may be of use to other researchers studying education among adult populations. Beyond the methodological implications I will also discuss the specific relation the learning pathways data holds with engineering education. As this portion of analysis was originally conceived as part of an exploration of making and engineering education the analysis here will reflect that. The specific learning pathways findings will then be discussed as they relate to higher education more broadly in the third section of this chapter.

Studying learning pathways. Identifying appropriate methods for studying pathways remains a challenge and in the case of the makers. Their pathways are nuanced, non-linear, and includes pivots due to defining life events (e.g., engineer to entrepreneur). Utilizing a qualitative research approach of constructivist thematic analysis with the instruments of artifact elicitation interview methods and critical incident interview methods is a useful contribution to telling the story of one's life path and provide a deeper look at the knowledge and skills that are learned by an individual.

The investigation of learning pathways seems to be most effective when a multi-scalar data collection approach is taken. Screening questionnaires provide demographic data, basic descriptions of education milestones, and career identity. The artifact elicitation interview unveils what specific skills were used in the creation of the artifact and how the learner developed those skills. Finally, the critical incident interviews provide a rich narrative of each maker's experiences. With each stage of data collection, there was something to be learned about the makers' pathways. This was useful in understanding the breadth of makers' pathways and how they overlap with one another and intersect with engineering.

The screening questionnaire was useful in unearthing the major milestones along the individual's pathway (e.g., degrees, clubs, and what they make). However, the responses from the screening questionnaire provided no context for making. With this data set alone, individual pathways might have looked linear (e.g., an engineering major working in a technical field) and overlooked other important events and turning points in the pathways. The artifact elicitation interview provided a context for the makers' pathways. By providing an opportunity to conduct a live-action interview (i.e., interviewing the maker with their artifact), we (the maker research team) were able to ask probing questions about the artifact and the knowledge, skills, and attitudes that the maker learned from making. By watching the maker operate and showcase their artifact, we gained an understanding of the functionality of the device and technical and non-technical components, which informed probing interview questions. From the probing interview questions, makers had the opportunity to bring up experiences they have had in their pathways (e.g., examples of learning knowledge and skills through self-directed learning and informal education activities). The setting for artifact elicitation interviews was exciting. The Maker Faires were filled with people that had enthusiasm for the artifacts. Makers were ready to show their artifact and interact with the public. These interviews could only last fifteen minutes in order to be respectful of the participants' time and allow them to interact with other attendees. The critical incident interview further extended our understanding of the makers' pathways by providing an opportunity to ask the makers to walk us through their critical points in their life (e.g., education, career, and future aspirations). By conducting this interview via Skype, the makers could give more of their time to responding to questions and could elaborate upon their pathways to making.

From this combination of methodological tools, we only get a snapshot, though a very detailed snapshot, of one of artifact at one point in time. The critical incident interview is in relation to this one artifact and does not provide a fully fleshed out life history. However, when aggregated, these snapshots form a broader picture which describes the community of makers in a useful way and allows us to see possibilities for broadening engineering pathways.

Learning pathways, making, and engineering education. Making can offer valuable insight into how to identify practices that promote the access and success of a larger and more diverse population of students within engineering. Opportunities may exist to export interview techniques for other uses. Analyzing the ways in which entrepreneurs develop products could be interviewed to better understand the values and skills behind product development or robotics engineers could be interviewed to gain insight into how they understand the creation of a robot. Combining this with critical incident interviews could offer new insights that relate to new opportunities for pathways into engineering. The life pathways of makers can begin to change the conversation to highlight the efficacy and the possibility for those who are engaged in making and seeking meaning and impact through their studies.

Adult makers show us that engineering is often not a binary category where one is either an engineer or a non-engineer. Instead we see a wide range of actors with widely varying skill sets engaged in engineering activities. More importantly, we see non-engineers valuing engineering expertise and knowledge in new ways through the lens of making. Likewise, engineers are either discovering new outlets for their existing engineering skills or learning new engineering and non-engineering skills in pursuit of their passions. While this work is still preliminary, it may showcase some ways in which engineering education can be enhanced to better reach the goals outlined in *The Engineer of 2020*. If adults are finding interdisciplinary projects framed by personal interest as a way of learning practical ingenuity, creativity, and some analytic skills, perhaps there is a way educators can harness student passions in a similar manner to achieve similar results. Furthermore, the interest shown by non-engineers for learning engineering as adults, along with existing engineers expanding their scope of knowledge could have ramifications in the adult education sector. Perhaps there is a currently unmet demand for adult education in engineering, which could be met by existing universities offering, for example, night courses on circuits for non-engineers. And, as demonstrated by the quote:

> *"If I had had somebody actually advising me when I was getting out of high school and going to college and I knew engineering as a career, I might have been an engineer to be honest, because I love engineering as a concept of being aware of your world and being in your world."*

Engineering is perhaps being presented to young adults in a way that obfuscates the creativity and impact that engineering can have on the world around them. When adult artists suggest they would have chosen different career paths if they had been presented with engineering as a creative career which embraces practical ingenuity, ethics, and communication as well analytic skills, then there is perhaps a better way going forward to market engineering to incoming students.

Through an in-depth exploration with qualitative inquiry, a new perspective is offered that can inform us of how access to engineering from qualified learners may be improved. Makers are self-directed learners and have diverse technical and non-technical backgrounds; many may be qualified to enter engineering majors. The study of maker unveils opportunities and new dimensions for access and migration to engineering. A more inclusive vision of engineering crossed with making could build future engineering capacity as well as raise awareness to the general public of the work and impact such work offers.

The pathways presented in this study are far different than what many early engineers imagine. Instead of a linear progression of high school to college to work to professional engineer qualification to retiring someday, these pathways show that engineers can be much more broadly interdisciplinary and engage with multiple fields, both within engineering and with disciplines such as art or business. Engineering is often perceived as an activity lacking in creativity and, for some, meaning. However, interdisciplinary interactions with engineering can show adults, and presumably youths, that engineering is a creative way to interact with and affect the world around you and could be a way to improve access to engineering. These pathways show that engineering may be approachable for non-engineers involved in making and technical activities. The examples of maker pathways could be used as example stories for how students may pursue engineering in the future.

The stories and life pathways of adult learners engaged in making can offer valuable insight into how we might identify practices that promote the access and success of a larger and more diverse population of students. We do not equate engineering students, practicing engineers, and makers completely but find the possible overlaps and stories of pathways within to be possible for transformational change in our field. Makers are engaged in activities that embody the Engineer of 2020 (e.g., lifelong learning, creativity, and practical ingenuity). By studying makers, we can consider the multiplicity of pathways into engineering majors and careers.

Maker skills and ABET Analysis and Interpretation

Making can be considered an example of open ended, student led project based learning and can provide a useful template for teaching some ABET applicable skills and attitudes. The findings in chapter 4 demonstrate that ¾ of makers are learning how to communicate technical details to a wider audience, ½ are learning valuable techniques to foster lifelong learning, ½ are learning how to apply engineering knowledge to solve problems, ½ are learning specific skills applicable to electrical engineering and manufacturing engineering programs, ⅓ are working on multidisciplinary teams, and ⅓ are designing systems with realistic constraints. Each of the above categories is part of ABET's accreditation process for engineering programs.

Making, in the context of student led project based learning, is producing young people and adults who possess valid engineering skills which are applicable to ABET accreditation. The Maker Mindset, with its focus on celebrating failure, learning through hands-on iteration, and collaboration between makers could well be adopted in some engineering courses to instill many of the ABET Student Outcomes as well as program specific criteria for electrical, mechanical, and manufacturing engineering. Specifically, the ability of making as a form of project based learning to instill a high level of communications ability, strong collaboration skills, the ability for self-directed learning, and perseverance is valuable to traditional engineering programs. This value remains, in an accreditation sense, whether or not Student Outcomes are revised as proposed. Additionally, maker faires and artifact elicitation interview protocols themselves offer a possible way for engineering educators to harness the Maker Mindset for their students. In a student driven, project based course, a mini-maker faire, the equivalent of an art class's final exhibition, combined with professors asking probing questions on the skills learned in the creation, successful or not, of a student's artifact could lead to successfully accomplishing ABET Student Outcomes. While perhaps more time consuming than a multiple-choice test, an instructor can clearly determine what skills were used in the creation of an artifact through a semi-structured interview with the student.

This is not to suggest that making should entirely replace rigorous engineering training. As the data presented in this dissertation shows, there would be a clear need for the purposeful integration of higher level math into project based making. Making alone does not appear to teach the math skills needed for today's engineer. The integration of higher mathematics into making could come in the form of post-prototype write-ups. Engineering students could, as often occurs in professional product engineering settings, create and test rough prototypes of their ideas, then, once a working model is established, dig further into the design by creating mathematical models for the object in terms of durability, cost, efficiency, etc. Future research on how to best integrate the qualities of a Maker Mindset with traditional engineering courses remains to be done, but the benefits of doing so are compelling.

Making and the Future of Education

Both the exploration of maker learning pathways and the exploration of maker skills were originally designed with engineering education specifically as their target. However, when taken in context with the desired learning outcomes seen in P21's 21st century skills and Learning 2030's Habits of Mind, it becomes clear that making has something to offer education much more broadly.

Table 19. A Comparison of Visions for Learning

ABET	Learning 2030 Habits of Mind	P21 Learning Framework	Engineer of 2020
a) Apply STEM knowledge		ICT Literacy	Strong analytical skills
b) design and conduct experiments	Questioning and posing questions	Make judgements and decisions	Strong analytical skills
c) design systems with constraints	Striving for accuracy and precision	Use systems thinking	Strong analytical skills
d) multidisciplinary teams		Work creatively/ collaborate with others	
e) identify and solve engineering problems			Strong analytical skills
f) professional and ethical responsibility	Taking responsible risks	Life and career skills	Leadership and High ethical standard
g) communicate effectively	Thinking and communicating with clarity	Communicate Clearly	Communication
h) broad education	Gathering data through all senses	21st Century Themes	Practical ingenuity
i) lifelong learning	Learning continuously	Life and career skills	Lifelong learners
j) knowledge of contemporary issues	Thinking flexibly	21st Century Themes	
k) use modern engineering tools		Apply technology effectively	Strong analytical skills
	Creating, imagining, and innovating	Creativity and Innovation	Creativity
	Persisting		Dynamism, agility, resilience, flexibility

From the findings on ABET and Maker skills, we can see that makers are learning, often through the creation of a single artifact, skills and attitudes that are applicable to the future of education. Traits like strong communications skills, critical thinking skills, lifelong learning, and the application of technology for problem solving can be seen across the visioning documents framing this dissertation. Other traits displayed in the maker mindset, failure positive learning and a sense of play, also map nicely to the desired outcomes envisioned in Learning 2030.

The adult pathways study provides an in depth look at the learning and career paths of six different makers. The number of data points here is too small to make gross generalizations, but it is clear that these makers, and many of our other interviewees experience education as a series of loosely connected events rather than a linear pathway. For these makers, they have altered their life paths based on their interests, often learning new skills or returning to previously learned skills later in life. Their experiences strongly reinforce the image of what a growth mindset looks like over time and what a lifelong learner is.

While in some ways making is little more than learner led project based learning, the Maker Movement has managed to capture a large audience's imagination and interest in technology and learning. Universities, schools, communities, and libraries are all creating makerspaces with the intent of engaging makers for many years to come. However, to sustain the Maker Movement as an educational tool requires more than mapping it to existing accreditation criteria. The practical methods of integrating aspects of making into existing education programs, whether as formal courses, extracurricular activities, or both remain to be explored. Some recommendations will be presented in the following chapter.

Summary of Analysis and Interpretation

The data presented in the previous chapter was interpreted in several ways. The work on learning pathways presented two major results, one in terms of analytical methods and a second in terms of making and education. Analytically, the pathways research shows that using multi-scaler instruments in the form of a screening questionnaire, an artifact elicitation interview, and a follow-up critical incident interview provide an incredibly nuanced snapshot of a makers learning pathways, skills, and experiences. This technique could be replicated in other situations where a nuanced view of learners is required. A second result of the pathways research is that, while the makers interviewed shared much in common with engineers in terms of education, careers, and attitudes, the lived experience of those shared traits was not in the linear fashion most engineering students imagine for themselves. Instead, the six makers described learning pathways that show that being "an engineer" is not a binary quality. Instead a wide range of actors engage in engineering and engineering like activities through their experiences making. This new perception of what an engineer does and who an engineer is could lead to new opportunities such as opening the doors of engineering education to adults who are interested in making or changing the narrative presented to young people who are interested in engineering to highlight engineering's creative aspects.

From comparing maker skills to ABET student outcomes resulted in a demonstration of the value of making experiences to engineering education. This comparison demonstrates that ¾ of makers are learning how to communicate technical details to a wider audience, ½ are learning valuable techniques to foster lifelong learning, ½ are learning how to apply engineering knowledge to solve problems, ½ are learning specific skills applicable to electrical engineering and manufacturing engineering programs, ⅓ are working on multidisciplinary teams, and ⅓ are designing systems with realistic constraints. These traits, when compared more broadly to visioning documents on the future of education, show a wide range of similarities, which suggests aspects of making could be invaluable for reaching the goals desired for the 21st century learner.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Making is an education methodology that can prepare students for a future where collaboration with technology is vital for success. While making can be seen as a broad description for student led project based learning with an emphasis on technology, the benefits of this style of learning are in the mindset created rather than the explicit skills developed. Through making experiences, successes and failures, learners embrace the lifelong learning strategies and broad technological familiarity required to become resilient citizens in a technologically complex future. Adult and Young makers are developing lifelong learning strategies, technical skills in fabrication and electrical and computer systems, communication skills, and developing resilience in terms of experiencing and growing through failure. Though, for the purposes of present day engineering accreditation, the most important finding in this dissertation is that those involved in the Maker Movement are learning both technical skills and the softer skills that will be required for the 21st century. Making offers clear benefits to engineering education in the form of meeting many of ABETs student outcomes. Furthermore, makers exhibit many of the traits seen as vital by education organizations as suggested in their visioning documents. Whether the document of analysis is from a national academy, an independent accrediting organization, a public private partnership, or a group of education experts, making shows itself as an effective learning tool.

Making may offer a new way, or at least a new veneer on an old way, to educate students in hard to learn areas like lifelong learning and critical thinking skills, but determining what methods are most effective will likely take a variety of long term studies. While this research clearly shows that makers are learning valuable skills in terms of reaching future education goals and present day engineering requirements, additional questions are also raised. However, as making exists now, it is part of a movement, part of a social phenomenon outside of, or at best adjacent to, formal education. This brings us to the main challenge in making, how can it be best integrated into education more broadly, and for this dissertation, higher education specifically. While this dissertation has thus far focused on performing the empirical work required to show that maker do exhibit strong learning outcomes, much work remains in describing how those outcomes can be achieved more widely.

Many stakeholders are involved in education systems, from government actors at the state and federal level to individual instructors and managers of campus makerspaces. Each of these actors face particular challenges with regards to how and if they should integrate making into their work. Below I will briefly discuss some of these actors and their challenges in terms of future research that could be undertaken to better understand the intersection of making and higher education. Drawing from interview data and personal experience during participant observations, I will present several recommendations on how to integrate making into higher education. These recommendations are informed by the rest of the scholarship presented in this document, but would require their own studies to verify. The following recommendations can be seen as future areas of inquiry for those interested in making and education.

Recommendations and Future Areas of Inquiry

The primary challenges facing institutions revolve around how to integrate and develop makerspaces and how to reframe education to meet 21^{st} century goals. Integrating makerspaces more effectively is important for departments and individuals that have already, or are in the process of creating spaces for maker education. In contrast, reframing education to prepare students for work in the 21st century is a challenge for university administration and government institutions focused on education. These two issues, the integration of spaces and integrating making to reframe education to meet tomorrow's challenges are explored below.

Makerspaces in higher education. For universities, the primary challenges are how to, and how much should they, integrate making and makerspaces into the formal curriculum and formal education activities and how to staff makerspaces. Many of the university makerspaces I have visited have essentially used a philosophy of "If we build it, they will come", which has had varying, and usually very low, levels of success. In public and commercial makerspaces, a space can open and judge its success by whether it continues to have enough funds to operate. Of the 2149 hackerspaces listed on hackerspaces.org, only 1335 are currently marked as active, most of the difference represents spaces that opened, tried, and closed (hackerspaces.org, 2016). Most university makerspaces do not charge students membership fees and instead justify their existence by the number of students using it on a regular basis. However, without a means of formally introducing students to the space, and ensuring their return to the space, attendance often dwindles over time or is reliant on a core group of maker students who, being students, eventually graduate. From my experience the most successful makerspaces on campuses are those that house courses across disciplines, regularly hold events, are aggressively marketed on campus, and ideally include at least one day on the schedule for first year student orientation, insuring that all students have at the very least visited the space. While makerspaces should also allow for informal making throughout the day, in all but the most entrepreneurial, or artistically, motivated environments, formal integration is much more likely to insure the space remains in operation. One of the great challenges with formal integration of a makerspace is that it requires either existing faculty who are willing to learn, and teach or co-teach, new skills, or the hiring of new faculty to operate specifically as team teachers who partner with existing faculty to add a hands-on, project based dimension to existing courses.

Makerspace staffing faces similar challenges in a university environment. Often, these spaces are staffed by student workers. While these workers are often students with a strong interest in making, they may also be hourly employees who require a great deal of training, both on the tools of the space as well as how act as mentors for fellow students interested in making. An engaged student worker can be an ideal employee until they graduate, but student workers can also inadvertently foster an environment that is hostile to many students through unconscious bias. From interviews and observations of makerspaces, it was often clear that makers can be cliquish and off-putting, particularly to women, minorities, and those with little existing technical expertise. An example of how to overcome these issues can be seen at TechShop. TechShop is a for profit commercial makerspace with 11 locations in the US, including a makerspace partnered with Arizona State University. In their model, they have staff on hand who are trained in the use and safety of all shop equipment. These staff are called Dream Consultants and their primary job is to help members of the space feel welcome and explore and realize their project goals. In a university makerspace, student workers or other hired staff could go through a training program like TechShop's dream consultants, albeit with additional training on understanding diversity and bias, to make university makerspaces more welcoming to students. These workers could provide additional university value by helping faculty with fabrication for research needs.

State and local governments may also be interested in how making and makerspaces are situated and developed within campuses, particularly for state universities. Making, with its focus on technological exploration and experimentation, is often an apparent catalyst for entrepreneurial activity. For state and local governments, campus makerspaces can be part of an ecosystem of entrepreneurial activity and support platforms. By incentivizing campuses to create makerspaces that are accessible to alumni and the surrounding community governments can participate in the creation of local innovation clusters, where graduating students may stay to continue prototyping their product ideas or potentially open the door to collaboration between university students and local business. So far, very few examples of such collaboration exist, such as Arizona State University's TechShop collaboration with the city of Chandler (ASU Now, 2014) or Case Western Reserve's Sears think[box] (Case Western, 2015) both of which are open to all students as well as the public. Additional research on these collaborations between universities and their surrounding communities could lead to new ways of spurring innovation and economic growth on a state and local level.

Reframing education for the 21st Century. The makers interviewed during this study are acquiring skills and traits that are useful for learners in the 21st century and that apply to engineering education goals. However, these makers are doing so through self-guided exploration on a project by project basis. Translating makers' methods of inquiry to a formal learning environment is a challenging subject. Here, it is valuable to focus on the how aspect of maker learning rather than the what. The how of maker learning describes the approach used by makers when they encounter an idea, project, or problem that inspires them to action. Makers, both young and adult, described their learning process in similar ways. These two ways can be described as problem focused and tool focused. In the problem focused method, makers had an issue they wanted to solve and they explored through iterative processes and physical prototypes how to solve it. In the tool focused method, they started with a tool, for example a 3d printer or an Arduino, and just wanted to play around and learn how to use it. In either case, a maker would usually spend a short period of time deciding what they were going to try first, followed by an often failed attempt, followed by a refining of the original idea, often with input from members of the maker community or through engaging with online learning tools. Prototyping, reflection, collaboration, information gathering, and a return to prototyping was a commonly followed pattern. Through the process, the maker would either learn to solve a problem or learn to use a tool. To translate this format to higher education would require more open ended exploration in classes and a greater focus on the process over the product. This format however requires greater instructor comfort with ambiguity and new assessment techniques (perhaps artifact elicitation exams?). A halfway point to pure maker learning could also be explored and may be applicable to courses that require no physical artifacts at all. This halfway point to maker learning includes student led inquiry within a defined realm. For example, one could allow term papers on entirely student decided topics, require that an object be built that incorporates certain types of circuits but that is otherwise open to student design choices, or for a history course require a sketch and narrative of a monument to a historical figure. In each case, student choice and open exploration into areas the instructor might not be an expert in are present. These sorts of student led explorations focus on the acquisition of lifelong learning skills, collaboration skills, and critical thinking within a more complex system. An example syllabus for a course that would encourage open ended student exploration can be found in Appendix B. Other ways institutions could engage students in maker style learning could be through student or faculty participation in programs like the NSF I-Corps (NSF, 2017), which focuses on entrepreneurship and iterative prototyping through customer interviews, or through sponsoring students to engage in extracurricular programs like the University Innovation Fellows, a Stanford based program to turn students into agents of change on their campuses (Britos Cavagnaro & Fasihuddin, 2016).

Attempts at reframing higher education to foster a maker mindset face several challenges. Making as a pedagogical method, with its focus on learning through the creation of objects, generally requires a higher faculty to student ratio, smaller class sizes, and material expenses for hands-on prototyping. The previously stated factors are in direct opposition of most universities' focus on increasing class sizes and expanding web-based digital courses. The tension between serving as many students as possible as inexpensively as possible and preparing students in a rigorous hands-on manner with a great deal of faculty input are not unique to making, but are particularly visible when compared to traditional lecture style learning. To relieve this tension, it may be helpful to separate the goal of instilling a maker mindset from the broader lessons of the Maker Movement. While the Movement focuses on hands-on project based learning with physical artifacts as the output, integrating parts of the maker mindset might be achieved through open ended project based learning with digital artifacts, such as code or 3D models, as the output. Instead of faculty intensive facilitation, such a digital maker model might include instead a curated selection of how to videos and internet guides which students could explore on their own when encountering difficulty. While some of the experience and physicality might be missing, a more digital model could potentially reach a much larger audience. A second challenge comes in the form of government and university support for both the Maker Movement and makerspaces. While the Obama administration strongly supported the Maker Movement publicly, the National Science Foundation was similarly funding a wide range of research on making and makerspaces. Uncertainties with funding on a national level could lead to less interest, or at least less paid interest, among academics focused on enhancing university education with lessons from the Maker Movement. With regards to university administration, if university makerspaces are not well integrated into courses and program curricula more broadly, attendance at such spaces could fall to a point where the university is no longer interested in funding the space. Similarly, if attendance in makerspaces falls due to a lack of inclusivity or bias against students from diverse backgrounds, the space could also fail.

Final Remarks

Finally, there are serious areas for concern about how making intersects with issues of diversity, inclusion, gender, and inequality both across and within disciplines and spaces. While makers, both within and outside of academia, often consider the Maker Movement as open and inclusive, there appear to be systemic issues with how male makers view women in making. Often, women and minorities face unconscious discrimination in the form of assumptions on what tools they may wish to use, i.e. sewing machines for women, or what their existing level of expertise may be (Davies, 2017). For successful university integration, these unconscious biases against women and minorities will have to be addressed. The challenge of determining how to best develop a Maker Mindset among students in fields outside of those that typically engage in prototyping and technological tinkering will also be vital to continuing integration of making and higher education. To insure making does not become merely another resource intensive way of preparing white men to enter industry in Silicon Valley, significant thought and care must be taken with how it is integrated more broadly into higher education.

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APPENDIX A

PARTICIPANT CONSENT AND ASSENT FORMS

MIGHT YOUNG MAKERS BE THE ENGINEERS OF THE FUTURE?

Dear Potential Participant:

Dr. Shawn Jordan and Dr. Micah Lande, Assistant Professors in the College of Technology and Innovation at Arizona State University (ASU) invite your participation in a research study.

The purpose of the research is to understand the knowledge, skills, and attitudes possessed by Young Makers. In addition, this research seeks to understand how life pathways of Makers intersect with formal engineering education experiences.

We are inviting your participation in this study because your child is a Young Maker and is participating in this study. If you agree to participate in the study, you will be asked to participate in an interview in person or by videoconference to describe how you support your child in making and your attitudes about making and engineering. Participants can skip questions in the study at their choosing. The total time for participation in this study will be less than 4 hours and a $25 gift card will be compensation for your participation. Approximately 80 subjects will be participating in this study nationally. If you choose to participate, then you will join a study funded by the National Science Foundation involving research to understand Young Makers and the Maker community.

You the right not to answer any question, and to stop the interview at any time. Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty.

Although there is no benefit to you, possible benefits of your participation are that the results of this study may transform the conversation of who the engineer of the future could be, linking “making” with engineering the same way that students who excel in science and math are pointed toward engineering by parents and career counselors. We aim to illuminate pathways for Young Makers to become the engineers of the future. There are no foreseeable risks or discomforts to your participation.

All information obtained in this study is strictly confidential. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, the research team will replace yours and your child’s name in the data with a unique identifier code. A master file linking the unique identifier code with your identity will be kept in a secure location at ASU. Should you drop out of the study, your information will be destroyed immediately.

We would like to record this interview. This may include audiotape, videotape and photographs. The interview will not be recorded without your permission. Please let us know if you do not want the interview to be audiotaped, videotaped or photographs taken; you also can change your mind after the interview starts, just let the interviewer know.

Raw audio and video files will be stored on secured digital storage devices and housed in a separate secure location at ASU. Access to these data will be limited to Dr. Shawn Jordan and Dr. Micah Lande, and the research team responsible for analyzing these data. Consent is sought to grant the research team the right to use video and audio from your interviews when presenting and publishing this research, and on a website (makingengineers.com). Without said consent, all audio and video files will be destroyed by December 31, 2015.

By initialing below, you are granting to the researchers the right to use your likeness, image, appearance and performance - whether recorded on or transferred to videotape, film, slides, and photographs - for presenting or publishing this research (or for whatever use).

_____I agree to be videotaped

_____I agree to be audiotaped

____I agree to be photographed

The information is strictly confidential unless you give us consent to identify you.

____I agree to allow the researchers to reveal my name

The research team may also seek to follow up with additional questions as part of continuing research efforts. We may want to contact you in the future for additional research.

____I consent for the researchers to contact me for future research by ___Email or ____Phone

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be part of the study.
Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Dr. Shawn Jordan, (480) 727-1405, Shawn.S.Jordan@asu.edu or Micah Lande, (480) 727-1063, Micah.Lande@asu.edu, or their address is 7171 E. Sonoran Arroyo Mall, Mesa, AZ 85212.

By signing below you are agreeing to participate to in the study.

____
Signature

____
Printed Name

____
Date

MIGHT YOUNG MAKERS BE THE ENGINEERS OF THE FUTURE?
PARENTAL LETTER OF PERMISSION

Dear Parent:

Dr. Shawn Jordan and Dr. Micah Lande, Assistant Professors in the Fulton Schools of Engineering at Arizona State University (ASU) invite your participation in a research study.

The purpose of the research is to understand the knowledge, skills, and attitudes possessed by Young Makers. In addition, this research seeks to understand how life pathways of Makers intersect with formal engineering education experiences.

If you decide to allow your child to participate, then your child will join a study funded by the National Science Foundation involving research to understand Young Makers and the Maker community. A screening questionnaire will determine your child's eligibility to participate in the study. If selected and you say YES, your child will be asked to participate in an interview in person or by videoconference to describe one or more of your inventions and talk about how your life pathways have or have not intersected with formal engineering education. Participants can skip questions in the study at their choosing. The total time for participation in this study will be less than 4 hours and a $50 gift card will be compensation for your child's participation. Approximately 40 subjects will be participating in this study nationally.

Your child has the right not to answer any question, and to stop the interview at any time. Your child's participation in this study is voluntary. If you choose not to participate or to withdraw your child from the study at any time, there will be no penalty.

Although there is no benefit to you, possible benefits of your child's participation are that the results of this study may transform the conversation of who the engineer of the future could be, linking "making" with engineering the same way that students who excel in science and math are pointed toward engineering by parents and career counselors. We aim to illuminate pathways for Young Makers to become the engineers of the future. There are no foreseeable risks or discomforts to your child's participation.

All information obtained in this study is strictly confidential. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, the research team will replace your child's name in the data with a unique identifier code. A master file linking the unique identifier code with your identity will be kept in a secure location at ASU. Should your child drop out of the study, your information will be destroyed immediately.

We would like to record this interview. This may include audiotape, videotape and photographs. The interview will not be recorded without your permission. Please let us know if you do <u>not</u> want the interview to be audiotaped, videotaped or photographs taken; you also can change your mind after the interview starts, just let the interviewer know.

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By initialing below, you are granting to the researchers the right to use your likeness, image, appearance and performance - whether recorded on or transferred to videotape, film, slides, and photographs - for presenting or publishing this research (or for whatever use).

_____ I agree to have my child videotaped

_____ I agree to have my child audiotaped

_____ I agree for my child to be photographed

_____ I agree to allow researchers to use my child's work in publications & presentations

The information is strictly confidential unless you give us consent to identify you.

____I agree to allow the researchers to reveal my child's name

The research team may also seek to follow up with additional questions as part of continuing research efforts. We may want to contact you in the future for additional research.

____I consent for the researchers to contact me for future research by ___Email or ____Phone

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By signing below you are agreeing to participate to in the study.

____
Signature

____________________________ Email:
Printed Name

____________________________ Phone:
Date

Your Child's Name: ____

MIGHT YOUNG MAKERS BE THE ENGINEERS OF THE FUTURE?

STUDENT LETTER OF ASSENT

Dear Participant:

Dr. Shawn Jordan and Dr. Micah Lande, Assistant Professors in the Fulton Schools of Engineering at Arizona State University (ASU) invite your participation in a research study.

The purpose of the research is to understand the knowledge, skills, and attitudes possessed by Young Makers. In addition, this research seeks to understand how life pathways of Makers intersect with formal engineering education experiences.

If you decide to participate, then you will join a study funded by the National Science Foundation involving research to understand Young Makers and the Maker community. A screening questionnaire will determine your eligibility to participate in the study. If selected and you say YES, you will be asked to participate in an interview in person or by videoconference to describe one or more of your inventions and talk about how your life pathways have or have not intersected with formal engineering education. Participants can skip questions in the study at their choosing. The total time for participation in this study will be less than 4 hours and a $50 gift card will be compensation for your child's participation. Approximately 40 subjects will be participating in this study nationally. If you are under 18, then your parent will need to give you permission to participate.

You have the right not to answer any question, and to stop the interview at any time. Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty.

Although there is no benefit to you, possible benefits of your participation are that the results of this study may transform the conversation of who the engineer of the future could be, linking "making" with engineering the same way that students who excel in science and math are pointed toward engineering by parents and career counselors. We aim to illuminate pathways for Young Makers to become the engineers of the future. There are no foreseeable risks or discomforts to your participation.

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By signing below you are agreeing to participate to in the study.
By signing below you are agreeing to participate to in the study.

____
Signature

____________________________ Email:
Printed Name

____________________________ Phone:
Date

APPENDIX B

EXAMPLE MAKER SYLLABUS

Special Topic - Design, Invent, MAKE!
EGR/BUS/HAD/CTI 294
3 Credit Hours, Fall 2016
Aubrey Wigner

Course Time and Location:
Lecture: 2pm – 3:20pm Tuesday
Studio: 2pm – 5pm Thursday
ACIC 130 (TechShop classroom)
TechShop facility: 7am – 2am, see http://www.techshop.ws/ts_chandler.html for details

Contact Information and Office Hours:
Aubrey Wigner Aubrey.wigner@asu.ed
TechShop Tuesday/Thursday 11am -1pm or by appointment

Communication:
This course uses the class Blackboard site for all communications and course updates. It can be accessed at http://technology.asu.edu/DIM

Course Description:
Solving real world problems require interdisciplinary collaboration and an understanding of both social as well as technical systems. The Design, Invent, MAKE! (294/494/594) series of courses provide students the tools to creatively approach complex problem solving through design thinking, create low fidelity prototypes, and gain an understanding for how those prototypes might be turned into real world products/solutions. This course is open to students from all majors. Students and teams are welcome to enter the class with project ideas in mind or choose from those classmates create.

Collaboration is a key component in the solution design process. Students will work in teams of 3-5 to develop and prototype a project idea. Teams may be composed of students from any major and any year. Teams may continue, individually or collaboratively, to work on projects from previous Design, Invent, MAKE! courses.

The problems tackled in this class are student designed and defined. The instructor is intended to act as a facilitator for problem solving, not as a provider of problem statements or judge of an ideas worth. As a result, grading and assessment will be based on *the process* undertaken rather than whether or not the final prototype is fully functional.

Structure:
This course consists of a weekly hour and twenty minute lecture where key topics for design and prototyping will be presented. Additionally, each week there will be a 3 hour studio session where students will gain hands on prototyping skills. The majority of homework assignments for this class will require additional shop time, as such, students are encouraged to attend office hours and/or plan for additional time spent at TechShop.

Course Objectives:
The objective of this course is to equip students with the skills needed for identifying needs with a focus on human centered design. Students will also learn how to creatively produce ideas for solutions, explore low-fidelity examples of those solutions, and then iterate with user feedback towards a usable prototype.

At the end of the course the students should be able to do the following:
Identify needs within a social and technological context.
Work effectively with interdisciplinary teams.
Ideate possible solutions with a team.
Build low-fidelity example solutions.
Present their ideas and product plans visually and orally.
Iterate based on user feedback.
Build working (or close to working) prototypes.

Learning Outcomes:
Students will develop a Maker Mindset including the traits below.
An ethos of ***Sharing*** via collaboration and positive criticism
The development of ***Practical Ingenuity***
Passion for learning based on ***Personal Investment*** in their projects
A love of ***Playful Invention***
Comfortable with ***Risk Taking***
A capability for ***Self-Directed Learning***

Course Policies

Attendance:
This course requires active participation both in the lecture session as well as the studio portion of the class. Attendance will be taken for all class and studio sessions. Students can make up classes in the case of excused absences such as religious holidays, university sponsored events, documented illness or emergency. In all cases except for illness or emergency, the absence must be communicated to the instructor ahead of time. After the first unexcused absence, the final course grade will be dropped by 5 points per absence (1/2 letter grade). If there is something happening that could interfere with your attendance, please contact the instructor before the absence to discuss possible solutions other than a lowered grade for unexcused absences.

Grading:
Course letter grades will follow the traditional percentage rubric (A+: 100%, A: 90% to less than 100%, B: 80% to less than 90%, C: 70% to less than 80%, D: 60% to less than 70%, E/F: less than 60%). Plus and minus (+/-) grades *may* be assigned at the discretion of the instructor. As mentioned above attendance is crucial for this class. Every unexcused absence after the first will result in a 5% reduction to your final grade. Do not miss class without contacting the instructor first.

Assignment	Points Possible	Due Date
List of 10 Potential Projects (individual)	5	8/30/16
Bios and Team Roles (team)	5	9/14/16
Project Pitch (team)	10	9/21/16
TechShop Classes (2 classes, individual)	10 (5 each)	9/11 and 10/2
Prototype Plan (team)	10	9/27/16
What's out there report (team)	5	9/29/16
Customer Interviews (individual, five interviews)	5	11/3/16
Tech Article Presentation (individual)	10	varies
Team Presentations (team)	10	11/22/16
Video Pitch (team)	10	12/1/16
Peer Evaluations	10	12/1/16
Innovation Showcase (team)	5	tbd
Personal Evaluation	5	12/1/16
Total	100 Points	

Academic Integrity:
All students in this class are subject to ASU's Academic Integrity Policy (available at http://provost.asu.edu/academicintegrity) and should acquaint themselves with its content and requirements, including a strict prohibition against plagiarism. All violations will be reported to the Dean's office, who maintains records of all offenses.
Student Code of Conduct:
In addition, ASU adheres to a university-wide Student Code of Conduct. The philosophy behind this policy states: The aim of education is the intellectual, personal, social and ethical development of the individual. The educational process is ideally conducted in an environment that encourages reasoned discourse, intellectual honesty, openness to constructive change and respect for the rights of all individuals. Self-discipline and a respect for the rights of others in the university community are necessary for the fulfillment of such goals. The Student Code of Conduct is designed to promote this environment at each of the state universities.

Accommodations for Disabilities:
To obtain disability-related accommodations for this class, students with disabilities are advised to contact the course instructors and the Disability Resource Center. To establish eligibility and to obtain services & accommodations for qualified students with disabilities see: http://www.asu.edu/studentaffairs/ed/drc/

Appreciation and Utilization of Diversity:
We value the diversity represented by the participants in this course. Diversity is a primary source of ideas, and you are encouraged to explore and appreciate the diversity of people and their perspectives in this course.

Course Reading:
The Art of Tinkering, Karen Wilkinson and Mike Petrich
MAKE: Electronics: Learning through discovery, Charles Platt
Arduino in a Nutshell, Jan Bochers, available at http://hci.rwth-aachen.de/arduino
FAB: The coming revolution on your desktop, Neil Gershenfeld

Required TechShop classes:
These courses are helpful for almost any project and useful for understanding how rapid prototyping machines work. If you have already taken either of these courses, please inform the instructor and you will be able to attend a different class of your choice (waterjet excluded).
Laser Cutting SBU
One of choice from the list below

Additional and optional classes:
Many additional classes are available at TechShop on their website. A few that can be useful for this course include the following. SBU indicates basic safety and operations course. All students automatically have $100 credit for courses at TechShop in addition to the two courses provided above for this class.
Form 1+ 3D Printer SBU
Autodesk Inventor Basics (accessible without the class)
Soldering and Basic Electronics (accessible without the class)
Milling Machine - SBU
Basic Metal Shop - SBU
Basic Sewing Machines - SBU
Woodshop – SBU
Shopbot (CNC router) - SBU

Examples of Past Student Projects:
Below are brief examples of some past projects students have crafted during the course of this class.

The Zombie Run – A fundraiser for campus Halloween celebrations
The Desk Buddy – An extending platform to make small desks usable
uLearn – A cooperative study app for getting homework help from peers
BurritoBot 5000 – A motorized burrito maker
Boost our boards – A knockoff of Boosted Boards to add electrical power to longboards
Shade on the streets – A proposed design for a streetside shade area in Tempe
DiskUS – Movable disk golf holes and a campus club for the sport
Pandamonium – A board game with microcontrollers, buzzers, lights, and 3d printed pandas

Fall 2016 Course Schedule

Class Date		Topic	Due Before Class
Week 1	18-Aug	Class overview, TechShop tour	
Week 2	23-Aug	Intro to Design Thinking	Watch Extreme by Design
	25-Aug	Studio – Design exercises, material introduction	Read "The Art of Tinkering"
Week 3	30-Aug	Group ideation	List of 10 potential projects
	1-Sep	Studio - Team formation and low-fi prototyping	
Week 4	6-Sep	Introduction to circuits and electronics	Watch IDEO video Read "Make: Electronics: Learning through discovery"
	8-Sep	Studio – Soldering and electronics	First TechShop SBU completed
Week 5	13-Sep	Arduino basics	Bios and team roles Read "Arduino in a Nutshell"
	15-Sep	Studio – Wearable tech	
Week 6	20-Sep	2D design fundamentals	Idea pitches
	22-Sep	Studio – CorelDraw and 2D CNC	Second TechShop SBU completed
Week 7	27-Sep	3D design fundamentals	"What's out there" report
	29-Sep	Studio – Rhino 3D, design for 3D printing	Prototype plan
Week 8	4-6Oct	Fall Break!	
Week 9	11-Oct	Feedback and planning	Read "Fab: the coming revolution on your desktop"
	13-Oct	Studio – Open shop time	
Week 10	18-Oct	Team Presentations – The Prototype	Initial prototype
	20-Oct	Studio – Group critiques and feedback	
Week 11	25-Oct	Business Model Canvas	Read Business Model Canvas Handout (on Blackboard)
	27-Oct	Studio – Open shop time	
Week 12	1-Nov	Iterative Design Methods	Customer interviews
	3-Nov	Studio – Open shop time	
Week 13	8-Nov	Crowd Funding	Browse Kickstarter and Indiegogo
	10-Nov	Studio – Open shop time	
Week 14	15-Nov	About the Innovation Showcase	
	17-Nov	Studio – Open shop time	Innovation Showcase Poster
Week 15	22-Nov	Team Presentations	Lessons learned presentation
	25-Nov	Studio – Open shop time	
Finals	29-Nov	Innovation Showcase	Innovation Showcase Participation
	1-Dec	Video Pitch Viewing and Wrap-up	Video pitch