A Case Study of a High School Fab Lab

By

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Dedication

To Eric, Sandy, Noah, Daniel and all the educators I have had the pleasure to *encounter*. You offered me more than your knowledge. You offered me your presence.

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Abstract

This dissertation examines *making* and design-based STEM education in a formal makerspace. It focuses on how the design and implementation of a Fab Lab learning environment and curriculum affect how instructors and students see themselves engaging in science, and how the Fab Lab relates to the social sorting practices that already take place at North High School. While there is research examining design-based STEM education in informal and formal learning environments, we know little about how K-12 teachers define STEM in *making* activities when no university or museum partnership exists. This study sought to help fill this gap in the research literature.

This case study of a formal makerspace followed instructors and students in one introductory Fab Lab course for one semester. Additional observations of an introductory woodworking course helped build the case and set it into the school context, and provided supplementary material to better understand the similarities and differences between the Fab Lab course and a more traditional design-based learning course.

Using evidence from observational field notes, participant interviews, course materials, and student work, I found that the North Fab Lab relies on artifacts and rhetoric symbolic of science and STEM to set itself apart from other design-based courses at North High School. Secondly, the North Fab Lab instructors and students were unable to explain how what they were doing in the Fab Lab was science, and instead relied on vague and unsupported claims related to interdisciplinary STEM practices and dated descriptions of science. Lastly, the design and implementation of the Fab Lab learning environment and curriculum and its separation from North High School's low tech, design-based courses effectively reinforced social sorting practices and cultural assumptions about student work and intelligence.

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Chapter 1: Introduction

In 2005, *MAKE* magazine, a bimonthly publication, began featuring do-it-yourself projects like electronics hacks and artifacts built with the latest digital fabrication software and technologies. The following year the first Maker Faire, an event where people gather to display and demonstrate a wide range of creative projects, brought thousands of people to the Bay Area (Anderson, 2012; Dougherty, 2012b; Hatch, 2014). These two events helped launch a community of do-it-yourselfers, hackers, tinkerers, hobbyists, entrepreneurs, and educators who now identify as the Maker Movement. Martin (2015) defines *making* as "a class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a 'product' of some sort that can be used, interacted with, or demonstrated" (p. 31).

Many *makers* design and create with older technologies and practices (e.g. sewing, woodworking). However, supporters of the Maker Movement attribute the rapid growth of the movement to decreasing costs of digital fabrication software (e.g. AutoCAD, SolidWorks) and technologies (e.g. 3D printers, Arduino microcontrollers) and the ability to connect and share designs online (Dougherty, 2013; Honey & Kanter, 2013; Sheridan et al., 2014).

As the movement has grown, *makers* have been creating physical locations called makerspaces in informal and formal learning environments like libraries, museums, art studios, tech shops, and K-12 classrooms. Here, *makers* access fabrication materials and technologies and collaborate and support each other through the creative process. Many *makers* create artifacts for personal use while others have turned their creations into entrepreneurial opportunities (Barton, Tan, & Greenberg, 2016; Blikstein, 2013; Britton, 2012; Fab Foundation, n.d.; Hatch, 2014; Sheridan et al., 2014). Dale Dougherty describes *making* as

> important on many levels. On a personal level, it can be a source of satisfaction and accomplishment, as you learn to do new things. On a social level, Making can lead to discovering other Makers who share you interests in local or online communities, and re-invigorating community bonds through Making. On an economic level, Making is bolstering personalized manufacturing, local workforce development, entrepreneurship, and

> expanding opportunities for Americans to unleash innovations that can lead to the industries and jobs of the future. (Larson, 2014, para. 12)

The excitement of *making* reached President Obama in 2014 when the White House hosted its first Maker Faire. The movement continues to grow as K-12 public schools, community colleges, and universities adopt design-based STEM learning pedagogies featuring digital fabrication software and technologies. Many educators position *making* as an educational reform movement that will provide students with opportunities to learn and engage in personally meaningful projects through design-based STEM education (Barton et al., 2016; Blikstein, 2013; Honey & Kanter, 2013; Kafai, Fields, & Searle, 2014; Martin, 2015; Martinez & Stager, 2013). Many also hope a *maker* education will contribute to the nation's economic growth and development (Anderson, 2012; Dougherty, 2012a; Hatch, 2014; Kalil, 2013).

Research on *making* as a learning process for design-based STEM education is growing each month. As a researcher and high school science teacher, the research literature on *making* continues to provide me with a vision for what could be possible in formal K-12 settings. Researchers Kafai et al. (2014) and Barton et al. (2016) demonstrate how *making* learning experiences can be designed and implemented to create opportunities for all students to access design-based STEM education as they solve personally meaningful problems. Yet, the educational successes observed in these studies may be due, in part, to their position outside of typical formal K-12 settings where instructors and the pedagogy of *making* avoid the everyday tensions of public education, such as the separation of subject areas, the tracking of students into different coursework paths, and the pressures of preparing for high-stakes tests. We do not yet know how teachers will design and implement *making* learning experiences in their K-12 classrooms when they face the structural tensions of schooling and there are no researchers present to facilitate. Researchers discussing the potential for *making* in formal educational settings have already pointed to some of the structural tensions of public education, questioning whether access to STEM tools, activities, and identities will be available to *all* students and if the newest tools for *making* (e.g.

digital fabrication technologies) will overshadow opportunities for collaborative learning and problem solving (Halverson & Sheridan, 2014; Martin, 2015).

The goal of this study was to observe how *making* plays out in a formal, public school setting where teachers define *making* and design-based STEM education without the collaboration of educational researchers. This research study is among the first to observe *making* in a public high school where administrators and teachers have designed and implemented the learning environment and curriculum independent of a university or museum partnership.

This case study research took place at North High School, a public high school in the northern Midwest region of the United States. North High School is one of the first schools in the country to offer design-based STEM coursework through the exclusive use of digital fabrication software and technologies in a Fab Lab makerspace. The original Fab Lab designed by Neil Gershenfeld at the Massachusetts Institute for Technology (MIT) Center for Bits and Atoms inspired the design of the North Fab Lab (Gershenfeld, 2005). The North Fab Lab adopted the Fab Lab platform for teaching STEM to students interested in engineering and entrepreneurship. I share more information on how the North Fab Lab differs from other makerspaces in Chapter 3 when I discuss the North Fab Lab setting.

Every North Fab Lab instructor participated in the Fab Foundation’s Fab Academy to learn how to use digital fabrication software and technologies (Fab Foundation, n.d.). The North Fab Lab is also a member of the United States Fab Lab Network (USFLN) an organization that physically connects Fab Lab participants through the annual FAB conference and virtually through live videoconferencing screens.

The North Fab Lab is unique in many ways, but one of the things that distinguishes it from other makerspaces is that it does not feature any hand-operated technologies. The North Fab Lab adopted the Fab Foundation’s “Ideal Lab Layout” that only includes digital fabrication software and technologies like AutoCAD software, 3D printers, laser cutters, CNC routers, and vinyl cutters.

The North Fab Lab is just one kind of makerspace and does not represent all makerspaces and *making* in public education; however, it does provide a setting where researchers and educators can learn what *making* looks like at one public high school. Because the North Fab Lab was one of the first high school makerspaces in the country, this private-publicly funded project is now a model for nearby school districts that seek to create their own. The state governor recently created the Fab Labs Program that will provide funds for 25 school districts to support a Fab Lab, including continued support of the North Fab Lab ("Fabrication Laboratories Grant," n.d.). An understanding of what *making* looks like in the North Fab Lab is an important first step to learning the different ways *making* curricula and learning environments can be designed and implemented in K-12 public education.

I conducted a case study of a formal makerspace by observing an introductory Fab Lab course for one semester at a public high school. Later observations of an introductory woodworking course provided an instructive point of contrast and set the Fab Lab more clearly in the broader school context. Qualitative evidence from observational field notes, participant interviews, course materials, and student work allowed me to examine the place of *making* in STEM education and the school structure more broadly, and to provide one story of *making* at a public high school. For reasons that I discuss more fully in the next chapter, I was particularly interested in the following research questions:

(1) How does the design and implementation of the North Fab Lab learning environment and curriculum affect how instructors and students see themselves engaging in science; and

(2) How does the Fab Lab contribute to or depart from the social sorting practices that already take place at North High School?

The findings and discussion from this research have direct implications for researchers, educators, and policymakers interested in *making* as a pedagogical approach for design-based STEM education and who seek to design and implement learning environments and curricula that provide all students access to STEM tools, activities, and identities.

Theoretical Perspectives: Boundaries

The theoretical perspectives I chose to focus this research project come from the epistemology of science and the philosophy of technology and center around the theme of boundaries and their social ends. I specifically focus on the boundaries between science and non-science and how Fab Lab instructors use rhetorical and material symbols of science to distinguish the Fab Lab from other design-based learning environments at North High School. I then demonstrate how these boundaries create and reinforce the categorizing and sorting of students on different coursework paths.

I draw upon Gieryn's (1999) "boundary-work" to examine how the Fab Lab instructors' rhetorical "boundary-work" gave the Fab Lab the status and credibility of a science and STEM learning environment, which in turn gave them access to recognition, material resources, and funding that other design-based learning environments at North High School struggled to access. Winner's (1986) "politics of artifacts" conception provides a lens to examine the power and authority embodied in the tools and activities of digital fabrication and how their movement from the wood shop to the Fab Lab reinforced boundaries between social groups and the kinds of *making* activities that were possible for each group. Lastly, Dorothy Nelkin's (1987) work on the imagery of science and technology in the press provides a lens for examining the imagery of science in the North Fab Lab and how this imagery gave the Fab Lab higher status, authority, and monetary and material resources. Her work is helpful in understanding why Fab Lab students and instructors associated engagement in scientific practices with the Fab Lab, but not other design-based courses at North High School and why the school chose to prioritize the development of the Fab Lab over other design-based courses like the woodworking shop that was also in need of resources.

Together these perspectives provide a useful framework for examining how the creation and reinforcement of boundaries in the school structure, especially between the North Fab Lab and woodworking shop, affect how we define subject areas and student engagement and how these definitions ultimately categorize and sort students into different groups within the social structures of schooling. These theoretical perspectives will help readers to understand the importance of addressing the structural tensions of public education before implementing reform measures. Lastly, these perspectives will help move *maker* research beyond defining *making* and STEM education and the social goals educators hope to achieve through them to considering how the learning structures that already exist could change those definitions and goals and reinforce social sorting practices that have been shown to disadvantage girls, students of color, and low-income students.

Overview of Dissertation

In Chapter 2, I provide some background on the Maker Movement including how it began, why it appeals to different interest groups, and its values and goals for education. I then discuss its growing presence as a learning process for design-based STEM education in informal and formal learning environments and how the literature demonstrates the potential of *making* for democraticizing access to STEM tools, activities, and identities. I end the chapter by taking a brief look at the diverse goals of the manual training and the home economics movements that took place a century ago. I show how these movements parallel many of the goals and values of the Maker Movement, and argue for the need of research in formal K-12 setting where *making* will likely face the same structural tensions of schooling (e.g. separation of subject areas, social sorting) that hindered the success of the earlier movements.

In Chapter 3, I describe the methods and methodology of my study, including detailed descriptions of the overall study design, specific methods for data collection, strategies for analyzing and interpreting the data, and the steps I took to increase the validity and reliability of my findings. I end the chapter by addressing my ethical concerns and possible limitations of the study design. This study strives to understand how Fab Lab instructors and students saw themselves engaging in science in the Fab Lab and how the Fab Lab related to the social sorting practices at North High School. The case study design gives readers a closer look at the settings and activities of a Fab Lab at a public high school and allowed me to observe how the design and implementation of the Fab Lab learning environment and curriculum relate to existing school structures like the practice of sorting students on advanced placement and work-based coursework paths.

Chapter 4 reports on my findings in two parts. Part 1 addresses the first research question by examining the material culture and rhetoric of science and STEM in the North Fab Lab, drawing attention to two specific student projects that illustrate how popular images of science and STEM are used by the Fab Lab to establish credibility and status as a science and engineering course. Part 2 examines how the Fab Lab relates to the social sorting practices that already take place at North High School. I begin by focusing on the idea of "comfort" and the material and social differences between the Fab Lab and shop. I then focus on how the Fab Lab instructors aligned the Fab Lab with the advanced placement coursework path and not the work-based coursework path at North High School. Lastly, I dig into the rationales Fab Lab instructors give to explain why particular student groups enroll in Fab Lab classes and others do not. I end by making the case that the design and implementation of the Fab Lab learning environment and its alignment with the advanced placement coursework path offers a better explanation for who does and does not take Fab Lab courses than the intrinsic features of students mentioned by Fab Lab instructors—such as the idea that female students prefer clean and quiet learning environments.

Finally, Chapter 5 presents a summary of findings, discussion points, limitations, and possible implications, and concludes this body of work by outlining an agenda of future research.

Chapter 2: Literature Review

Background

The Maker Movement refers broadly to a community of people engaged in the creative production of artifacts, with emphasis on the use of digital fabrication technologies, and who share their artifacts in both physical and digital spaces. The Maker Movement emerged about 10 years ago as digital software and technologies and online communities began changing the way people engaged in more traditional hobbies and crafts like sewing, woodworking, metalworking, and electronics (Martin, 2015; Sheridan et al., 2014). The introduction of new digital technologies like 3D printers, laser cutters, and microcontrollers created opportunities for *makers* to create and share their digital and physical prototypes with other *makers* who support each other with project information, critique, and expertise (Dougherty, 2013; Honey & Kanter, 2013; Sheridan et al., 2014).

The Maker Movement began after the publication of *Make* magazine in 2005 and the first Maker Faire (a DIY showcase event) in 2006 (Anderson, 2012; Dougherty, 2012b; Hatch, 2014). As of 2012, *Make* magazine had a readership of 300,000, and now over 100 Maker Faires take place annually in most major cities in the United States. The 2014 Bay Area Maker Faire attracted more than 130,000 people (Maker Media, n.d.). People who identify with the Maker Movement use the terms *making*, *maker*, and makerspace to help distinguish the Maker Movement from art and crafts movements that use terms like craftsman and workshop.

The movement continues to grow as the tools for digital design and fabrication have become more affordable and accessible through the development of non-profit and for-profit community makerspace*s.* Makerspaces are now a part of schools, libraries, museums, churches, hackerspaces, tech shops, and afterschool programs, each with different values and goals (Barton et al., 2016; Blikstein, 2013; Britton, 2012; Fab Foundation, n.d.; Hatch, 2014; Sheridan et al., 2014).

Part of the Maker Movement's appeal is that it holds different meaning for different people including teachers, educational researchers, corporate leaders, and government officials. Some educational supporters see *making* as a playful learning process for design-based STEM education (Blikstein, 2013; Honey & Kanter, 2013; Martinez & Stager, 2013). Others focus on *making* as an empowering practice that can reconnect students' home life with their school life as they solve meaningful problems (Barton et al., 2016; Blikstein, 2013). Still others believe *making* will encourage students to pursue STEM-related jobs (Kalil, 2013), especially those students "not well served by the academic tracks traditionally available to them" (Dougherty, 2012b, p. 13). Lastly, some believe *making* will create a new generation of entrepreneurs like Steve Jobs, who will design products faster and cheaper and help increase economic and job development (Anderson, 2012; Hatch, 2014). This study will touch on many of these goals, but will focus on *making* as a learning process for design-based STEM education in formal K-12 settings.

A Growing Presence in Learning Environments

According to Brahms and Crowley (2014), one of the appeals of *making* as a learning process for design-based STEM education is that it provides multiple entry points to participation. *Making* provides participants opportunities to learn and apply multidisciplinary (e.g. science, technological, engineering, math, art) knowledge while tinkering, hacking, designing, building, and expressing one's self with multiple audiences both online and in-person (Barton et al., 2016; Martin, 2015; Martinez & Stager, 2013; Sheridan et al., 2014; West-Puckett, 2013). Educational supporters like Martinez and Stager (2013) and Lee Martin (2015) argue that *making* provides an opportunity to disrupt K-12 educational practices like high-stakes testing and the de-professionalizing of teachers that have, according to Martinez & Stager (2103), "created classrooms that are increasingly devoid of play, rich materials, and the time to do projects" (p. 1).

Interest in *making* as a learning process continues to grow as many people can now experience *making* at public libraries, museums, and K-16 schools that offer different kinds of makerspaces. Museum makerspaces like the Tinkering Studio at the Exploratorium in San Francisco, the Maker Space at the New York Hall of Science, and MAKEShop at Children's Museum of Pittsburgh provide visitors with opportunities to engage in STEM and the arts through hands-on projects. Neil Gershenfeld and colleagues created one of the first makerspaces in a formal educational setting. The Fabrication Laboratory or Fab Lab at MIT features digital fabrication technologies like 3D printers, laser cutters, and CNC machines and electronics equipment to build and program microcontrollers that students use to "make almost anything" (Gershenfeld, 2005, p. 4). In 2008, Paulo Blikstein created the FabLab@School project to create and support Fab Labs in K-12 schools (Blikstein, 2013). The first Fab Lab opened at MC2STEM High School in Ohio in 2009 and the number of Fab Labs in K-12 schools continues to grow with help from organizations like Blikstein's FabLearn Labs (formerly called FabLab@School) and the Fab Foundation. The Fab Foundation has helped support the development of approximately 700 Fab Labs worldwide with 30 of them in K-12 settings across the United States. Many schools use Fab Labs as a platform for STEM education (Blikstein, 2013; Fab Foundation, n.d.). The Fab Lab in this study is a model of the one at MIT. In the state where this research took place, the governor recently set aside $500,000 in the 2015-2017 biennial state budget to start a Fab Labs Program, which will provide funding to 25 school districts to start or expand a Fab Lab ("Fabrication Laboratories Grant," n.d.).

Opportunities to research *making* are also on the rise with federal grants becoming increasingly available. Dale Dougherty received a MENTOR grant in 2012 from the Defense Advanced Research Projects Agency (DARPA) to bring *making* into public education (Dougherty, 2012a), and the National Science Foundation recently sent a Dear Colleague Letter to encourage EAGER proposals for research on *making* and STEM education (National Science Foundation, 2015).

Research on *Making* as a Learning Process for STEM Education

Many educational researchers argue that *making* emerges from Seymour Papert's constructionist learning theory in which learning is both a mental *and* a physical activity. Students learn better when they are given opportunities to define, construct, and share solutions to problems with an audience (Blikstein, 2013; Martinez & Stager, 2013; Papert; 1980). The argument for constructionist learning experiences is growing as recent national standards in science education like the *Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS) are focused less on disciplinary content and more on the application of content using science and engineering practices. The NGSS (NGSS Lead States, 2013) adopted the *Framework's* (NRC, 2012) eight science and engineering practices and raised engineering design to the same level as scientific inquiry. These practices include,

1. Asking and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Supporters of *making* like Honey and Kanter (2013), Martinez and Stager (2013), and Quinn and Bell (2013) believe the design process is central to STEM education. Honey and Kanter (2013) write,

> Design is a powerful vehicle for teaching science, technology, engineering, and math (STEM) content in an integrated and inspiring way. Through the design process, one learns how to identify a problem or need, how to consider options and constraints, and how to plan, model, test, and iterate solutions, rendering higher-order thinking skills, tangible, and visible. Design-based learning engages students as critical thinkers and problem-solvers and presents science and technology as powerful tools to use in solving some of the world's most pressing challenges. (p. 3-4)

These supporters and others often reference the NGSS and *Framework* in their arguments for *making* as design-based STEM education, a learning process they believe has the potential to build students' interest in and knowledge of STEM and provide *all* students opportunities to engage in STEM and art education including those who have been historically underrepresented in STEM education. (Barton et al., 2016; Blikstein, 2013; Honey & Kanter, 2013; Kafai et al., 2014; Quinn & Bell, 2013)

While *making* is identified as a powerful method for design-based STEM education (Bennett & Monahan, 2013; Brahms & Crowley, 2014; Honey & Kanter, 2013; Kalil, 2013; Martinez & Stager, 2013), research is still in the early stages and mostly taking place outside of K-12 classroom settings (Vossoughi & Bevan, 2014). However, the connection between *making* and STEM in these initial studies seems promising. Sheridan et al.'s (2014) research on learning in out-of-school makerspaces found that the boundaries created between disciplines in schools like the STEM subjects are absent in makerspaces. Brahms (2014) found that while *making* may not lead participants into a STEM discipline, it does "encourage community members to tinker at the edges and intersections of disciplinary participation" and "has the potential to make disciplinary knowledge and skill more accessible to people who feel peripheral to the more refined and inaccessible aspects of disciplinary practice" (p. 93).

Paulo Blikstein's (2013) *Fablab@School* workshops with teachers and middle and high school students found that when students designed rollercoasters, they were introduced to physics concepts like friction and momentum and developed problem-solving and engineering practices as they worked through multiple iterations of their design. Peppler and Glosson's (2013) study of students' engagement in electronic textile (e-textile) materials found that participants developed understanding of circuitry concepts like current flow, circuit polarity and connectivity.

According to Martin (2015), *making* activities coupled with rapid-prototyping, digital fabrication software and technologies have been shown to give students even more opportunities to design, build, iterate, and share their work in the digital and physical world. For example, while many K-12 science kits include a unit on electronics that provides students with opportunities to tinker with circuit components and learn about electricity and circuitry, digital fabrication software and technologies have the potential to take students a step further by providing the tools to design, mill, and build their own circuit boards using milling and soldering tools. Students can connect their circuit boards to microcontrollers and program them to make artifacts that can perform an infinite number of actions. When Sheridan et al. (2014) observed a circuit activity at an informal makerspace, they observed participants not just learning about electricity, but applying their knowledge “to make a nightlight, customize a bike, fix a game controller, and photograph the Earth from space” (p. 38).

These kinds of tinkering and hacking opportunities also allow participants to experience the inner workings of technologies and devices, instead of experiencing them as a “black box” (Kafai et al., 2014; Resnick, Berg, & Eisenberg, 2000). When Kafai et al. (2014) observed high school students making e-textiles like a tote bag with light-sensing handles, they found that these experiences allowed students to “grapple with the messiness of technology [by] taking things apart, putting them back together, and experimenting with the purposes and functions of technology” (p. 536). They also found that when students engaged in the creation of e-textiles, that crafting and aesthetics were a natural part of the process, and those students that incorporated artistic elements in their designs created more challenging projects and had more ownership of their work. Sheridan et al. (2014) note how the digital and physical *maker* communities (e.g. makerspace communities, community events, YouTube, online forums, Maker Faires) provide participants with an audience to share work and receive valuable feedback and recognition.

According to Martin (2015), *making* promotes important elements of learning not often seen in public education. These elements are part of what Dale Dougherty (2013) calls the “maker mindset”: playful, asset- and growth-oriented, failure positive, and collaborative (p. 7; Martin, 2015). For example, research on tinkering (a *making* activity) found that in the process of tinkering the learner is met with a learning environment containing many different tools and materials without an apparent objective or plan (Resnick & Rosenbaum, 2013). Learners create their own goals and constraints and these evolve as their understanding and materials develop, and because the learners’ activities are based on their own goals and interests, they are more committed to their activity and find it to be fun and playful (Petrich, Wilkinson, & Bevan, 2013). The *maker* mindset holds a more positive outlook when experiencing failure. Instead of seeing failure as a time to disengage, learners interpret these obstacles as opportunities for further engagement. Unlike the treatment of failure in many formal education settings, the Maker Movement celebrates failure and sees it as an opportunity for learning. As Petrich et al. (2013) said, "The process of becoming stuck and then 'unstuck' is the heart of tinkering" (p. 55). Lastly, the *maker* mindset values sharing and collaboration, qualities that can be seen at Maker Faires and on online forums (Martin, 2015).

Many educators like Barton et al. (2016) and Kafai et al. (2014) believe the greatest promise of the Maker Movement is the democratization of access to *maker* activities and identities, as one who engages in STEM using 21st century technologies. Supporters believe *making* has the potential to include girls and students of color in STEM activities, two underrepresented groups in the STEM labor force (NSF, 2014). Researchers like Blikstein (2013) and Barton et al. (2016) understand *making* as an opportunity to educate and empower students as they design solutions to meaningful problems that affect them personally. Barton et al's (2016) recent study of an afterschool Boys and Girls Club Youth Makerspace found that when African American and Latino students were given opportunities to make artifacts that were personally meaningful and addressed community problems, that their sustained and mutual engagement "opened up more equitable opportunities to learn and become in STEM for them" (p. 18). For example, a pair of African-American girls decided to design "The Anti-rape jacket" after learning that African American girls make up 44% of the rape victims in their community. The girls designed the anti-rape jacket using e-textile practices and programmed an alarm to go off when they pushed a secret button. As students designed and made their artifacts, the makerspace support team provided "just-in-time" learning resources that helped to deepen students' understandings of STEM knowledge and practices. In the end, the girls had designed an artifact that incorporated both knowledge and practices of STEM and art and it addressed a community need (Barton et al., 2016, p. 20). In a similar study, Kafai et al. (2014) found that when boys and girls participated in e-textiles that both groups came to understand that sewing crafts are difficult and require expertise. These research studies align with other studies that have observed how *making* with e-textiles can disrupt notions about who can *make* and help to overcome cultural and gendered stereotypes that exist in school classrooms (Bucholz, Shively, Peppler, & Wohlwend, 2014; Buechley & Hill, 2010; Peppler & Bender, 2013).

While the research literature is still small, these early findings show a lot of promise for *making* as a learning process for STEM education. However, most of the published research on *making* as a learning process has taken place outside of K-12 classroom settings in out-of-school makerspace and museum settings (Vossoughi & Bevan, 2014). Research that does take place in formal classroom settings usually involves university or museum partnerships that provide workshops for students (Barton et al., 2016; Bevan, Gutwill, Petrich, &Wilkinson, 2015; Kafai et al., 2014; Vossoughi, Escudé, Kong, & Hooper, 2013), and researchers are the ones defining STEM and determining whether STEM learning has taken place. There is currently no body of research examining how *making* as a learning process for STEM education plays out in public K-12 classrooms when school instructors are left to design *making* curricula and define STEM education, though many educational researchers are concerned about get *making* right in these settings. Researchers Halverson and Sheridan (2014) and Martin (2015) understand that the goals and practices valued in *making* are not new to public education and that similar educational reform movements did not catch on due to the structural challenges of public education.

Halverson and Sheridan (2014) note that while the Maker Movement is new, its relevance to education can be found in progressive education reforms like “Piagetian constructivism, Dewey-ian progressivism, Montessori’s hands-on curriculum, and Papert’s constructionism” as well as science education (p. 5). Support for teaching engineering design practices in science education standards documents may have not been as explicit as it is now, but these practices are not new. Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman’s (2005) “design-based science,” Kolodner et al.’s (2003) “Learning-by-Design,” Krajcik et al.’s (1998) “project-based science,” and Schwartz, Mennin, and Webb's (2001) "problem-based learning" are all examples of design-based science education curricula developed before the NGSS. Science and engineering design practices have also been valued and taught for over a century in many career and technical education (CTE) programs (traditionally called vocational education). Several progressive movements in the early 20th century (e.g. manual training movement and home economics movement) also had similar goals and values as the Maker Movement including prioritizing hands-on, project-based learning, connecting students' school life with their home life, and preparing students with the science, engineering, and technological knowledge and skills needed to participate in the "new economy."

In the following section, I will take a brief look at the diverse goals of the manual training and the home economics movements and how they parallel many of the goals and values of the Maker Movement. Comparing these past movements to this current one is important as supporters of the Maker Movement and the curricular and pedagogical goals they hope to achieve in formal settings will face the same kinds of tensions that hindered the success of earlier movements. Tensions like the separation of subject areas in secondary schools and the sorting of students on different coursework paths still exist today.

The Progressive Movements

Kliebard's (2004) *The Struggle for the American Curriculum* demonstrates that behind any educational reform movement are "diverse and contradictory expressions of support" (p. 282), and that the success of movements is found in their ability to "act as a kind of magic mirror in which the powerful interest groups [can] see their own reflected ways of reforming" (p. 128). Two movements that fit Kliebard's description are the manual training and home economics movements that began over a century ago. Some of the values and goals that shaped their origin live on in public education today, though under different names like technical education and family and consumer science. Like the Maker Movement, these movements began with a diversity of goals.

Manual training. In the early stages of the manual training movement, educators like Calvin M. Woodward, founder of the Woodward's Manual Training School of Washington University in St. Louis, stressed the need to combine the practical skills of shop work with the traditional academic subjects like science and math (Gordon, 2008; Kliebard, 1999). For Woodward, the curriculum was designed "to foster a higher appreciation of the value and dignity of intelligent labor, and the worth and respectability of intelligent laboring men," not for specific trade training (Woodward, 1885, p. 623). When the Milwaukee public schools considered manual training in 1890, a special committee of the school board aligned their beliefs about manual training with those leaders in the movement like Woodward. "The schools," the committee stated, "are not established for the purpose of teaching scholars how to make a living but to teach them how to live; they are not to teach trades, but to enhance a desire for education" (Proceedings, 1890, p. 75). Manual training would "train the mind by training the hand" (Grubb, 1995, p. 11).

During this same time, John O. Runkle, president of MIT had other ideas of what manual training should be. In 1876, Runkle attended the Centennial Exposition in Philadelphia looking for a solution to solve the problem of graduating students from his engineering program with knowledge of theory and principles, but few skills using tools and machinery. He wanted to develop a curriculum that would expose students to the tools and skills of the artisan of preindustrial society while at the same time meet the needs of the new industrial society (Kliebard, 1999). While at the exposition, he observed Victor Della Vos from the Imperial Technical School of Moscow exhibit a system of tool instruction in which students constructed models from plans they had drawn. This system would provide Runkle with a solution by teaching skills independent of creating an actual product. It also took less time than apprenticeships and taught more students at once. Unlike Woodward's approach that focused on the growth of the whole student as they built artifacts in the shop, Runkle's approach focused on job training for the new industrial society. He supported the idea that one can learn skills in the absence of a particular job and then apply those skills later to a range of jobs. As Runkle convinced others of his approach, public schools introduced the Russian system to boys (Kliebard, 1999).

Lastly, another system of learning that focused on the use of tools was the American sloyd system. Unlike manual training that focused on teaching students how to use specific tools by completing exercises or building incomplete artifacts, the sloyd system was more like Woodward's, concerned about the development of the individual learner. To focus on the students' individual needs, students selected projects that they found interesting and built objects that could actually be used (Gordon, 2008).

The manual training movement attracted support from many educational reformers, but for many different reasons. For example, like the supporters of *making* as STEM education, Woodward (1885) sought to teach the natural sciences through "the senses of touch and sight, through the hand and the eye" (p. 614), two areas of education that he thought were lacking in the late 19th century humanist curriculum (Kliebard, 2004). As Kliebard (1999) mentions, "Woodward wanted manual training seen in the same way as the standard elements of the curriculum and not as an ornamental appendage" (p. 12).

David Snedden, an educational reformer and outspoken supporter of vocationalism and social efficiency, liked the differentiated curriculum manual training could provide to the new population of poor, immigrant, and African American students in secondary education. He saw manual training as a way to prepare them to fill jobs in the growing industries. Today, supporters like Anderson (2012) see *making* as an opportunity to upgrade "the school workshop class" to prepare students to use digital software and fabrication technologies needed in "the Web Age." Anderson believes that this time around, the school workshop class will not be "designed to train workers for low-end blue-collar jobs, but rather it's funded by the government's advanced manufacturing initiative aimed at creating a new generation of systems designers and production innovators" (Anderson, 2012, p. 19).

John Dewey was also a supporter of manual training and saw it as a way to combine students' school knowledge with their life outside of school. Blikstein (2008; 2013) and Barton et al. (2016) share similar support for the Maker Movement and believe *making* has the potential to both educate and empower students as they engage in projects that address personally meaningful problems.

Home economics. Beginning in 1899, the home economics movement (sometimes called domestic science) sought to redefine the home, especially the kitchen, as a place for social change, a place where educated women could apply their knowledge and talents to scientific and engineering studies related to nutrition, sanitation, and maintenance of home appliances (Bix, 2002; Stage, 1997).

As home economics moved into the 20th century, kitchens across the U.S. were being equipped with more sophisticated appliances like electric refrigerators, ranges, and microwaves. Using and maintaining these appliances created new challenges for women. In 1929, Iowa State became the first U.S institution to offer a major in household equipment. The curriculum provided women with a practical and scientifically based understanding of household technologies. Students were required to take coursework in physics, math, and electric circuits. They would apply their knowledge in the laboratory where women were seen taking apart and reassembling appliances in order to understand their construction, how they operate, and how to make common repairs. One would find students reviewing scientific concepts like magnetism and reviewing schematic wiring diagrams (Bix, 2002). Bix (2002) said, "Iowa State aimed to educate self-reliant homemakers who would confidently accept active responsibility for their kitchen equipment rather than cultivate attitudes of feminine helplessness." As women trained as "household engineers," Iowa State men in the agricultural department received similar training on the latest farm equipment (p. 730).

One of the movement's leaders was Ellen Richards, a trained chemist who had studied at Vassar and MIT. Upon her graduation in 1870, every chemical firm she applied to turned her down.

She quickly learned that if she wanted a career in academia or industry that she would have to create her own position. She would persuade MIT to open a Woman's Laboratory where she taught sanitary chemistry to women pursuing graduate work. She also organized the New England Kitchen and Boston School of Housekeeping (Stage, 1997). Preferring "domestic science" to home economics, Richard's students were encouraged to leave their homes and be empowered to use their knowledge and skills in their own science labs and towards social and political action (Stage, 1997).

John Dewey's "education through occupations" curriculum taught at the University of Chicago's laboratory school incorporated Richard's cooking practices (Mayhew & Edwards, 1936). Here Dewey and his colleagues used science and engineering practices to teach students the effects of different industries (e.g. textile, metalworking, construction) on people's lives by engaging them in the history of those industries. For instance, students learned about the textile industry, as they made their own spinning and weaving technologies and artifacts. Mayhew and Edwards (1936), two teachers at the laboratory school, share some of this experience,

> The shop becomes the laboratory where he manufactures his spindle or his loom, and the color or design of the working plan all enlist the aid of the art department. All of these aspects meet in and radiate from the continuous and direct activity or occupation of the children themselves. From the standpoint of the child there is but one thing going on. He is occupied with making things, with weaving, designing, cutting. (p. 335)

Dewey and his colleagues sought to teach students about themselves and who they could become through design-based learning in addition to teaching them about technological change and its effects on social systems. This kind of education was intended to give students the ability to engage in social and political action against evils of the economy and "become masters of their industrial fate" should they find themselves working in the factories (Dewey, 1916, p. 276).

Like Richards and the women who taught household equipment at Iowa State, supporters of the Maker Movement believe there are opportunities to engage students "who have not historically seen themselves as a part of STEM" (Barton et al., 2016, p. 4) in "historically feminized" activities (crafting) alongside traditionally “masculinized” activities (electronics) through e-textiles and hacking electronic household appliances (Buchholz et al., 2014, p. 283). However, unlike these earlier movements, supporters of *making* do not want to prepare underrepresented students to work in separate contexts and within particular social constraints, but wish to democratize access to *making* practices, tools, spaces, and identities to all students (Barton et al., 2016; Buchholz et al., 2014; Halverson & Sheridan, 2014; Kafai et al., 2014).

The introduction of vocational education. When the early manual training and home economics practices began entering K-12 public education, tensions between a changing society and the structure of public education began to re-shape these pedagogical reform efforts. Some of the goals and values of these movements were successful while others failed to catch on. During this time, Dewey (1916) warned against the promotion of concepts like vocationalism and social efficiency. He did not want to see schools using hands-on practices to teach students a narrow set of skills in preparation for future work. He wrote, “To predetermine some future occupation for which education is to be a strict preparation is to injure the possibilities of present development and thereby to reduce the adequacy of preparation for a future right employment” (p. 268). Yet, warning against tying manual training and home economics coursework to vocational training by Dewey and others had little impact after Congress passed the Smith-Hughes Act of 1917 that provided federal funding to bring manual training, home economics, and agricultural education to public K-12 education (Gordon, 2008; Kliebard, 1999). The rigor, status, and science-based orientation that was seen in the early days of the manual training and home economics movements was replaced with “a more vocational outlook, a skills-oriented sequence of courses” (Apple, 1997, p. 92; Kliebard, 2004). Those students who were more likely to enter the workforce upon graduation (typically lower class, immigrant, and African American students) were educated in these vocational programs and those students bound for the university or professional positions (typically middle class, white males) continued to be educated in academic programs (Grubb, 1995). Instead of combining the traditional academic subjects with hands-on, project-based learning, schools created a division. In this division, we see the beginnings of categorizing and sorting students into academic and vocational tracks more generally (Oakes, 1985; Rose, 2004).

Social sorting continues to disadvantage the working class students and students of color who are more likely to be tracked into vocational programs compared to other students. When Jeannie Oakes (1985) examined the effects of tracking on students' educational opportunities and outcomes in her book *Keeping Track*, she found that the goal of vocational education to provide poor and minority youth with the job skills to increase their economic opportunities has not been achieved. She summarizes two unfortunate outcomes of vocational education.

> First, research evidence points to the apparent ineffectiveness of these programs in providing either a substantial proportion of the trained workers needed for American industry or increased occupational opportunities for students. Second, many educational scholars agreed that an underlying function of vocational education has been to segregate poor and minority students into occupational training programs in order to preserve the academic curriculum for middle- an upper-class students. In this way, the differentiated curriculum has served to reinforce the racial and socioeconomic stratification of society. (p. 153)

We do not know yet how the Maker Movement will fare as it makes its way into K-12 public education. As a movement with both pedagogical and economic ties, it faces many of the same challenges as these earlier movements.

Problem Statement

In 1901, John Dewey considered the question of how curricular innovations are introduced and why they often fail. He said that the introduction of innovations occur when someone or some groups of people feel that the school is behind the times and that this other new thing will move education into the present age. The reform is instituted once public feelings are aroused. Once instituted, the reform usually fails for two reasons: There is no educational standard to test the new reform and the new reform does not address the structure of the school system including how students are grouped, the selection of teachers and separation of subject areas, and the system of rewards (Dewey, 1901; Kliebard, 2004).

Today, educational supporters of *making* like Martinez and Stager (2013) believe that "the maker movement may represent our best hope for reigniting progressive education" (p. 11). While the initial research on *making* as a learning process for STEM education is promising, this research is mostly taking place outside of K-12 classroom settings (Vossoughi & Bevan, 2014). Researchers like Halverson and Sheridan (2014) and Martin (2105) are concerned about what *making* will look like in public education. When they discuss the potential for *making* in formal educational settings, they too point to structural challenges that make educational reform difficult. Halverson and Sheridan (2014) believe some of these challenges include "questions of access, scale, staffing…" and the current educational climate's "need to standardize, to define 'what works' for learning through making" (p. 9). Martin (2015) warns Maker Movement supporters against taking a tool-centric approach to *making* as many reformers did during the introduction of computers in schools. Instead of identifying digital fabrication technologies as the new thing that will move education into the present age, he says to remain focused on the practices of *making* that highlight the *maker* mindset and collaborative learning. Others are concerned about whether *making* in schools will really include everyone and all types of hands-on activities (Buechley, 2014). Maker Movement supporters outside of educational research often presume that *making* is a universal, democratic activity that expands access to everyone (Anderson 2012; Dougherty, 2012b; Hatch, 2014); however, there is still little evidence that the Maker Movement has been successful at including a diversity of people and practices. When Leah Buechley (2014) analyzed 9 years of *Make* magazine covers, she found that 85% of covers featured men and boys and zero people of color, and participants were engaged in robotics, electronics, and vehicles, not traditional hobbies and craftwork.

If *making* is to live up to its goal of providing *all* students with a self-actualizing education through design-based STEM education then we must examine how the Maker Movement and *making* interact with the structural tensions of schooling that kept earlier movements from reaching this goal. The Maker Movement's impact on public education may not have the same outcomes as earlier progressive movements. Nevertheless, we should use this brief look at history as reason to critically examine any movement including the Maker Movement that is motivated by these same ideals knowing that they can result in outcomes (e.g. social sorting) that can limit students' learning experiences when the structural tensions of schooling are not taken into consideration.

Because interest in *making* as a learning process for STEM education is new, empirical research about *making* is limited (Martin, 2015). Most of the published research has taken place outside of K-12 classroom settings in out-of-school makerspace and museum settings (Vossoughi & Bevan, 2014). Research that does take place in formal classroom settings usually involves university or museum partnerships that provide workshops for students (Bevan et al., 2015; Kafai et al., 2014; Vossoughi et al., 2013), and the researchers are the ones defining STEM and determining whether STEM learning has taken place. We know little about how K-12 students and teachers define STEM in *making* activities when no university or museum partnership exists.

We need to be able to answer questions like how will *making* fit into school structures that already include design-based courses in art and CTE programs. Who will teach *making* coursework? Are the science and engineering practices defined by the *Framework* (NRC, 2012) and NGSS (NGSS Lead States, 2013) actually taking place in *making* activities? Will the movement's emphasis on STEM and the use of digital fabrication software and technologies help overcome or create new dynamics in the common practice of sorting students into academic and vocational tracks?

There is the possibility that *making* could introduce new science and STEM definitions and practices and expand access to STEM-rich learning; however, it is likely that *making* will adopt or connect with available norms and practices that already exist in public education. If *making* as a learning process for STEM education is to live up its promises then we must examine how the Maker Movement and *making* interact with the structural tensions of schooling.

Statement of Purpose and Research Questions

There is an under-theorized incursion of the Maker Movement and digital fabrication technologies into explicitly educational contexts. Like earlier educational reform movements, supporters emphasize the importance of providing young people with learning experiences that expose them to the newest technologies with the hope that these experiences will provide them with the knowledge and skills to participate in the new economy and reconnect them with their natural desires and abilities to learn with their hands. However, we are still at the beginning of the story of *making* in public education. If educators, researchers, and policymakers in the Maker Movement value learning experiences that provide *all* students in public education with opportunities to grow and develop as creative human beings, then we need to examine how the Maker Movement and *making* interfere with the structural tensions of schooling that have kept similar reform movements from reaching their goals.

To contribute to this gap in the *making* literature, I conducted a case study of an introductory Fab Lab course at North High School, a small school in the northern Midwest. Through this study, I examined the place of *making* in STEM education and the school structure more broadly to provide one story of *making* at a public high school. My research sought to answer the following research questions:

(1) How does the design and implementation of the North Fab Lab learning environment and curriculum affect how instructors and students see themselves engaging in science; and

(2) How does the Fab Lab contribute to or depart from the social sorting practices that already take place at North High School?

Chapter 3: Methodology

To answer my research questions, I conducted a case study (Stake, 1995) of a formal makerspace by observing an introductory Fab Lab course for one semester at a public high school in the northern Midwest, United States. To help build the case and set it into context, I also observed an introductory woodworking course. Observations of the woodworking course provided supplementary material that allowed me to better understand the similarities and differences between the Fab Lab course and a more traditional design-based learning course. For example, observing both courses allowed me to understand what a *making* course is and is not and the role of science in *making* at one public high school—understandings that may not have been obvious had I observed the Fab Lab course alone.

This case study is not “comparative” (Merriam, 2009) because I did not study the Fab Lab course and the woodworking course at equivalent levels. I made the decision to observe the woodworking course to provide contrast to the Fab Lab. This opportunity allowed me to sharpen my observations of the Fab Lab including the physical space, student work, and the interactions between instructors, students, and the learning environment. I chose not to observe a traditional science course because design-based pedagogies are rare in traditional science courses and my research interests and questions extend beyond science learning. Instead, I was interested in learning the role science, fabrication technologies, and categorizing and sorting students plays in design-based learning environments.

I chose the richly descriptive nature of case study design to give readers a closer look at the settings and activities of a Fab Lab course in a public high school and weigh my findings and evidence against detailed descriptions (Merriam, 2009). Case study design also allowed me to observe how the design and implementation of the Fab Lab learning environment and curriculum relate to existing school structures (e.g. categorizing students and coursework as “academic” or “vocational, “advanced placement” or “work-based”). A qualitative case study’s ability to “capture complex action, perception, and interpretation" made it an appropriate method for this study (Stake, 2007, p. 3).

Recruitment

The recruitment process for the Fab Lab 1 course began during the 2014 fall semester. I used this time to meet the Fab Lab instructors and observe a course before I formally recruited instructors and students at the beginning of the 2015 spring semester. Once I received verbal permission from the instructors, I contacted district administrators to seek permission and share my research materials including a research protocol and a background check. Once district administrators gave me verbal and written permission, I applied for IRB approval through UW-Madison. Throughout the UW-Madison IRB application process, I visited the Fab Lab course in order to gain the trust of the instructors and students before data collection began. Once I received IRB approval, about one month into the 2015 spring semester, I shared information about the study with instructors and students and sent informed consent forms home with students to share with their parents. I then recruited those students who returned a signed parental consent form by sharing information about the study and giving them an informed assent form. Recruitment for the woodworking course took place two months later after a student participant introduced me to the wood shop and the woodworking instructor.

During the 2015 spring semester, there were three Fab Lab 1 instructors. In addition to their Fab Lab 1 courses, they also taught courses in the science, math, and technology & engineering departments. There was also one volunteer instructor whose duties included assisting the Fab Lab instructors, granting writing, and maintaining industry partnerships. I recruited all four instructors to participate in the study, but only the math Fab Lab instructor and the volunteer instructor agreed to participate. Seven students from the Fab Lab 1 course agreed to participate in the study. I recruited the woodworking instructor in April after observations in the Fab Lab had already been taking place since March. One woodworking student agreed to participate in the study. After I completed research observations at the end of the 2015 spring semester, the Fab Lab department added two additional instructors from the art and science departments. After they completed Fab Lab training during the 2015 summer semester, I recruited and then interviewed them during the fall semester to provide arts and science perspectives on the Fab Lab that were missing in my data because I observed a math Fab Lab instructor's course.

Setting

The North School District is part of a small exurban community in the northern Midwest, United States. Approximately 12,000 people live in the local community that is also home to several large engineering companies. The school district has three elementary schools, one middle school, and one high school. North High School, the research site for this study, enrolls approximately 1,000 students each year. According to the state department of instruction, the student population is 91% White, 4% Black, and 2% Hispanic, and 22% of students qualify for free or reduced lunch prices. During the 2014-15 school year, approximately 64% of students planned to attend a 4-year college post-graduation, 20% planned to attend a vocational or technical college, 2% planned to join the military, and 4% planned to enter employment or job training.

North High School organizes its curricula around students' future career interests. The "Course Selection & Career Planning Guide" tells students that "the future holds many choices; few are more important than choosing a career path that is right for you." It goes on to say, "The choices you make and the courses you take while in high school, in large part, affect your ability to achieve the goals in life that you set or will set for yourself." While the student course handbook seems to place course selection in the hands of students, research in other contexts suggests that students can be counseled to select or avoid particular courses based on their past performance and parent, teacher, and counselor expectations as well as students' own beliefs about their abilities based on performance and expectations (Oakes, 1985).

Each student must complete 24 credits to graduate, and 16.5 of those credits must be in the core subject areas including language arts, social studies, science, math, physical education, health, fine arts, and career and technical education (CTE). Of the design-based courses, students are required to take at least one fine arts and one CTE course. Students select the additional 7.5 credits with advice from their parents, teachers, and counselors. Beyond the required courses, North High School also provides two coursework paths they call: "Advanced placement" and "work-based." Those students interested in taking college-level Advanced Placement (AP) and dual-credit courses can choose from 14 AP courses in the core areas. This coursework path is similar to traditional "academic" or "college-preparatory" tracks, though North high school does not use this language. According to the course guide, students interested in taking AP courses need to be self-motivated and disciplined in order to keep up with the material, be able to move rapidly and cover a lot of material inside and outside of class, and be willing to complete assignments in the summer prior to the start of the AP course.

North High School also provides work-based apprenticeship programs for students "interested in working in [their] chosen career field while still in high school" and who "want to earn high school credits and a paycheck at the same time." All 21 work-based courses are part of the state's CTE programs designed to prepare students for further education, training, or employment. Students can select from coursework in the following CTE departments: Agriculture, business & IT, family & consumer science, health science, marketing education, and technology & engineering. Those students who complete work-based or traditionally called "vocational" coursework receive a Certificate of Mastery awarded by the state's Department of Workforce Development.

I selected North High School as my research site because it offered an unusual opportunity to observe a newly developed Fab Lab designed to engage students in *making* and STEM education through digital fabrication software and technologies. Initially the case study focused entirely on the Fab Lab, but after talking to instructors and students and learning about the other design-based courses at North High School, I decided observing a traditional woodworking course from the work-based coursework path would be important to answering my two research questions. I believe the choice to observe a Fab Lab course and a woodworking course is interesting because they are both described as STEM courses in the course guide, yet the Fab Lab is mainly taught by science and math certified teachers who also teach advanced placement courses and the woodworking course is taught by a CTE certified teacher. Secondly, the Fab Lab claims to prepare students for careers in the science, engineering, computer science, and entrepreneurship fields, while the woodworking course mainly focuses on careers in the trades.

North Fab Lab background. Most of this study took place in the North High School Fab Lab. North High School is one of the first public high schools to house a Fab Lab and offer coursework to its students. The North Fab Lab was created in the fall of 2011 after Mr. Mitchell, a local engineer, was awarded a 3-year, $100,000 community involvement grant from his company to build and equip a Fab Lab at the local high school. The school district and local businesses raised an additional $106,000 to cover the costs of building renovations, equipment and supplies, and equipment upkeep. In 2015, state business, community, and entrepreneurial leaders nominated the North Fab Lab for a state innovation award in STEM education (School website, October 9, 2015). In 2016, it received a $23,400 grant from the state's new Fab Lab program through a Fabrication Laboratories Grant. The state funded 25 school districts to set up or expand a Fab Lab in 2016 ("Fabrication Laboratories Grant," n.d.).

The North Fab Lab instructors designed the North Fab Lab after the Fab Lab at MIT's Center for Bits and Atoms. Professor Neil Gershenfeld created this pedagogical environment as a space where students could "create almost anything" using digital fabrication tools like 3D printers (Gershenfeld, 2005). Since the development of the MIT Fab Lab, communities across the world have built Fab Labs to provide prototyping platforms for local entrepreneurship. Schools are increasingly adopting Fab Labs platforms for project-based, hands-on STEM education with support from the Fab Foundation and the Teaching Institute for Excellence in STEM (TIES), an organization that "provide[s] educational organizations support as they move toward using digital fabrication as a pathway to STEM teaching and learning" (Teaching Institute for Excellence in STEM [TIES], n.d.).

Fab Lab leaders at MIT created the Fab Foundation as an extension of the MIT Center for Bits & Atoms Fab Lab Program designed to facilitate and support the growth of Fab Labs around the world. Gershenfeld serves on the Fab Foundation board. The organization's services include "deploying, installing, training, and consulting for new Fab Labs as well as programmatic support of established Fab Labs" (Fab Foundation, n.d.). The North Fab Lab is modeled on the four qualities and requirements for being considered a Fab Lab by the Fab Foundation, which specifies that a Fab Lab: (1) Provides public access to the Fab Lab through evening and weekend community workshops; (2) Supports and subscribes to the Fab Lab charter; (3) Shares a common set of tools and processes; and (4) Participates in the global Fab Lab network by attending the annual FAB conference (Fab Foundation, n.d.).

The North Fab Lab drew upon the Fab Foundation's "Ideal Lab Layout" to select its digital fabrication technologies. This same resource is provided on the state's Fab Lab program grant website that was previously mentioned. These tools include 3D printers, a vinyl cutter, laser cutters and engravers, a milling machine to create circuit boards, soldering equipment, and design and programming software. All North Fab Lab instructors received training on these technologies from the Fab Academy through live videoconferencing with Fab Foundation leaders like Gershenfeld. The Fab Academy is a 5-month program from January to June. Participates who complete the entire program receive a Fab Academy Diploma (Fab Academy, n.d.).

The North Fab Lab is also a member of the United States Fab Lab Network (USFLN), another service provided by the Fab Foundation. This network functions to connect Fab Labs physically through annual meetings and virtually through live videoconferencing. The USFLN website describes its vision,

> The USFLN will be known as a robust community of Fab Labs who have dramatically advanced interest and participation in science and technology careers, collectively created a new generation of entrepreneurs, inventors and artisans; and proactively reunited education and training, art and the artisan, industrial production, and personal expression nation-wide, – all contributing to the resurgence of American innovation. (United States Fab Lab Network [USFLN], n.d.)

The USFLN partners with the International Technology and Engineering Educators Association, the National Association for Community College Entrepreneurship, the National Coalition of Advanced Technology Centers, and Solidworks, a corporation that provides 3D computer-aided design (CAD) software tools for digital fabrication technologies. The USFLN academic mission is to encourage Fab Labs in educational settings to engage participants in the STEM disciplines (USFLN, n.d.).

Like other Fab Labs in the network, the North Fab Lab is free and open to the public through afterschool community workshops, it supports and subscribes to the Fab Charter, and participates in the global network through public videoconferencing and by attending the annual FAB conference (Fab Foundation, n.d.). Each North Fab Lab instructor has attended at least one FAB conference. The North Fab Lab instructors also participate in the annual FabLearn conference, an outreach of Paulo Blikstein's *FabLab@School* project created to help students learn principles and practices of STEM (FabLearn Labs, n.d.). While the MIT Fab Lab inspired *FabLab@School* and FabLearn, there is no affiliation between the *FabLab@School* and FabLearn and the Fab Foundation or the USFLN.

I must note that while the North Fab Lab instructors understand the North Fab Lab as an "organized version" or "package" of the Maker Movement (Mr. Mitchell, interview, April 17, 2015), it is not representative of all makerspaces. Makerspaces support a growing range of goals, settings, and tools. For example, independent organizations like TechShop provide opportunities to *make* for a monthly fee (Hatch, 2014) whereas most public library makerspaces are open and free to the public. Some Fab Labs feature digital fabrication technologies, while makerspaces in most museums, art studios, and libraries feature both digital and non-digital fabrication tools. This study focuses on one particular Fab Lab course in one public high school. I do not mean this study to represent all makerspace learning environments or Fab Labs, although it may provide insight for informal and formal learning environments that wish to adopt similar models.

Courses Observed for Study

At the time of this study, the Fab Lab department had been offering courses to students for four semesters with six courses taught each semester. The Fab Lab department is similar to other subject area departments at North High School where instructors meet regularly to design curricula and engage in professional development; however, Fab Lab instructors hold certifications in different subject areas. As an interdisciplinary course, Fab Lab instructors hold certification in the areas of science, math, technology & engineering, and art. The North Fab Lab offers multiple courses with Fab Lab 1 being the introductory course through Fab Lab 3 that typically enrolls junior and seniors. Each course centers on using computer-controlled (digital) fabrication technologies such as 3D printers, laser cutters, CNC routers, vinyl cutters, and milling machines to design artifacts. North High School considers Fab Lab courses general electives because the state does not yet recognize Fab Lab courses as part of a particular state-licensed program. The three instructors that taught Fab Lab courses at the time of this study also taught in the science, math, and technology & engineering departments, respectively, and held state licenses in those areas.

In this research study, I observed one Fab Lab 1 course, a semester-long course that serves students with little to no experience using digital fabrication technologies. According the Fab Lab 1 course description,

> In Fab Lab Intro, computer-controlled fabrication technologies such as 3D printers, lasers, CNC routers, vinyl cutters and milling machines will be used to transform a product idea into its tangible form. Students will explore many interrelated career fields, including engineering, science, mathematics, art, graphic design, computer aided design (CAD), electronics, and entrepreneurship.

There are no prerequisites for enrolling in Fab Lab 1, though students must earn a grade of B or better in Fab Lab 1 if they want to enroll in Fab Lab 2. Fab Lab 2 is more self-directed than Fab Lab 1 as students do not complete teacher-planned projects, but "create innovative products to solve a problem" identified by the students. Students must earn a grade of B or better in Fab Lab 2 or have teacher permission to move on to Fab Lab 3. Fab Lab instructors expect Fab Lab 3 students to work on their own design projects and serve as mentors to Fab Lab 1 and 2 students.

The technology & engineering department offers a range of courses. Audio and video technology teaches students about the technologies and techniques for producing commercials, newscasts, and music videos for particular audiences. Drafting courses teach students how to design mechanical drawings using AutoCAD and Solidworks software. Woodworking and metalworking courses introduce students to technologies and techniques for carpentry, cabinetmaking, construction, and welding. There are also several courses related to automotive technology and services. The three technology & engineering teachers are certified through the state's technology education licensing. According to the school website, these courses focus on building skills that are applicable to many careers such as architecture, interior and landscape design, engineering, automotives, and trades like construction, carpentry, and welding. Students also have opportunities to earn college credit in welding, cabinetmaking and millwork, and CAD through a local technical college.

In this research study, I observed an introductory woodworking course, a semester-long course that serves students with little to no experience using woodworking technologies. According to the course description,

> This course deals with the development of skills, techniques and safe use of hand/ power tools and equipment. Classification and application of materials and calculation of material costs will be covered. Students will develop skills needed to complete a series of prototypes, projects and design solutions. Students will also experience activities related to trades that are in high demand.

There are no prerequisites for this course, but this course is a prerequisite for other courses in the technology & engineering department including cabinetmaking and millwork, rough and finish carpentry, and residential construction & remodeling.

Participants

The Fab Lab has six instructors who have completed training through the Fab Academy, though, at the time of the study, only four taught Fab Lab courses. As previously mentioned, Fab Lab coursework is not currently recognized by the state's department of instruction as belonging to a particular licensed subject area, so these courses are considered general electives and taught by instructors from a range of departments. North High School considers Fab Lab a STEM learning environment, so instructors come from science, math, art, and technology & engineering departments. While I recruited all six Fab Lab instructors to this study, only four agreed to participate.

To protect the participants and the school, all personal information and connections to the school remain confidential. I gave instructors and students pseudonyms in all documents including field notes and transcribed documents including audio and interview data. Mr. Carson is a Fab Lab instructor and the main instructor of the Fab Lab 1 course that I observed in this study. In addition to his Fab Lab teaching responsibilities, he also teaches AP Calculus 1 and 2 in the math department. These courses enroll juniors and seniors. The course guide recommends these courses "for the most advanced Pre-Calculus students who can handle the challenge of a college level mathematics course taught at full college speed." In addition to his teaching responsibilities, Mr. Carson also coordinates the talented and gifted program and sponsors the quiz bowl team which practiced in the Fab Lab every Wednesday during lunch.

Ms. Rhodes did not teach a Fab Lab course during the research semester; however, she uses her Fab Lab training to implement digital fabrication technology and practices in her art courses as part of the art department. She currently teaches advanced jewelry, basic art 2D, basic art 3D, and computer art. She teaches all grade levels.

Ms. Coleman does not teach a Fab Lab course either; however, she trained alongside Ms. Rhodes because she plans to teach a Fab Lab course in the future. Ms. Coleman currently teaches iSTEM and Chemistry for Science and Engineering Careers. According to Ms. Coleman, iSTEM stands for integrated science, technology, engineering, and math. This course, previously called physical science, was re-titled in the fall of 2015. All freshmen are required to take this course. Chemistry (Sci/Eng) is a junior-level course. All juniors take either Chemistry or Chemistry (Sci/Eng). According to course descriptions, these two courses are equally rigorous; however, Chemistry (Sci/Eng) is "intended for students pursuing careers in the areas of Science, Technology, Engineering, and Mathematics; Agriculture, Food, and Natural Resources; Health Science; and Science Education." This course also requires completion of Algebra 1 and Geometry. Like the Fab Lab, the science department has adopted the language and interdisciplinary nature of STEM education. Ms. Coleman co-sponsors the quiz bowl team with Mr. Carson.

Lastly, Mr. Mitchell, whose former employer helped fund the development of the Fab Lab, is now retired and acts as a volunteer instructor in the Fab Lab. During an interview, he referred to himself as a Fab Lab champion, "the person that has the bigger vision of the dream" (Interview, April 17, 2015). According to the Fab Foundation,

> [A Fab Lab champion] is the local community leader who believes in and is passionate about the Fab lab concept and what it can do for the community. This is a person who is closely connected to the community base in order to bring resources (financial and otherwise) and commitment to the fab lab from within. This person may already be running a NGO or community center, and has a personal commitment to and community mission for that center, rather than performing merely an administrative role. (Fab Foundation, n.d.)

Mr. Mitchell spends approximately three days a week in the Fab Lab helping students with their projects, applying for grants for future Fab Lab funding, and making connections with local industry that supports the Fab Lab through funds and materials. Mr. Mitchell describes how his background allows him to play the role of Fab Lab champion,

> So the part I really like is the industry connection because it's easy for me. I've done that all my career. I've worked with all companies throughout the world. I have no fear of, you know, applying for a grant at Honda Foundation or wherever… And I invite them in to one of our open houses that I help run. So those people that are skeptics, when they come here, they're walking out shaking their head yes. And this happened many times. I go and I don't try to sell, but sometimes they think I'm selling something. But usually, just inviting them to come, and once they do that, they see want we're doing and they like it. Industry really wants young, talented employees that can problem solve. (Interview, April 17, 2015)

At the time of this study, the North Fab Lab had enough funds to cover costs through 2018. The school district gives Mr. Mitchell a small stipend for his continued work with the Fab Lab. He was present almost everyday during classroom observations.

Mr. Gibson taught the introductory woodworking course that I observed for this study. Mr. Gibson is part of the technology & engineering department and is a CTE certified teacher. The technology & engineering department is broken into four areas including communication, construction, welding, and transportation. Mr. Gibson teaches all the construction courses including introductory woodworking, cabinetry & millwork, intro to building trades, rough & finish carpentry, and residential construction & remodeling. Students of all grade levels take introductory woodworking. Table 3.1. includes information on the instructors' course schedules.

Table 3.1.

Instructor Participants and their Course Schedules

Instructor Participants/Certification	**Course Observed**	**Additional Courses Taught**
Mr. Carson/Math	Fab Lab 1	Fab Lab 2 and 3; AP Calculus 1 and 2; Talented & Gift Program
Ms. Rhodes/Art	----------	2D Art; 3D Art; Advanced Jewelry; Computer Art;
Ms. Coleman/Science	----------	iSTEM; Chemistry (Sci/Eng Careers)
Mr. Kent*/Science	----------	Fab Lab 1; iSTEM; Physics; AP Physics
Mr. Smith*/CTE	----------	Fab Lab 1; Drafting 1, 2, and 3; Audio Video
Mr. Mitchell/volunteer	Fab Lab 1	------------
Mr. Gibson/CTE	Intro. Woodworking	Cabinetry & Millwork; Intro to Building Trades; Rough & Finish Carpentry; Residential Construction & Remodeling

*Did not participate in study

Table 3.1. Instructor participants and their course schedules

Mr. Carson taught the Fab Lab 1 course I observed. Mr. Mitchell, a Fab Lab volunteer, was also present most days to help students with their projects. This Fab Lab 1 course enrolled 13 students (11 male students and 2 female students), a typical number for Fab Lab 1 courses. I recruited five of the thirteen Fab Lab 1 students to the study. I recruited two Fab Lab 3 students, who acted as mentors to the Fab Lab 1 students, for a total of seven Fab Lab students. I observed Mr. Gibson and his introductory woodworking course that enrolled 18 students (all male students). Only one student agreed to participate in the study. This low number may be due to the recruitment period, which took place mid-semester instead of at the beginning when I recruited Fab Lab students. I also did not spend much time in the shop before recruitment and the shop environment made it difficult to build relationships with the students, as it was too noisy to hold conversations as I did with the students in the Fab Lab before recruitment. Table 3.2. includes additional information on student participants including how Andy, Blaise, and Landon had taken both Fab Lab and woodworking courses. Andy took advanced woodworking at the time of this study. Blaise and Landon had taken introductory woodworking to complete their CTE requirement for graduation. Every student at North High School has to enroll in one semester-long course in the CTE department to meet graduation requirements.

Table 3.2.

Student Information

Student Participants	**Course**	**Grade Level**
Rachel**	Fab Lab 1	Sophomore
Gwen**	Fab Lab 1	Junior
Nate	Fab Lab 1	Sophomore
Justin	Fab Lab 1	Senior
Tim	Fab Lab 1	Sophomore
Andy*	Fab Lab 3 mentor	Junior
Blaise*	Fab Lab 3 mentor	Senior
Landon*	Intro. Woodworking	Senior

*Took both Fab Lab 1 and Intro to Woodworking

**Rachel and Gwen were the only two girls in the Fab Lab 1 course and there were zero girls taking the woodworking course that I observed.

Table 3.2. Student information

Data Collection

Data collection included classroom observations using written field notes and audio recordings, instructor and student interviews, and the collection of additional materials including course handouts, student work, and press interviews. Table 3.3. includes information about the data sources including the number of classroom visits and hours of observation.

Classroom observations. I conducted structured observations of the Fab Lab and woodworking courses using written field notes and audio recordings. Audio recordings were limited in the woodshop due to the noisiness of the machines. Data collection in the Fab Lab began on March 11, 2015 and observations of the woodworking course began on April 29, 2015. Observations ended on June 8, 2015, during the last week of the school year. I observed both courses three days a week for 50 minutes each. I observed the Fab Lab 1 course for a total of 30 days and the woodworking course for a total of 18 days. For more information on class observations, see Table 3. After each observation, I captured my reflections in written memos. I used audio recording to capture conversations that were difficult to capture using written field notes alone.

Interviews. Using semi-structured interview protocols, I interviewed Fab Lab 1 course instructors, Mr. Carson and Mr. Mitchell, twice, at mid-semester and end-of-semester. I interviewed student participants once at the end of the semester. I interviewed Mr. Gibson once at the end of the semester. I interviewed Ms. Rhodes and Ms. Coleman once at the end of the 2015 fall semester after they completed Fab Lab training. I decided to interview Ms. Rhodes and Ms. Coleman after classroom observations were complete to provide perspectives that were missing from my initial observations. I interviewed both Ms. Rhodes and Ms. Coleman to provide their arts and science perspectives on the North Fab Lab. Because I am interested in how the design and implementation of the North Fab Lab learning environment and curriculum affect how instructors and students see themselves engaging in science, I thought it was important to interview a science instructor like Ms.

Coleman. I was also interested in Ms. Rhodes' perspective on the exclusivity of digital fabrication technologies in Fab Lab courses as an instructor who uses mainly hand-operated tools and some digital fabrication tools in her art courses. Each interview (see Appendix A for Interview Protocols) took place in a private setting at the research site. Interviews were audio recorded and transcribed.

Course handouts, student work, and press interviews. All course handouts including course syllabi, project information, software/technology tutorials as well as student work, and press interviews found through the North Fab Lab website were collected to supplement observations and interviews. These data allowed me to better understand the objectives of the course projects and gave me access to any design, science, and STEM language. The Fab Lab instructors published student work online for anyone to see, so it was necessary to modify details of some projects to protect student participants.

Table 3.3.

Data Sources

	Fab Lab 1	*Intro. Woodworking*
Classroom Observations		
Observational Field Notes	30 visits, 25 hours of written and audio recorded observations	18 visits, 15 hours of written observations
Instructor Interviews		
Mr. Carson	2 interviews/1.5 hours total	
Ms. Rhodes	1 interview/45 minutes	
Ms. Coleman	1 interview/45 minutes	
Mr. Mitchell	2 interviews/1.5 hours total	
Mr. Gibson		1 interview/45 minutes
Student Interviews		
Rachel	1 interview/45 minutes	
Gwen	1 interview/45 minutes	
Nate	1 interview/45 minutes	
Justin	1 interview/45 minutes	
Tim	N/A	
Andy	1 interview/45 minutes	
Blaise	1 interview/45 minutes	
Landon		1 interview/45 minutes
Course Handouts	Syllabus, project instructions and tutorials	Syllabus, project instructions, technology information sheets, safety quizzes
Student Work	Project documentation	Pictures of hand-drawn designs and documentation
Press Interviews	Press releases from local newspapers and the North website	

Table 3.3. Data sources

Data Analysis

Data analysis took place throughout the research process (Stake, 2000). I transcribed and analyzed field notes and interviews after each observation and wrote reflections in the margins and in separate memos. I often used these reflections to capture ideas and develop new questions to pursue in future observations and interviews (Merriam, 2009). I transcribed the audio recordings of classroom observations when I needed to fill in missing observations and to capture participant quotes.

I applied descriptive coding to all the data sources as a first round of first cycle coding (Miles, Huberman, & Saldaña, 2014). I used this method to summarize the basic topic of a passage in a word or short phrase. Using this method resulted in an inventory of codes. Below I provide some examples from my observational field notes and an instructor interview.

[1]I notice a couple more tools in the ShopBot room that are new. There is a jigsaw and a drill press. There was also mention of getting a band saw by another instructor (Field notes, May 15, 2015).	[1]TOOLS
[1]So when I think of this, students now have opportunities to be entrepreneurs first. Maybe they'll go and do a company and maybe it will fail. Great!	[1]ENTREPRENEURIALISM
[2]What a great time to fail when they're 18, right? You learn so much by doing that (Mr. Mitchell, interview, May 27, 2015).	[2]LEARNING THROUGH FAILURE

Following descriptive coding methods, I applied a second round of first cycle coding using In Vivo methods to understand instructors' and students' beliefs about engagement in science in the Fab Lab. I used this method to create codes based on the participants' own words to try to understand what was significant to the participants. This coding method allowed me to analyze instructors' and students' "science talk" in their own words. This analysis provided important imagery and symbols that I examined later using the values coding method (Saldaña, 2009). I took the following examples from interview transcripts and coded them to understand how participants' describe the North Fab Lab and their engagement in science in that space.

One of the most important things is to have everyone feel [1]welcome. And I don't think a [2]noisy, dusty workshop is welcome to everybody. I'm perfectly [3]comfortable there (Mr. Mitchell, interview, April 17, 2015).	[1] "welcome" [2] "noisy, dusty workshop" [3] "comfortable"
Well, I mean I feel like math and the rest of it goes into science so therefore science [1]isn't necessarily a single subject, but I mean there's [2]a science involved in everything. But here you get to put science to a [3]test (Nate, interview, June 05, 2015).	[1] "isn't necessarily a single subject" [2] "a science involved in everything" [3] "test"

I used the values coding method (Saldaña, 2009) to analyze the sociotechnical system of the Fab Lab. The values coding method involved examining the thoughts, feelings, and actions of the participants to identify their values and beliefs. This coding method helped me to identify participants' values and beliefs embodied in the design and implementation of the North Fab Lab as a STEM learning environment, the values and beliefs they hold about digital and hand-operated fabrication technologies, and the values and beliefs that play into the social sorting practices that take place at North High School. The following examples are from observational field notes and an instructor interview.

I come to school early to interview [Andy]. He asks me if I want to observe him during his shop class. He says he'll be better to watch than the 3rd hour class because that class is full of freshmen—[1]"hicks who don't care about school" (Field notes, May 27, 2015).	[1] Unintelligent and lazy
[1]And really what [Fab Lab sponsor is] looking for is employees, number one, right? [2]Number 2 is some recognition of what they're doing, but also in [Fab Lab sponsor's] account, [3]they want to engage their employees into the community (Mr. Mitchell, interview, May 27, 2015).	[1] Vocationalism [2] Recognition [3] Private-Public Partnership

I applied pattern coding to all the data as a second cycle of coding. This method involved me pulling together all the data to identify emerging patterns and themes. These pattern codes helped me organize my data into smaller, more meaningful units (Miles et al., 2014). Analytic memo writing took place throughout the research process and served many purposes. Some memos were reminders to ask a specific question during interviews concerning something I observed. Others reminded me to look for particular words used by instructors like "interdisciplinary" or "entrepreneur" on the school website and in course documents and interview transcripts. Still others addressed theoretical concepts like "boundary-work" (Gieryn, 1999) and most served as my initial codes. Throughout the coding cycles, I wrote memos about my codes and reflected on how to cluster them. I then identified categories that described those clusters (Saldaña, 2009). Once I had a list of categories, I went back to my data sources to examine how my categories mapped onto the data. Those categories that did not map well or did not help me answer my research questions were set aside. I then used those categories that mapped onto my data sources to identify patterns across the data.

Validity and Reliability

I took several steps to increase the probability of producing credible findings. First, I relied on the "triangulation" of multiple methods of data collection including observational field notes, interviews, and course documents (Merriam, 2009). Secondly, I relied on a "peer debriefer" (Carspecken, 1996) to check my interpretations of the data to make sure the results were consistent with the data (Merriam, 2009). Thirdly, I used rich, thick description to help enable transferability (Guba & Lincoln, 1985). I included detailed "thick" descriptions of the Fab Lab learning environment and research findings. These descriptions included quotes from field notes, participant interviews, and course documents. Observing the woodworking course also provided variation to the study of a formal *making* course and allows readers to apply the findings in a greater range of school systems (Merriam, 2009). Lastly, I documented the data analysis process in order to reflect on the decisions I made, from the categories I selected to the data I chose not to include in my findings (Luttrell, 2010).

Ethical Concerns

Before gaining consent from Fab Lab participants, I spent several weeks building rapport with teachers and students as I visited their classrooms to observe activities. After this period of time of getting to know me and learning about my research interests, teachers and students could then make a more informed decision about whether or not they wanted to participate in the study. I was not able to spend several weeks in the woodworking course before recruitment because recruitment took place mid-semester. I did not use observations made prior to consent in my research findings (Luttrell, 2010).

All participants had the ability to opt out of the research at anytime, and I reminded them of this right to withdraw throughout the research process. I also gave participants the chance to speak off the record during interviews. During the 2016 spring semester, I shared a subset of my findings with the school to help improve their students' learning experiences, but I did not discuss any participant by name.

Possible Limitations

There is possible selection bias involved in the low number of students who agreed to participate in the study, especially from the woodworking course. Only one student from the woodworking course, a senior male, agreed to participate in the study. From my interview with him, I learned that he had also taken several Fab Lab courses and is planning to attend a local university to study engineering upon graduation. Many of the students who take introductory woodworking plan to attend college post-graduation. There are also students who plan to attend a technical school or find employment post-graduation. Some of these students may have also taken Fab Lab courses. Every student at North High School is required to complete a one-semester course in the CTE department. It was difficult to determine which students took the introductory woodworking course to fulfill this credit and which were planning to take multiple CTE courses to fulfill their "work-based" coursework path requirements. I was unable to get a sense of how many students are on the “work-based” coursework path and who had also taken Fab Lab courses because I was not able to interview them. All of the students who agreed to participate in this study told me during their interviews that they plan to attend college post-graduation. Recruitment in the woodworking course also took place in the middle of the semester because I was originally not planning to observe another course besides the Fab Lab 1 course. Waiting until mid-semester did not give me much time before the recruitment period to get to know the students and earn their trust as I did in the Fab Lab.

Another limitation of the study is that I was unable to observe instructors from the same department. Observing Mr. Smith, the Fab Lab instructor from the technology & engineering department, and Mr. Gibson, the woodworking instructor from the same department may have created a more natural experiment. Because Mr. Carson is a certified math teacher, his approach and philosophy on the Fab Lab may be different from Mr. Smith. Mr. Smith’s approach to design-based learning may have been more similar to Mr. Gibson’s in the woodworking course. Mr. Smith may have also been able to attract more students on the “work-based” coursework path because he would have seen them in his other courses in the technology & engineering department.

Chapter 4: Findings

Using evidence from observational field notes, participant interviews, course materials, and student work, I tell one story of *making* by addressing the following research questions: 1) How does the design and implementation of the North Fab Lab learning environment and curriculum affect how instructors and students see themselves engaging in science; and (2) How does the Fab Lab contribute to or depart from the social sorting practices that already take place at North High School? I will share this story in two parts. Part 1 addresses the first research question by examining the material culture and rhetoric of science and STEM in the North Fab Lab including two student projects that illustrate how popular images of science and STEM are used to establish credibility and status as a science and engineering course. Part 2 addresses the second research question by examining how the Fab Lab relates to the social sorting practices that already take place at North High School.

Part 1. The Material Culture and Rhetoric of Science in the North Fab Lab

North High School has several learning environments designed to provide creative, hands-on learning experiences: a technology & engineering shop, a culinary arts kitchen, an art studio, and a Fab Lab. However, the Fab Lab is the only learning environment designed to reflect popular images of science and said to engage students in science. The following paragraphs illustrate how the material culture and rhetoric of science in the design of the Fab Lab learning environment and curriculum—and the values and assumptions attached to artifacts and rhetoric—may contribute to student and instructor beliefs about their engagement in science in a Fab Lab 1 course.

It's science because it's STEM. How science education standards define engagement in science has changed over the past century. While the field has traditionally taught content and practices as separate entities, curriculum documents and standards such as the NGSS have progressively become more interdisciplinary and focused on epistemic practices and solving real world problems (NGSS Lead States, 2013). Today, the recently published *Next Generation Science*

Standards (which is based on the earlier *Framework for K-12 Science Education*) has integrated engineering into science education “by raising engineering design to the same level as scientific inquiry in science classroom instruction at all levels, and by emphasizing the core ideas of engineering design and technology application” (NGSS Lead States, 2013, p. 1; NRC, 2012). When I interviewed Ms. Coleman, a science instructor and Fab Lab trainee, she shared how the science department at North High School adopted the eight NGSS science and engineering practices and how students are using those same practices in the Fab Lab (Interview, January 14, 2016). For this reason, when I discuss students’ engagement in scientific practices in the following paragraphs, I too will refer to the eight science and engineering practices outlined in the NGSS.

The homepage of the North Fab Lab website says, “Science, technology, engineering, art and math all come together in our state-of-the-art digital fabrication laboratory (Fab Lab).” When I mentioned this claim to the Fab Lab instructors and students and asked them how they engage in science in the Fab Lab, I found that neither the Fab Lab students nor instructors could explain how what they were doing in the Fab Lab was science, and instead, they relied on vague and unsupported claims related to interdisciplinary STEM practices and dated descriptions of science.

Before Mr. Carson, the Fab Lab 1 instructor and math teacher, answered my question, his first response was to distance himself from the claim. “I didn’t write that.” He then told me my question would be better answered by a Fab Lab science teacher, “But no, that’s certainly true and that would probably be a better question for my science colleagues, which is like Ms. Coleman and other science teachers” (Interview, June 1, 2015). His initial response suggests that he did not have a prepared answer to my question. He then went on to vaguely describe science as “a broader topic of engineering”.

> I mean there is going to be some of that actual electronics, that electrical science and a little bit of physics that they are picking up, but the specifics are not there… Only if you’re counting science to include a broader topic of engineering because certainly they are learning a lot of engineering… Yes, we can say that it’s science definitely because of the engineering component (Interview, June 1, 2015).

When I asked Ms. Coleman, a science teacher, if she sees students engaging in science, she replied, "I do… So we've adopted the NGSS standards here and really thinking about the [eight] science and engineering practices, they are totally doing that stuff down there all the time" (Interview, January 14, 2016). She later described how she sees students engaging in science.

> I think the iterative process, the figuring out what to do based on evidence… But that idea of designing something, prototyping it. Oh, that didn't work, let's go back. I need to tweak this. They are certainly using measurement a lot. I think the computer programming is. That problem solving. The logic that they're using there with it and just the logic that they're using in all their kind of thinking for their projects. So that's the kind of science that I think they're doing. Certainly a lot of electronics too. That's one that you can really firmly see the connections in terms of like— if you don't have a full circuit, your LED is not going to light up. (Interview, January 14, 2016)

Ms. Coleman did not describe the eight NGSS science and engineering practices directly, but she did mention the "iterative process" on two different occasions during her interview as a practice that engaged students in science. When she says, "But the idea of designing something, prototyping it. Oh, that didn't work, let's go back. I need to tweak this," she is describing a practice that the NGSS classifies as engineering, rather than a science practice. According to the NGSS (2013), the iterative process takes place in both science and engineering. In science, the iterative process includes evaluating and refining explanatory models by comparing predictions with evidence from the natural world. The iterative process in engineering involves designing, testing, and refining prototypes based on their performance (NGSS Lead States, 2013). In this example, Ms. Coleman describes the iterative process of designing a functioning circuit board, not an explanation of how and why circuit boards work. When she says, "If you don't have a full circuit, your LED is not going to light up," she is talking about the performance of a circuit board. Nowhere in our discussion did she mention science practices like developing and using models and constructing explanations—practices that would suggest engagement in scientific practices as defined in the NGSS. Like Mr. Carson, she seems to argue that because instructors developed the North Fab Lab for STEM education and students are engaging in engineering practices, then students must also be engaging in science. In other words, the Fab Lab involves science because it involves materials and practices from other fields that comprise STEM.

Fab Lab students offered differently worded but similarly vague responses, suggesting that they are also uncertain about how the Fab Lab 1 course involves science. One student, Gwen, said, "I mean its trial and error like in science… I mean there's experiments and stuff, and if it doesn't work you have to figure out what you did wrong" (Interview, June 8, 2015). She did not provide a specific example to explain what she meant by "trial and error." Gwen's explanation that science is trial and error is close to the ideas of inquiry and science in the early 20th century, but does not map onto contemporary accounts of science practice like those stated in the *Framework* (NRC, 2012) or the NGSS (NGSS Lead States, 2013) that promote science as an epistemic process.

When I asked Nate if he engaged in math in the Fab Lab, he said, "Everyday. It's everyday." He then described how the laser cutter requires him to think about the x and y coordinates of artifacts. When I asked him the same question about science, he was less confident, "I feel like math and the rest of it goes into science, so therefore, science isn't necessarily a single subject… There's a science involved in everything… It's like a place where there's no single multiple subject—it's one subject" (Interview, June 5, 2015). Like the instructors pointing to engineering practices as places for scientific engagement, Nate saw his engagement in science within math because the Fab Lab is "one subject" that involves everything, including science. In other words, because the Fab Lab is interdisciplinary, science is everywhere and in every activity.

The students and instructors perceive the Fab Lab to be science because their lifelong exposure to science (in school and the media) and things associated with science has led them to think about science in particular ways. However, the instructors may be drawing some of their beliefs about STEM education from organizations like the Fab Foundation and the Teaching Institute for Excellence in STEM (TIES).

The North Fab Lab draws its inspiration and philosophy from the Fab Foundation, an organization that has helped create hundreds of Fab Labs in communities across the world. Though the Fab Foundation describes Fab Labs as a potential platform for STEM education, very little attention is given to STEM education on the organization's website and their teacher training program (Fab Academy, n.d.) that all North Fab Lab teachers completed. The Fab Academy's focus is to train Fab Lab facilitators how to use digital fabrication software and tools by having them complete a number of projects, not how to engage students in science, engineering, and math using these technologies (Fab Foundation, n.d.). The Fab Foundation does partner with TIES, but like the Fab Foundation, TIES provides only a vague description of STEM education. Neither organization actually mentions what engagement in science looks like in a STEM learning environment beyond referencing "the Next Generation Science Standards and other similar state standards for science education and the Common Core State Standards" (STEM Ecosystems, n.d.). The TIES webpage titled, "What is STEM Education?" provides a definition for engineering, "The art or science of making practical applications of the knowledge of pure science," but not science. This definition does not reference the NGSS and comes from dictionary.com. The webpage goes on to describe STEM,

> TIES always views STEM instruction and the STEM resources that support the instruction with a transdisciplinary lens. Since before Da Vinci, we have taken up this call to action through the design process. It asks for a multiplicity of pathways to offer a series of plausible solutions. From that process has come the power of prototyping, and beta testing. Rarely have our classrooms offered children the chance to engage in such questioning and processes. Now, through STEM education we have the chance to invite our children to look at their school work as important to the world. (TIES, n.d.)

TIES provides a vague description of STEM education and focuses on the design process as a transdisciplinary activity that includes engineering practices like prototyping. This description does not mention practices specific to science like developing models and explanations for natural phenomena—practices described in the NGSS (NGSS Lead States, 2013). These vague science and

STEM descriptions from the Fab Foundation and TIES may contribute to the North Fab Lab instructors' own vague understandings of a Fab Lab as a place where students engage in science.

In addition to the rhetoric of science related to STEM and interdisciplinary education, the Fab Lab instructors' and students' beliefs about their engagement in science in the Fab Lab may also be related to the design of the Fab Lab as a lab, and not a shop, studio, or other space associated with design-based activities.

Fab *Lab* not Fab *shop.* The design of the North Fab Lab learning environment did not stand out to me until Andy, a Fab Lab 3 student, invited me to observe him in the shop one afternoon (Field notes, March 16, 2015). When I walked into the main shop room, it was not long before I noticed differences between the Fab Lab and the shop. More differences became apparent when I began observing an introductory woodworking course three days a week. I made the decision to observe the woodworking course to provide contrast to the Fab Lab. This allowed me to sharpen my observations of the Fab Lab including the physical space, student projects, and the interactions between instructors, students, and technologies.

The North Fab Lab does not look like a typical science lab or a shop. It contains three rooms: A computer lab, a main lab room that houses most of the digital fabrication tools, and a ShopBot room that houses a ShopBot CNC machine. The computer lab contains desktop computers that provide students with access to the Internet and design software like AutoCAD, Solidworks, and Adobe Photoshop and Illustrator. Fab Lab students spend most of their time in the computer lab searching Google Image or Thingiverse for project ideas, using digital fabrication software, and documenting their progress on their personal Google web pages. The presence of computers in the Fab Lab provides more of a "techy" feel when compared to the shop. Woodworking students do not have access to computers in their classroom. Instead of using computers, woodworking students draw inspiration from racks of woodworking magazines that fill the back wall of the classroom.

When I observed Andy building a sofa table, he showed me plans from one of these magazines (Field notes, May 27, 2015).

The walls of the Fab Lab rooms are painted white and are mostly empty. During an interview with Ms. Rhodes, an art teacher, she described the Fab Lab as a “sterile environment” (Interview, January 12, 2016). The walls of the shop rooms, on the other hand, are covered with posters and cabinets that house past and current student projects. A series of posters feature the words “Trade up” and include information on different trade jobs like construction, carpentry, ironworking, and plumbing. When Mr. Gibson, the shop teacher, discussed future careers with his students, he always referred to the trades, and instead of talking about university programs, he talked about apprenticeship education and the advantages of getting paid while enrolled in school (Field notes, May 1, 2015). Despite his department being called technology & engineering, he was never observed discussing engineering careers like mechanical or electrical engineering—careers that were often mentioned by Fab Lab instructors and students (Field notes, March 13, 2015). When participant instructors like Mr. Gibson, Mr. Carson, and Ms. Coleman spoke of courses in the technology & engineering department, they often dropped engineering from the department name and called it simply “tech ed” (Mr. Gibson, interview, June 03, 2016; Mr. Carson, interview, March 23, 2015; Ms. Coleman, interview, January, 14, 2016). Data collection does not provide sufficient evidence to make claims about the woodworking students’ post-graduation plans; however, the material culture and rhetoric of the trades and apprenticeship in the shop and engineering and college in the Fab Lab gave the impression that these courses were preparing students for different career paths. When I asked Fab Lab 1 students about their post-graduation plans, they all mentioned attending college. Andy, Nate, Blaise, and Rachel shared how they planned to major in an engineering field (Interview, May 27, 2015; June 5, 2015; May 29, 2015; June 3, 2015).

The Fab Lab’s main room contains most of the digital fabrication tools including two laser cutters, two CNC milling machines, a vinyl cutter, and three 3D printers as well as soldering and molding and casting equipment. These machines are relatively quiet and do not produce a noticeable amount of dust compared to the woodworking machines (e.g. table saws, band saws, miter saws, routers, planers). In contrast to the whine and hum of a table saw, for example, a 3D printer sounds like a computer printer. Three tall lab benches fill the center of the main lab room. These lab benches are topped with chemical and water-resistant black laminate like those often seen in research laboratories. Instead of lab benches, the shop's workbenches are wooden and the surfaces contain years of dried wood glue and scars from hand-operated power tools. The Fab Lab's main room is also painted white and the walls are mainly bare besides one wall where white lab coats are hung and another wall that displays eight banners, each featuring a private engineering firm that has donated money and/or materials to the Fab Lab. The first time I saw the white lab coats hanging in the Fab Lab, I was reminded of my high school chemistry class. Like the computer lab, the white and bare walls of the main lab room make the space feel open and clean. The shop walls are filled with cabinets containing hand and power tools (e.g. measuring tape, sand paper, wrench sets, drills, jigsaws). A large wooden sign provides steps to an engineering design process and the rest of the wall space features safety posters and newspaper clippings from a couple years ago that feature construction job opportunities in the area. Instead of white lab coats, woodworking students have access to thick, denim aprons that hang in the finishing room where the paint and wood stains are housed.

According to Mr. Mitchell, the Fab Lab was intentionally designed to reflect a lab and not a shop. He mentioned during an interview how the school wanted the Fab Lab to be "a big space, feel open like a lab, not like a shop" (Interview, April 17, 2015). To achieve this image, the Fab Lab has been renovated each summer since it began offering courses in the fall 2013 semester. During an early renovation, the ceiling was raised and a separate ShopBot room was built to house the ShopBot CNC machine that is noisier and dustier than the other Fab Lab machines. The ShopBot was originally housed in the shop due to the noise and dust it produces. Building the separate

ShopBot room allowed the Fab Lab instructors to move the ShopBot to the Fab Lab while maintaining a clean and quiet main lab room. Three large windows were installed in 2015 to increase the amount of natural light entering the main room. These windows replaced two smaller windows. Soft LED lights replaced fluorescent ceiling lamps during the window renovation. The Fab Lab is the only space in the high school with these softer ceiling lamps. During an interview with Mr. Mitchell, he describes some of these renovation projects.

> So those three windows over there are expanding and so we'll get more light, more natural light. And then somebody in our maintenance group, she's an interior designer; she's going to do like an accent wall with color because this color is all white. (Interview, April 17, 2015)

Unlike the rest of the school, the Fab Lab department can afford to make these renovations because it is funded by private donations and grants in addition to school district funding. This level of attention given to renovating the North Fab Lab to achieve a particular look and feel is not typical of public school buildings, and does not typically involve the use of private funding.

Calling the learning space a lab instead of a shop and using artifacts and rhetoric symbolic of science (e.g. clean, quiet, lab coats, advanced technologies) helps to create the feeling that one is working in a research lab and not a shop. The use of these popular science images were most obvious during monthly Fab Lab tours given to community members, school administrators, and business owners interested in learning more about the North Fab Lab. For example, when the lieutenant governor and a local news station toured one afternoon, students stood next to their projects wearing white lab coats that featured the Fab Lab logo (Field notes, June 3, 2015). Observing the students wearing lab coats was interesting because I had never seen a student wear a lab coat on a regular day. The only person that consistently wore one was Mr. Mitchell. There is also no real need to wear a lab coat in the Fab Lab on a regular day because students do not work with materials that could harm their clothes or body (though some students did choose to wear latex gloves while handling molding and casting materials).

The physical design of the North Fab Lab is interesting because it does not map well onto actual research labs. Many research labs to do not have high ceilings, natural lighting, accent walls, or advanced technologies. At best, one might call the North Fab Lab "science-y," a space that includes popular images of science often seen the media. Yet, the use of these images help to set the North Fab Lab apart from the other design-based learning environments at North high school like the shop. These popular images may also contribute to the Fab Lab instructors' and students' beliefs about their own engagement in science. For students like Rachel, Justin, and Nate, the most obvious distinction between the Fab Lab and the other design-based learning environments was the Fab Lab's possession of more advanced, digital fabrication technologies.

It's science because it's cool technologies. As I previously mentioned, the design of the North Fab Lab learning environment did not stand out to me initially, but the technologies featured in the Fab Lab did. The North Fab Lab almost exclusively features digital fabrication tools like 3D printers, laser cutters, and CNC routers. These technologies stand out because they are not typically found in most people's homes or garages, at least not yet. Unlike hand-operated fabrication tools (e.g. miter saws, power drills, and hammers) one would find in many American garages or shops, digital fabrication tools are still relatively new to the general public. Instead of being hand-operated, these tools do all the fabrication work based on digital design plans that have been created using CAD software. Depending on the digital fabrication tool, they either add material or remove it. For example, a student can design a structure using CAD software and a 3D printer can print a 3D copy of that structure with plastic filament, or if a student wants to remove material from an existing object, she can use a laser cutter to etch an image into a piece of wood material. When I asked students why they decided to take the Fab Lab 1 course, all of the students shared a similar response to Rachel, "I really thought the 3D printer was cool" (Interview, June 3, 2015).

Some Fab Lab participants believed they engaged in design-based STEM education when using the Fab Lab's more advanced technologies; however, they did not believe the older, less advanced technologies in the shop provided the same opportunities. The association of advanced technologies with STEM came up when I asked instructors and students if they thought taking a woodworking course would provide the same opportunities to engage in science. When I asked Justin, who has never taken a course in the technology & engineering department, if he thought he would have the same opportunities to engage in science in the shop, he said,

> I would not have learned the science… Well, hmm… I probably would not have learned too much of the science aspects as much as I would have learned the technology, engineering, and maybe math…. I've definitely learned science stuff in Fab Lab, but I don't know if I would have learned the same things or as much in other engineering courses. (Interview, May 20, 2015)

When I asked Justin to describe what science he learned in the Fab Lab, he said, "There's definitely science behind doing circuit boards and actually knowing how to do that." He ended his response by admitting that while you may learn science in the Fab Lab 3 course, "you're not going to see too much very specific science concepts in Fab Lab 1" (Interview, May 20, 2015). When I asked Nate, who has also never taken a woodworking course, if he thought he would have the same opportunities to engage in science in the shop, he said, "With the woodshop class, I mean it's kind of the same thing, but you don't have the intuitive design. It's more primitive. I mean here [you're using] lasers and over there you're using a 6 bit saw" (Interview, June 5, 2015). Nate seems to associate engagement in science with opportunities to engage in the design process and believes that those opportunities occur more naturally when one is using more advanced technologies like those found in the Fab Lab. He does not believe a woodworking course holds the same opportunities because students use tools like six bit saws that are "primitive." Mr. Mitchell expressed similar sentiment as Nate. Though Mr. Mitchell has never taught a shop course, he often referenced his past experiences taking shop courses in middle and high school and attending a technical school when explaining how a Fab Lab is different from a shop.

> [Fab Lab students] can design something that they can dream up and make versus a standard industrial shop, from the industrial ages. These are the tools we have and there's not a lot of design work. There might be some sketches or something, but here you actually

> design it and then you go build it. You have to get the design part that they wouldn't get in a woods class or a metal shop class or a welding class. (Interview, May 27, 2015)

Like Nate, Mr. Mitchell believes Fab Lab students have more opportunities to engage in the design process in part because of tools they use, which are newer and more advanced and not from the "industrial ages." In other words, the Fab Lab engages students in science because it contains advanced technologies—a common symbol of science (Nelkin, 1987). Neither Nate nor Mr. Mitchell ever articulated what they meant by design or how science and design are related. They also did not provide evidence for why Fab Lab tools provide more opportunities to engage in the design process or science compared to shop tools.

Nowhere on the North Fab Lab website or in the Fab Lab 1 syllabus is design or a design process defined. The course syllabus does include the word design in the documentation guidelines, but the instructions to "describe/explain the tools/techniques/process etc used in the programs and software to create the design" seem to use the word design as another word for artifact (Course Syllabus). The following list includes topics students should have included in their documentation for the molding and casting project.

- Programs and software used
- describe/ explain the tools/ techniques /process etc used in the programs and software to create the design
- describe/ explain the settings in the 3D printing software or milling machine, how did you determine these?
- container
- describe/ explain the process of preparing the oomoo mixing, portions, removing air
- molding result- vacuum pump?
- casting-- describe/ techniques /process etc
- material used- why/ process of preparing
- portions
- working with the material, safety
- result of the cast

Similar documentation guidelines were required for each project. Instead of requiring students to share their design practices like defining problems, developing prototypes, and analyzing and interpreting data (NGSS Lead States, 2013), students created more of a cookbook recipe describing the tools and materials they used when making their artifacts.

The curriculum's focus on tools and materials combined with the nature of digital fabrication often allowed student to skip the actual design and building process entirely. For example, during the molding and casting project, four of the five students I observed downloaded an artifact from Thingiverse even though the project instructions said, "Use your own design." When Gwen began working on her molding and casting project, she created a 3D design of a candle mold using Solidworks software. She mentioned to me how she wanted to use the candle mold to make and sell candles (Field notes, March 13, 2015). When I caught up with Gwen the following Monday, she told me how she had changed her mind about the candle idea and had decided to use her design to make a cup. She then asked Mr. Carson if the Fab Lab's casting material was food safe and he directed her to a website where she could find food safe materials for her project. When I returned to check on Gwen's progress near the end of class, I found her on the Thingiverse website looking at cups that other people had designed and that could be printed using a 3D printer (Field notes, March 16, 2015). The following Wednesday Gwen had printed a small tiger figurine using someone else's design from Thingiverse. She told me how she had given up on her candle/cup design and how she planned to use the tiger for her molding and casting project (Field notes, March 18, 2015). When Gwen finished her molding and casting project, she did not mention her original candle/cup designs in her project documentation; however, she was still successful because she provided a detailed description of the materials and tools she used to complete her project.

The vague notions of design in the course syllabus and the lack of design required for each project was consistent with Ms. Rhodes's observations of the Fab Lab. In an interview with Ms. Rhodes, an art teacher who uses some digital fabrication in her courses, she mentioned how she does not observe a lot of creativity or original design in the Fab Lab courses.

> If we're constantly doing technology and not art, there's no creativity. I go into the room and I don't see anything creative in the Fab Lab. I mean there are nice box things and that kind of stuff, but there are not a whole lot of students doing anything out there that's really creative. They might know how to do a circuit board and they might do the technology part of it, but the aspect that is missing I think is creativity. How can you take this further? I'm

> looking at it as—it's a tool. It's like a paintbrush or it's like anything else. But I think you have to design first before you actually create. (Interview, January 12, 2016)

Ms. Rhodes points out how the North Fab Lab's approach to teaching is tool-centric instead of design-centric. When students do not design first then the activity becomes about the technology and not design and self-expression. Ms. Rhodes mentions how technologies are just tools and should not be confused for the creative experience.

One reason Fab Lab instructors may struggle to implement design practices could be due to their lack of design training. Their training through the Fab Academy focused on how to use the digital fabrication technologies not how to use these tools to teach design-based STEM education. During an interview with Ms. Rhodes, she suggested that the Fab Lab is not a course based on the "principles and elements of design" because none of the Fab Lab instructors currently teaching Fab Lab have been trained to teach design.

> The other day I was in a meeting for Fab Lab and I hear [Mr. Mitchell] mention that the Fab Lab is a fine arts credit and I didn't question him on that, but I have to ask that question because up until when we first started, it was not a fine arts credit. Because that would be taking away from art class [laughs]… It is not a fine arts class because there are no fine arts teachers teaching that class, so it can't be [laughs]. Our [art] classes are based on the principles and elements of design, so there is some sort of reason that we're teaching it. We're teaching about elements and we're teaching about principles and we're teaching rules of composition, so everything that is created follows those rules. (Interview, January 12, 2016)

Ms. Rhodes suggests that the Fab Lab is not a design-based course because she does not see the instructors teaching the "principles and elements of design" and the lack of focus on design is at least partly related to the Fab Lab instructors' lack of design training. While Ms. Rhodes did not explain the "principles and elements of design," she seems to suggest that her idea of design is different than the one presented in the Fab Lab.

Despite very little design actually taking place in the Fab Lab 1 course, instructors and students like Mr. Mitchell and Nate still believe that advanced technologies like 3D printers and laser cutters allow them to engage in science and design in the Fab Lab, but not the shop. The association between design, science, and advanced technologies may seem more obvious to Fab Lab participants because the design of the Fab Lab space highlights advanced technologies in a "science-y" lab.

Other examples from my observations confirmed that some members of the Fab Lab associated the newness of digital fabrication technologies or the sense of awe they experience while observing them in action with engagement in science. For example, one afternoon when Nate and a friend were watching the laser cutter cut an image into an acrylic keychain, Nate leaned over the machine and excitedly said, "Science! Science!" (Field notes, March 11, 2015). At the time I did not think to ask him what he meant by that, but the awe, like Nate expressed, that can be experienced when observing advanced technologies can confuse observers and users of technologies in believing that they are actually engaging in science when they are not. Scientific knowledge was certainly applied during the development of technologies, and observers may mistake their experiences of awe with a belief that science is taking place. This awe, like when one watches a NOVA science documentary, is also symbolic of science (Nelkin, 1987).

Thus far, I have illustrated several ways in which the design and implementation of the North Fab Lab curriculum and learning environment may affect how instructors and students see themselves engaging in science. In the following paragraphs, I will illustrate two Fab Lab 1 projects and how the North Fab Lab uses artifacts and rhetoric symbolic of science to establish credibility and status as a science and engineering curriculum and learning environment. The ShopBot project highlights the beliefs and values of the North Fab Lab and how instructors draw upon them to segregate the Fab Lab from more traditional design-based courses like woodworking. The EAGLE project illustrates how the activity of building and programming a circuit board appears to be "science-y" even though there was no evidence, a least not explicitly, that suggests that engagement in science is required to be successful.

ShopBot project: Separating digital from non-digital fabrication technologies. The ShopBot project introduced students to the ShopBot, a brand of CNC router that can cut and engrave wood and similar materials. For this project, instructors told students to create a 2D design using AutoCAD or Illustrator software and then use VCrave software to transform the design into a tool path that could be read by the CNC machine. I observed Rachel on the day she used the ShopBot to fabricate her 2D design of a star into MDF board. Andy, a Fab Lab 3 student, was also there to help Rachel set up the machine. In the following paragraph, I share this incident from my field notes.

When the ShopBot had finished cutting her design, Rachel and Andy learned that the ShopBot had not cut all the way through the board. They soon realized that the program was set for 0.5 inch material and Rachel had selected 0.75 inch MDF board. During her second attempt, Rachel changed the cut depth but she forgot to tell the ShopBot to go to the home position, so instead of cutting over the original cut, the ShopBot cut next to it resulting in another failed attempt. By this time, Mr. Carson had entered the ShopBot room to check on their progress. When Rachel and Andy told him what happened, he said with a smile, “And you have something to document!” Mr. Carson said these words almost every day because the Fab Lab instructors believe having students document their failures is part of the learning process. After Mr. Carson left the ShopBot room, Andy told me how he hates the ShopBot machine because “these kinds of things always happen.” After a third failed attempt, Andy told Rachel that the computer changed the location of the image, which caused the ShopBot to cut in the wrong place. Mr. Carson returned to the ShopBot room to determine the problem, and he decided that the problem was a machine error. Mr. Carson mentioned that the machine might be losing its “z.” At this point, class was ending and Andy asked if he could cut her design out with a jigsaw. Mr. Carson said, no. He told them that they had time to re-cut it on the ShopBot because no one else needed to use the machine. As Mr. Carson was leaving the room, he said, “Think of all the awesome practice you’re getting at using this machine.” When Mr. Carson was gone, Andy decided to cut her star out with a jigsaw anyways. Andy told me how he used the jigsaw quite a bit in the shop (Field notes, April 24, 2015). Rachel’s documentation on this project revealed that she never did cut out her star design using the ShopBot machine. She and Andy took the star that he cut with a jigsaw to the shop and used an electric sander to smooth the artifact to the appropriate dimensions.

When Mr. Carson told Andy not to use a jigsaw and reminded Rachel to document her work, he was drawing upon the Fab Foundation's philosophy of maintaining a common set of tools and processes in the Fab Lab and documenting in order to share work with other Fab Labs. Every Fab Lab that is part of the USFLN must "share a common set of tools and processes."

> The idea is that all the labs can share knowledge, designs, and collaborate across international borders. If I make something here in Boston and send you the files and documentation, you should be able to reproduce it there, fairly painlessly. If I walk into a Fab Lab in Russia, I should be able to do the same things that I can do in Nairobi, Cape Town, Delhi, Amsterdam or Boston Fab Labs. (Fab Foundation, n.d.)

Mr. Carson shares this same belief when he describes how a USFLN Fab Lab is different from other makerspaces.

> The main difference or the main distinction between what a Fab Lab is and just a makerspace in general… Well, there's a series of them that are generally based on these principles that all Fab Labs follow. One of them is that, the goal is to have similar equipment to all the other Fab Labs. Ideally the same equipment although because they're worldwide and the way distributors work and sometimes you can't get equipment without shipping it long distances, but it's very similar so that you could take a chair that was designed in a Fab Lab in Barcelona, take the digital file and cut it in [North High School], and it would work… (Interview, March 23, 2015)

Many Fab Labs and other makerspaces around the world feature both hand-operated and digital fabrication tools (Blikstein, Martinez, & Pang, 2015); however, the North Fab Lab has chosen to adopt the Fab Foundation's criteria for participation in the USFLN which including sharing "a common set of tools and processes" as other Fab Lab's in the network. So for Mr. Carson, using a jigsaw to cut out an artifact violates the principle of sharing a common set of tools and processes. He said they selected these tools because they are the same ones used at the MIT Fab Lab (Interview, March 23, 2015). The Fab Foundation's list of hardware and software for setting up a Fab Lab does not include traditional hand-operated tools like jigsaws—only digital fabrication tools. They do list a band saw, but only for stock cutting purposes (Fab Foundation, n.d.) When I asked Mr. Carson if he allows students to use other tools like those found in the art room or shop, he said,

> Oh no, absolutely. I mean that's fine. There's a certain artistic beauty to be limited to certain tools or certain colors or along those lines, but no, in our case, no. If your project is a great project but I have to cut these particular pieces on a table saw or something, that's fine. I mean we have the resources. But ideally your project should be something that could be passed on to someone at another lab that could recreate it. So having to do that is fine with the understanding that it would be better if you didn't have to do that. (Interview, March, 23, 2015)

For Mr. Carson, using a hand-operated fabrication tool like a jigsaw hinders one's ability to reproduce the exact same artifact that was digitally designed. He believes recreating an exact artifact can only happen digitally. This ability to make "exact" artifacts was also mentioned on the ShopBot assignment page, "The advantage of using a CNC router rather than traditional tools is the ability to make an unlimited number of parts that are exactly the same. This method improves productivity and efficiency."

The tension around digital fabrication technologies as the only tools available to make exact replicas of digital designs came up during a conversation between Mr. Carson and Andy as they discussed the appropriate tool for cutting out another student's ping-pong paddle design. Mr. Carson had told the student to use the laser cutter instead of the ShopBot. Andy argued that the student should use the band saw in the shop.

> Andy: It makes more sense to do it that way or do it in the wood shop on the band saw. It's much quicker.
>
> Mr. Carson: Because with the band saw, it's not going to be exact.
>
> Andy: It is if you follow a traced line.
>
> Mr. Carson: But it's not going to be exact.
>
> Andy: It's exact enough (Audio field notes, May 18, 2015).

Andy was not convinced by Mr. Carson's argument that digital fabrication tools are the only ones that can produce "exact" artifacts. Mr. Carson's belief conflicts with Andy's own experiences as a student in an advanced woodworking course. For example, during a visit to the shop, Andy showed me a sofa table he was building for his mother using plans from a woodworking magazine. He described his process for cutting materials and how one does not want to cut materials to exact lengths initially. He told me how you make a “rough cut” of all pieces, so when you encounter mistakes, you have “room for changes” (Field notes, May 27, 2015).

When I interviewed Ms. Rhodes, an art teacher who often uses Fab Lab tools, I shared the incident between Andy and Mr. Carson though I made sure not to reveal participant identities. She responded to Mr. Carson’s claim about exactness by saying,

> What bothers me about that statement is [the paddle] might not have been cut out exactly in a circle, but then you take your extra time and you sand it and you finish it and you get a handmade product. I think that’s the big difference. You know if you’re taking a shop class and you’re creating something with your hands, you appreciate it more than, I just printed this out on the ShopBot, sanded off the edges, and it’s done… If I’m looking at a handmade piece, I’m still going to feel it and see, oh, did they do a nice job on the sanding? Is the varnish uniform? Is it stable? Is there some sort of practicality to the piece? Is it functional? And I think the student who probably made the comment probably had taken shop class. (Interview, January 12, 2016)

Ms. Rhodes, like Andy, has experience taking the extra steps like sanding needed to achieve a particular design and does not believe these extra steps make a product any less valuable or usable.

This incident brings up an old debate about the values of craftsmanship versus mass production. In David Pye’s (1968) book *The Nature and Art of Workmanship*, he describes two kinds of workmanship, the workmanship of certainty and the workmanship of risk. Like Fab Lab tools, “in the workmanship of certainty the result of every operation during production has been predetermined and is outside the control of the operative once production starts.” Once Fab Lab students press print, it is up to the machine to turn their digital design into a physical product. In craftsmanship, like the workmanship of risk, “the result of every operation during production is determined by the workman as he works and its outcome depends wholly or largely on his care, judgment and dexterity” (p. 52). What is unique about the North Fab Lab is that unlike most hands-on environments like the shop that rely on both kinds of workmanship, the Fab Lab only values the workmanship of certainty. While woodworking students cut, sand, and finish wooden materials, they also rely on mass-produced screws, nails, and hinges to assemble them. North Fab Lab students neither build their projects by hand nor do they use assembling devices like screws and nails. Instead, they learn how to create press fit designs.

While the exclusive use of digital fabrication technologies in the North Fab Lab may help to justify the Fab Lab's presence in a school that already has similar design-based courses, this choice is not a neutral one. The symbolic meaning embodied in the design of the tools and learning space—and the values and assumptions attached to those symbols—can establish patterns of power and authority that do not exist with other tools and learning spaces (Winner, 1986). The valuing of digital fabrication tools over hand-operated tools not only separates the Fab Lab from other learning spaces and activities that value hand-operated tools, it also dissociates the Fab Lab from the negative connotations of craftsmanship (e.g. dirty, noisy, risky, subjective). Instead, the North Fab Lab is able to draw upon language and values often associated with science and technology. Just like the idea of a quiet and clean lab space, the valuing of digital fabrication allows Fab Lab participants to draw upon words like "exact" and related terms like accuracy, precision, certainty, objectivity, and reproducibility that are symbolic of science and contribute to the common belief that science exists *out there* away from subjective and error-prone human activity like the arts and crafts (Pye, 1968). Valuing the artifacts and rhetoric symbolic of science (e.g. advanced technologies, objectivity) over those in the arts and crafts may reinforce the stereotype held by some Fab Lab students, that shop technologies do not have the ability to engage users in science or design like Fab Lab tools.

Andy was not the only student who valued hand-operated tools for their ability to make quick changes to Fab Lab artifacts. When other students became frustrated by the ShopBot or did not like the ridges left by its drill bit, they would often ask Andy to take them to the shop. On one occasion, Andy taught Gwen how to use a pad sander and how to select the appropriate sandpaper (Field notes, May 25, 2015). I would occasionally see Mr. Mitchell in the shop during my observations of the woodworking course. One morning, Mr. Mitchell brought a female student to the shop because she wanted to sand ridges left by the 3D printer (Field notes, June 5, 2015).

This practice of going to the shop; however, slowly became unnecessary as the Fab Lab began acquiring its own hand-operated tools despite the USFLN criterion about having a common set of tools and practices. Over the course of this study, the Fab Lab acquired a jigsaw, a power drill, a drill press, other basic tools, and Mr. Mitchell was in the process of purchasing a pad sander, an orbit sander, and a wrench set (Field notes, June 5, 2015). The instructors housed all of these tools in the ShopBot room. This choice to purchase hand-operated tools contradicts the instructors' stated beliefs about Fab Labs and digital fabrication and demonstrates the artificiality of an ideal Fab Lab. During an interview with Mr. Mitchell, he notes how students should not have to use the same tools he grew up with in his shop classes.

> I think this is a new way of learning. Somewhat, I mean if I look at myself, born in the industrial age. Our learning was in that noisy and dusty shop, right? That was the learning part of it. But that's not this generation. This is the digital revolution, not the industrial revolution. I really preach that because that's the truth, that these kids aren't learning the way that I learned. They shouldn't have the same tools. It's a different world" (Interview, April 17, 2015).

It is unclear whether Mr. Mitchell would consider the Fab Lab's hand-operated tools "Fab Lab tools"; still, the purchase of these tools and the ability to store them in the ShopBot room allows the Fab Lab to maintain its image of being a quiet and clean lab and remain separate from the shop.

I believe what the ShopBot project examples demonstrate is that even if students are not engaging in the scientific and engineering practices outlined in the NGSS that the North Fab Lab can rely on artifacts and rhetoric symbolic of science to say—This is not another shop class. What is going on in here involves science. In the next project example, I will demonstrate how the activity of building and programming a circuit board can appear to be "science-y" even though there was no evidence, a least not explicitly, that suggested that engagement in science was required for students to be successful.

EAGLE project: Making and programming a circuit board. When I asked the Fab Lab instructors where they see students engaging in science, they all referred to "electronics" (Ms. Coleman, interview, January 14, 2016), more specifically the EAGLE project. This project introduced students to EAGLE (easily applicable graphical layout editor) software and required students to create a digital circuit board using EAGLE, build the board using milling and soldering tools, and program the board to light an LED bulb as shown in Figure 4.1. The instructors told students to download the EAGLE file and "follow the EAGLE assignment tutorial."

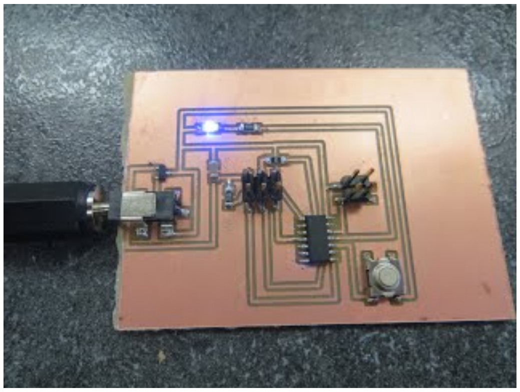


Figure 4.1. EAGLE Circuit Board. This figure illustrates a simple circuit board that lit an LED bulb.

While the instructors often pointed to this project as an activity that required engagement in science, data from student conversations, interviews, and students' own project documentation show no clear evidence that students engaged in scientific practices or even that design practices were necessary to successfully complete the project. For example, when Justin was using the EAGLE software, he said,

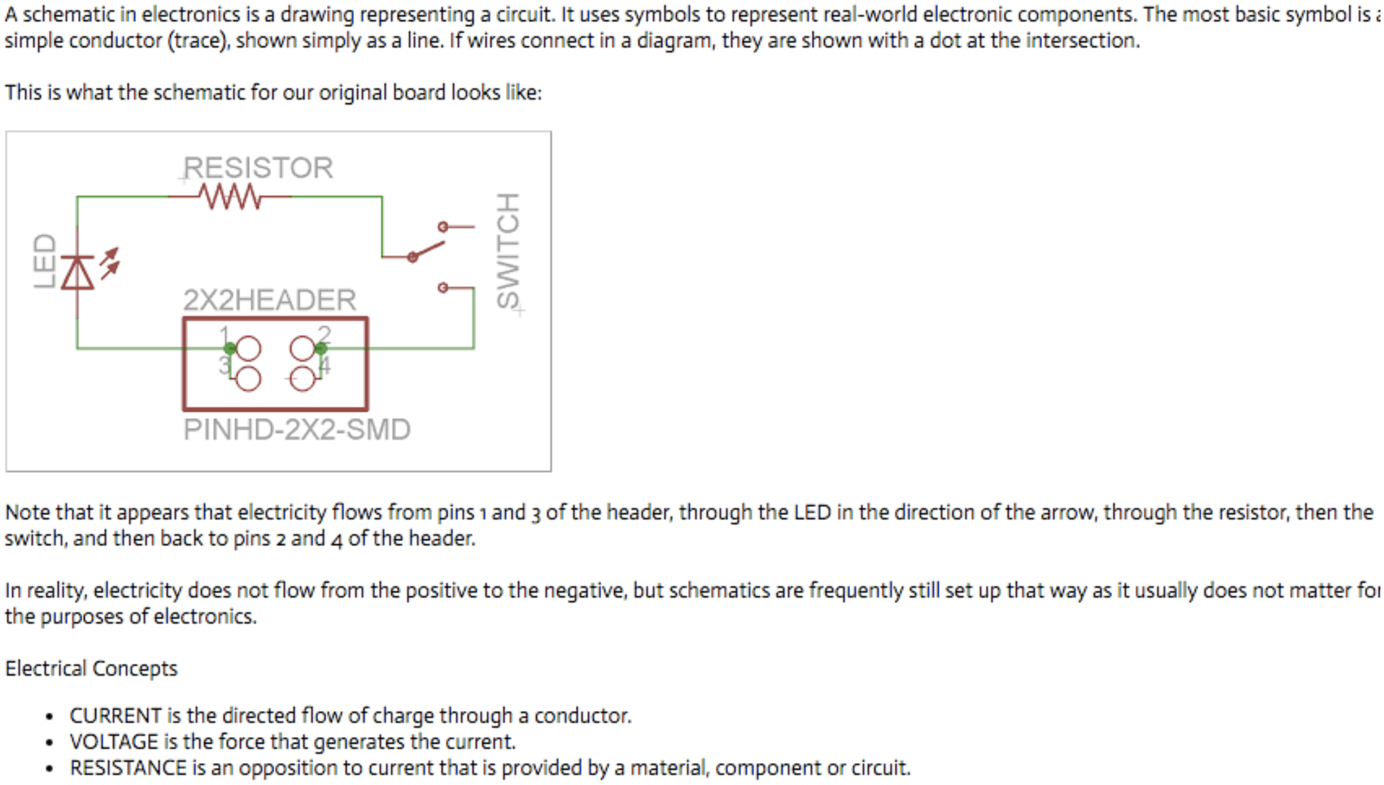
> EAGLE is apparently a mess. I'm not going to really care for originality. I just want something that works so I'll follow their example and take inspiration from a demo or an example… Like I've never designed a circuit before and they already have one there. Like they already have one, so the purpose of the EAGLE project, as far as I can tell, is essentially letting you know how to use EAGLE and not like designing a circuit board. (Audio fieldnotes, April 8, 2015)

Justin's understanding of the purpose of this project was true for many of the Fab Lab 1 projects. Though instructors often referred to the Fab Lab as a place where students engaged in design-based STEM education, all nine of the Fab Lab 1 projects emphasized learning how to use the digital fabrication tools, not designing artifacts that solve particular problems. The goals and outcomes of these projects were determined by the instructors and could be completed by following a tutorial. Even the Fab Lab students' final project did not require students to address a particular design problem. When I checked in with Justin a week later, he again shared his belief about the EAGLE project being an activity designed to teach students how to use EAGLE, not designing a circuit board.

> Justin: At the moment it is just connecting things actually, and as normal, learning how to use the software. And right now, it's just, make a line, name it, make a line, name it. But I know eventually that I'm going to have to switch to this and actually make a circuit with it, which is either going to be a really fun logic puzzle or a lot of copying what is already on the website.
>
> Researcher: So you can do either? Copy the tutorial or…
>
> Justin: Honestly, as long as it works and we know how to use EAGLE, I don't think they're too concerned about that.
>
> Researcher: About getting it just like the one that's pictured?
>
> Justin: It does need to work because we are going to use it for something or another.
>
> Researcher: I think you're lighting an LED.
>
> Justin: But knowing how to use EAGLE is the primary… You're learning how to use EAGLE and how to make an Arduino circuit board or something like that, which is just a tiny circuit board. And normally with most projects I would be able to just dive in, but with this software, I have to follow a rigid set of instructions, which is different than what we have done before… The only problem I see is actually connecting everything and documentation. Because documentation is going to be… well, what do I say? I followed a set of instructions and they don't want me to copy and paste them, so it's just like retyping what is already there and take pictures.
>
> Researcher: You had mentioned resistors and capacitors and that in 8th grade you had learned a bit about circuits. Were any of those concepts taught in this course?
>
> Justin: With this, no. They might just expect you to know that because everyone goes through that and then they go here, and everyone does take that class, but I don't think they were talked about in this class. But if you do go into the instructions, it does tell you things like what's a microcontroller. It at least gives you a very brief overview of the things in the schematic. (Audio fieldnotes, April 15, 2015)

Mr. Carson did not provide any direct instruction about circuitry during this project. I asked Justin if he had learned about circuitry before taking Fab Lab 1 and he mentioned that he had completed a circuitry unit in his eighth grade science course. Mr. Carson may assume that because all his students completed eighth grade that they remember how and why circuit boards work, or he may expect them to read the tutorial that provides some (quite minimal) information on circuitry.

The EAGLE tutorial reads like a typical cookbook science lab. The tutorial begins with the goal of the project— "Take the board that we created in the first activity, modify it by adding a processor, an input device (switch) and to change the voltage to the more appropriate 5V with a regulator." The tutorial than provides a schematic of a basic circuit board and includes scientific terms like current, voltage, and resistance. Figure 4.2. and 4.3. show how scientific concepts related to a circuitry were introduced in the EAGLE tutorial.



A schematic in electronics is a drawing representing a circuit. It uses symbols to represent real-world electronic components. The most basic symbol is simple conductor (trace), shown simply as a line. If wires connect in a diagram, they are shown with a dot at the intersection.

This is what the schematic for our original board looks like:

Note that it appears that electricity flows from pins 1 and 3 of the header, through the LED in the direction of the arrow, through the resistor, then the switch, and then back to pins 2 and 4 of the header.

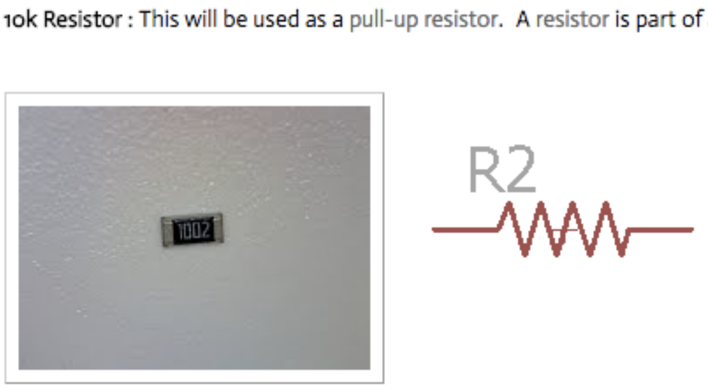
In reality, electricity does not flow from the positive to the negative, but schematics are frequently still set up that way as it usually does not matter fo the purposes of electronics.

Electrical Concepts

- CURRENT is the directed flow of charge through a conductor.
- VOLTAGE is the force that generates the current.
- RESISTANCE is an opposition to current that is provided by a material, component or circuit.

Figure 4.2. A Schematic of Students' Original Circuit Board. This figure illustrates students' original circuit board and includes electrical concepts like current, voltage, and resistance.

This schematic shows students a drawing of a circuit; however, there are no descriptions that explain the parts, how they interact, and why their placement is important. This missing information makes understanding how a circuit board works difficult without any prior knowledge of circuitry. The concepts: current, voltage, and resistance are introduced at the end, but the definitions do not help explain how these concepts are related or why knowing these concepts are important to completing the project. Later in the tutorial students are introduced to the components (Figure 4.3) they will need to solder to their board. The definitions provided next to each picture are vague and do not explain how they interact with the other components.



10k Resistor : This will be used as a pull-up resistor. A resistor is part of an electrical circuit that resists the flow of current.

Figure 4.3. A Circuit Board Component. This figure illustrates how pictures and definitions of components were used to help students learn the parts of a circuit board.

The rest of the tutorial is written as a list of instructions that students are to follow like a recipe. For example,

1. Add a component (either type "add" or select the "add icon from the toolbar". The add menu will open.
2. You can either look through the listed libraries for a component to add or you can type it into the box above the "drop" button.
3. You already have an LED, a resistor and a 4-Pin connector, power and ground on your board.
4. Add two Resistors (in the ng library). You should select the one labeled 1206. 1206 is the type of component that is mounted directly to the board. One will be the 10K resistor, the other the 0 ohm bridge.
5. Click "ok" and then click on the schematic to place the component. It doesn't matter where you place it, just try to find some open space so that the lines are not overlapping. You can use Esc to return to the add screen after placing.

Once students have completed the tutorial and the LED light blinks twice then the students have completed the project. The instructors did not ask the students to reflect on how their circuit board works, or if it does not work, why it might not work. One could argue that the tutorial exposes students to circuitry concepts; however, not all students saw the need to read the tutorial when making their circuit boards. Below is a conversation I had with Gwen where she describes how she relied on visuals to complete the project, not the written instructions.

> Researcher: So Gwen, did your EAGLE board work the first time?
>
> Gwen: Yeah.
>
> Researcher: You seem to be one of the lucky ones.
>
> Gwen: I know. I'm so happy… I'm glad it worked, because it didn't work for Rachel, and I was like oh great, mine's definitely not going to work.
>
> Researcher: And some people are on their like fourth or fifth one.
>
> Gwen: Right, they keep going at it, new boards and everything. Like I'm not sure why… There's so much that can get messed up, I guess. But honestly, I just looked at the example he had on the website because his board worked. Okay, so I'll just copy it. I didn't really read the instructions either. I'm more visual, so I was like the line is there, so I'll just draw it there. It worked out okay. I mean it works! (Audio field notes, June 8, 2015)

When I asked students if the EAGLE project engaged them in science, they again provided vague responses that suggest that they did not. For example, when I asked Gwen if the EAGLE project helped her understand how a circuit board works, she said,

> I do. I mean I asked a lot of extra questions that I don't think everyone asked. I learned that it's an Arduino board and like what you can do with it. I mean at first I asked why are we doing this because it's just another light switch and it's just turning on and off and stuff, and I didn't understand, but there's like programming behind it and what you could do, not just with a light, but opening and closing a door or how to use it in real life. (Interview, June 8, 2015)

Instead of describing how a circuit board works, she explained how the project allowed her to see how her new skills could be applied to different projects. This may be an important outcome, but it does not point to engagement in science. When I asked Rachel how the EAGLE project allowed her to engage in science, she said,

> You know with the LEDs, you have to know the… Well, like the charges… Like I made a battery holder for the programmer, to program a board, and so I had to connect the negative charges and the positive to certain places so, I mean, science and stuff. (Interview, June 3, 2015)

Rachel's response starts out promising as she refers to electrical charges, but then she is unable to finish her idea and how it relates to science beyond saying, "Science and stuff." She later admits that she does not know how a circuit board works.

> I'm still a little confused on some stuff, like programming the board because my board didn't work and I never really fixed that because I didn't have time. So I don't really understand beyond just creating the routes of the board and soldering. (Interview, June 3, 2015)

Although Gwen and Rachel were unable to explain how a circuit board works and neither Justin nor Rachel were able to build a working circuit board, all three students were successful based on the North Fab Lab assessment guidelines.

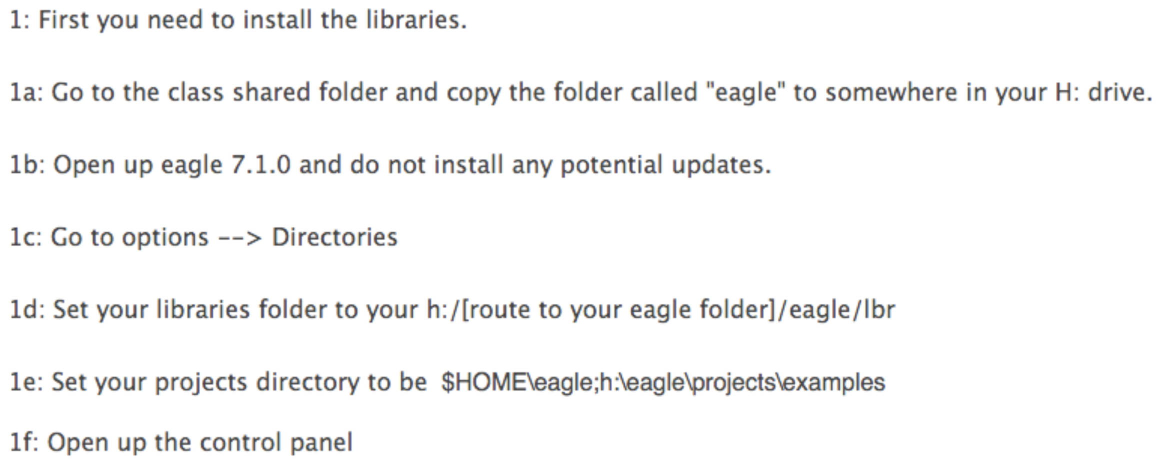
North Fab Lab students are required to document every step of each project. The purpose of documentation is taken from the Fab Foundation's philosophy of sharing your work and making sure that someone from another Fab Lab has the instructions to make exactly what you made. The Fab Lab 1 syllabus explains,

> Documentation is the practice of describing an event or process so that a viewer and/or reader can follow the event and come away with an orderly and logical understanding of why and how the event took shape. This is a standard practice for engineers during the design and building process… Describe clearly, adequately, thoroughly and in detail what it is that you did, accomplished, learned, skills developed and the process/procedure that got you to a final product including failures and how you overcame them.

In this explanation for why documentation is important, the writer makes a point to say that by documenting their work, students are engaging in an engineering practice. When I asked Justin what skills helped him be successful in the Fab Lab, he mentioned the skills needed for documentation.

> I feel like actually being able to type decently quickly helped out because then I can actually document quicker, and also being able to explain things well is something that really helped out with my documentation because that's essentially what you're actually graded on. Like you have pictures of what you did, but unless you have the documentation to show for it, you get no points. So being able to do stuff like that really helps out. (Interview, May 20, 2015)

Figure 4.4. shows a segment of Justin's documentation work for the EAGLE project.



1: First you need to install the libraries.

1a: Go to the class shared folder and copy the folder called "eagle" to somewhere in your H: drive.

1b: Open up eagle 7.1.0 and do not install any potential updates.

1c: Go to options --> Directories

1d: Set your libraries folder to your h:/[route to your eagle folder]/eagle/lbr

1e: Set your projects directory to be $HOME\eagle;h:\eagle\projects\examples

1f: Open up the control panel

Figure 4.4. Justin's EAGLE Project Documentation. This figure illustrates how Justin's EAGLE project documentation reads like a cookbook recipe.

Justin began his documentation by stating how it looks very similar to the EAGLE tutorial. He then provides a link to that document. He does include a segment on problems he faced, but he did not always know why his boards did not work and the project did not require him to figure out why the boards did not work.

> First of all, I screwed up the traces by not changing them from their original size. That was my first mistake. Second board I made had a slight difference when compared to the master board, and that may have screwed it up. Or bad soldering. Something like that. Either way, that second board didn't work either. The third board didn't work because I don't know. I will be returning to this project in an attempt to actually get it working after I'm done with my final project. (Student work, n.d.)

Justin's documentation is not written in a way where a reader could "follow the event and come away with an orderly and logical understanding of why and how the event took shape." Instead, it was written as list of instructions, which suggests that he did not document like engineers do in the field. There is also no evidence from his documentation that the EAGLE project required him to engage in science to be successful. He does not share what he learned and he does not use any of the science concepts included in the EAGLE tutorial to help explain how and why circuit boards work or why his three circuit boards did not work.

Justin, Gwen, and Rachel's experiences during the EAGLE projects do not align with Fab Lab instructors' beliefs about the EAGLE project's ability to engage students in science or engineering. During an interview with Mr. Mitchell, I asked him how he thinks making a circuit board helps students engage in science.

> Well, we're the only ones doing it… [laughs] We're going to keep doing circuit boards because it's a difficult thing to do. It's a master's level course at MIT that teaches circuit boards. To make the circuit board isn't easy. You first have to machine it and then you have to solder it and then you have to load it… (Interview, May 27, 2015)

Mr. Mitchell begins by suggesting that activities that are not easy must include science because science is hard. He then goes on to associate building and working with electronics technology with engagement in science. During an earlier interview, Mr. Mitchell described scientific concepts and explanations that students learn as they make circuit boards.

> They all won't be circuit board designers or electric engineers, but now when they look at an LED light, they know how that thing works. They know how many Ohms of resistance it is, they know how a battery works. When they go to Calculus class and you learn Ohms law in Calculus, right? Why do you learn Ohms law in Calculus, because it applies here. So when they go in there, they like oh, I'll stop asking that question that I always asked, "Why am I learning this?" "When in life will I ever need to know this, Mr. [Carson]?" And he said they never ask that question in here. They never ask that. Why do I need to learn it, because I need it for my project. It's almost like… [Student Name] built a quad copter the first year here. He developed the need to know. So that's what I think is really cool is they develop their own need to know and they surpass all of us. (Interview, April 17, 2015)

Mr. Mitchell believes the activity of building and programming a circuit board teaches students how a circuit board works and allows them to draw upon concepts like Ohms law, a concept taught in their Calculus courses. Mr. Mitchell assumes students who complete this project also take Calculus, a point I will return to in part 2 when I discuss which students take Fab Lab courses. He goes on to share how building a simple circuit encourages students to begin thinking about input and output and how "they develop this need to know."

> The simple circuit board they build first is a power source, a light, and a switch. That's all it is, and if you look around us, how many lights, power sources, and switches are there? [Mr. Mitchell laughs] They're everywhere. So that's a simple circuit, right? And now we're going to do something else, we're going to control that circuit; we're going to put a programmable controller in it. Now we're going to tell that controller when to turn on that light or a sensor to say, the light should be on when it's dark in the room… They start to think about

> input/output devices and then that gets them into the next level, which is really the need to now. You know they develop this need to know. Because the curriculum isn't as much as, when they want to go build something, they have to figure it out, and then they learn by the need to know. They look it up and start to figure it out. That's pretty neat to watch. (Interview, May 27, 2015)

Mr. Mitchell believes that this kind of activity causes students to "develop this need to know" science, but he does not state what science he thinks they need to know in order to build and program a circuit board. There is no evidence that students needed to know or engage in science to successfully complete the project. There is also no explicit evidence from student interviews and documentation that they began thinking about input and output during the EAGLE project. What students need to know to complete the project might not be science.

When I asked Ms. Coleman, a science teacher, how she sees students engaging in science, she also pointed to the circuit board project. "Certainly a lot of electronics too… That's one that you can really firmly see the connections in terms of like— if you don't have a full circuit, your LED is not going to light up" (Interview, January 14, 2016). She seems to believe that building a successful circuit board is evidence that science learning took place. However, students' documentation of the EAGLE project and their conversations about the EAGLE project showed no evidence of any scientific questions, models, or explanations that would suggest engagement in science—as described in the NGSS. Instead, the students understood the project as an opportunity to learn the EAGLE software by following a tutorial and copying another person's circuit board design. Student conversations and their documentation pages reflect this understanding.

I also want to briefly point out that Fab Lab 1 students may also not be engaging in the engineering practices described in the NGSS. Though not the focus of this study, one could raise a similar set of research questions about whether or not students are actually engaging in engineering practices and if the North Fab Lab is using artifacts and rhetoric symbolic of engineering in the same way as science to establish credibility and gain status at North High School.

Just because building and programming a circuit board requires students to use advanced technologies and exposes students to terms like resistance and current (terms they might hear in a science course), it does not necessarily follow that students are engaging in science as it is defined in the NGSS. The EAGLE project demonstrates that while instructors and students think science is important, there is a gap between their beliefs about their engagement in science in the Fab Lab and students' actual need to engage in science to be successful.

If engagement in science is not required then why do Rachel, Mr. Mitchell, and Ms. Coleman assume science is in the EAGLE project and why is it important to say that it is? I think they assume the EAGLE project requires engagement in science for several reasons. Circuitry is a topic often taught in science courses. Justin mentioned how the topic was taught in his eighth grade science course. The EAGLE tutorial includes scientific terms like current and resistance and the project requires students to use high tech tools, a symbol of science (Nelkin, 1987). Lastly, Mr. Mitchell mentions how the Fab Lab is the only learning space that requires students to build circuit boards and that this activity is one that is taught in a "masters-level course at MIT." He then makes the connection between MIT, a university with a reputation for science and engineering, and how making a circuit board "isn't easy" (Interview, May 27, 2015). He seems to be making the assumption that if MIT does it and it is hard, that this activity must require students to engage in science.

The subtle rhetorical and symbolic work of associating scientific engagement with Fab Lab 1 projects like the EAGLE project is important because it allows participants to say that the Fab Lab is not another shop course, but rather that it engages students in science and engineering. The North Fab Lab relies on artifacts and rhetoric (e.g. hard, electronics, high tech) symbolic of science to establish credibility and status as a course for students who take Calculus and other advanced placement courses.

Using evidence from observational field notes, participant interviews, course materials, and student work, I found that (1) The North Fab Lab relies on artifacts and rhetoric symbolic of science and STEM to set itself apart from other design-based learning environments and curricula at North High School; and (2) North Fab Lab instructors and students were unable to explain how what they were doing in the Fab Lab was science, and instead relied on vague and unsupported claims related to interdisciplinary STEM practices and dated descriptions of science. Together these findings help explain why the instructors and students believed they were engaging in science in the Fab Lab, yet were unable to explain how what they were doing was science.

Dorothy Nelkin's (1987) research examining how people experience science through the press helps shed some light on these findings. In her research, Nelkin found that people "understand science less through direct experience or past education than through the filter of journalistic language and imagery… that imagery often replaces content." (p. 2-6). In this study, the participants' direct experiences with popular images of science (e.g. clean and quiet lab, intellectually hard, advanced technologies) may cause them to believe they are engaging in science when there is no evidence, at least not explicitly, that suggests that engagement was taking place.

The second finding is consistent with Berland et al's (2013) research examining students' ability to identify their engagement in science and math during engineering-based activities. In that study, researchers found that when they asked students to describe specific instances in which they used math and science ideas, many students provided vague answers. Similarly, the Fab Lab students *and* instructors believed they engaged in science during interdisciplinary activities featuring engineering design practices; however, when they were asked to identify specific scientific practices, their responses were vague and referenced practices like working through "trial and error" or the "iterative process" and not aspects of design like modeling and developing explanations. These findings are important because they point to how artifacts and rhetoric symbolic of science, STEM, and interdisciplinary education, when attached to design-based activities, *making*, and Fab Labs, create the impression that participants are engaging in science when, in fact, their activities do not match up with the characterization of science in NGSS and other documents. These findings are also important because North High School promotes the Fab Lab as a learning space that engages students in science, when science learning might not be taking place.

Summary. If the Fab Lab instructors did not write the claim on the North Fab Lab's website about STEM engagement, then who is making this claim and why is this claim important? The importance of associating the Fab Lab with science and other STEM subjects may have less to do with teaching science content and practices and more to do with the benefits afforded the Fab Lab when it reflects popular images of science and not those of more traditional design-based learning environments like a shop. As one student said, "I think [the claim about science, technology, engineering, art, and math learning taking place in the Fab Lab] is more of a thing that's made to say, 'Hey, look at what we're doing!'" (Justin, Interview, May 20, 2015). I believe the North Fab Lab relies on artifacts and rhetoric symbolic of science in the learning environment and curriculum to gain credibility as a science and engineering course and status as a course for students on the advanced placement coursework path, topics I will address in part 2.

In part 1 of this chapter I demonstrated how the North Fab Lab learning environment and curriculum relies on popular images of science (e.g. clean, quiet, lab coats, advanced technologies, intellectually hard) to set itself apart from more traditional design-based courses, and how these images may cause instructors and students to believe they are engaging in science even when they cannot provide explicit evidence that engagement took place. Still, the North Fab Lab is able to use these popular images of science to establish its credibility and status as a STEM course. In part 2, I will demonstrate how the North Fab Lab's reliance on popular images of science and their intentional dissociation with images of craft and technical work (e.g. dirty, noisy, risky, unintelligent work) reinforce social sorting practices at North high school.

Part 2. North Fab Lab: A "Comfortable" Learning Environment for Everyone

Mr. Mitchell used the word "comfortable" more than any other word when he described why the instructors designed the Fab Lab like a lab and not like a traditional shop classroom. For example, during an interview he said,

> One of the most important things is to have everyone feel welcome. And I don't think a noisy, dusty workshop is welcome to everybody. I'm perfectly comfortable there. I'm used to it, right? But that's not where it comes from, right? (Interview, April 17, 2015)

Two days earlier, during a Fab Lab tour, he told visitors that the North Fab Lab was designed "so that everyone feels comfortable walking in. It's not a traditional shop space in any sense" (Audio field notes, April, 15, 2015). Mr. Mitchell's idea of designing a space where "everyone feels comfortable" appears to be a unifying idea, but in practice, it is potentially divisive, especially when instructors base their design decisions on creating a space that does not look and feel like another space where some students already feel comfortable—the North High School shop. In the following paragraphs, I will provide several examples of how the North Fab Lab was designed to be different from the shop and what Mr. Mitchell might mean by "comfortable."

When Mr. Mitchell mentioned student comfort in the Fab Lab compared to the shop, he often mentioned how the Fab Lab is not "noisy" and "dirty" (Interview, May 27, 2015). To achieve the feel of a quiet and clean lab, the instructors designed the Fab Lab to house its noisier and dustier tools like the ShopBot CNC router in a separate "ShopBot room." Instructors originally housed the ShopBot in the shop before they had a separate room built in the Fab Lab during a summer renovation. This room now houses all the noisier tools that produce noticeable dust and pose a greater safety risk. It is the only space where visitors are required to wear safety glasses and ear protection. Although the ShopBot is both "noisy" and "dirty," its enclosure in a separate room enables it to be part of the quiet and clean Fab Lab environment. More generally, the separate room allows the Fab Lab to house all the digital fabrication technologies while maintaining its image as a quiet and clean lab, where Fab Lab students feel more "comfortable." As Mr. Mitchell explains,

> We brought the ShopBot over, but when we did that, we wanted to make sure that it wasn't noisy. So you can run this noisy machine and still see it running and kind of contain the dust and that kind of thing. So that's our biggest gig, but the students can work around it without… They're comfortable doing it. (Interview, April 17, 2015)

Because the ShopBot room has large windows, one can "still see it running" while not having to expose oneself to the noise and dust that makes working in the shop uncomfortable. To further reduce exposure to dust, instructors connected the ShopBot to a dust collector; thus, even when Fab Lab students enter the ShopBot room to pick up their projects, they need not be exposed to dust. In addition to the ShopBot room renovation, the Fab Lab has been renovated to include other features that might make it feel more "comfortable," including higher ceilings and larger windows to let in more natural light. At the time of my observations, Mr. Mitchell was making plans to have someone paint an accent wall to provide more color (Interview, April 17, 2015).

If comfortable means quiet and clean, then North High School did not design the shop to be comfortable – particularly in comparison to the Fab Lab. The shop is noisy and dusty; there are no windows in any of the shop rooms to provide natural light or fresh air. Shop students rely on noisy fans for ventilation. Despite the ventilation fans, students in the shop often leave class with dust on their clothes because the machines are not connected to dust collectors. There is also a real potential for harming one's clothes and body in the shop, so students wear closed-toe shoes as well as aprons and masks in the finishing room to protect themselves from wood finishes and paints that can stain clothing and cause irritation if touched or inhaled. When shop students have finished their work for the day, I often saw them washing their hands and using an air compressor to remove dust from their clothes (Field notes, April 29, 2015).

These material differences affect the daily routines and norms of practice in both spaces. Shop students complete their assigned cleaning tasks at the end of each class. These tasks include putting away tools, wiping down tables, and sweeping floors. Fab Lab students do not have cleaning assignments because most of the Fab Lab machines, besides the ShopBot, do not produce a noticeable amount of dust. They are expected clean up after themselves by putting away materials they got out of drawers and shelves, but they are not expected to wipe down tables or sweep floors like students in the shop.

The Fab Lab is also more relaxed because most of the Fab Lab machines do not pose any serious risk to the user (the exception being the ShopBot, which is safely removed behind the observation windows). In the shop, risk and safety is emphasized more than anything else. Unlike the digital fabrication technologies in the Fab Lab, the shop technologies are hand-operated, requiring students' fingers and arms to be in close proximity to blades and drill bits. Mr. Gibson repeatedly reminded students of the injuries they could experience if they lose focus or do not use equipment properly. At the beginning of one woodworking class, Mr. Gibson discussed the importance of safety and after he was done, he said, "Safety is always…" and in unison the students said, "First!" indicating that they had practiced saying that phrase many times before (Field notes, May 1, 2015). A sign in the main shop room reminds students that safety glasses must be worn at all times and a well-marked first aid kit is kept near the door. Students' first project in the introductory woodworking course is to make a push tool that helps protect their fingers as they guide materials through the table saw.

Because safety is so important, Mr. Gibson has developed an ear for when a machine is producing a noise that suggests improper use. For example, one day when Mr. Gibson was helping a student at a workbench, he quickly turned his head to the back of the shop after hearing a familiar sound. He then yelled to a student to lower the planer table. Later that day, he told me that he had to be even more aware of sounds of improper use before the table saws were equipped with sawstops. Sawstops have the ability to immediately shut down a table saw when it detects human flesh. He installed sawstops after a student with special needs cut his finger badly. At the time, Mr. Gibson requested the school install these safety devices because parents would sue the school if they knew the technology existed, but was not being used. He said the school did not think it would be an issue, so he found his own funding through a special education grant (Field notes, May 13, 2015).

Safety is less of an issue in the Fab Lab because digital fabrication technologies do all of the fabrication work; students just have to click a button to tell the machine to “Start” or “Stop” if they detect a problem. Woodworking students spend several weeks learning the parts of each machine and how to use them, and then each student must pass a written and performance exam before they are allowed to use the machine on their own (Mr. Gibson, interview, June 3, 2015). The only safety instruction Fab Lab students are given is to stay by the laser cutter and ShopBot machines while they are in operation in case something goes wrong and the machine needs to be shutdown (Course tutorials, n.d.).

The contrasting material environments of the shop and Fab Lab, together with the contrasting norms and routines that go along with those environments, create markedly different social atmospheres and afford different sorts of social interaction. In the Fab Lab, I often saw students sitting and talking to their friends while working on projects. Each Fab Lab machine is connected to a computer, so students are typically seen sitting in front of these computers while a fabrication machine builds their artifact. For example, if a student is using a 3D printer, he or she may sit the entire class period waiting for the printer to finish. In the shop, there are no computers and no chairs sitting next to fabrication machines; shop machines sit at waist or chest level and require hand-operation, so students must stand to use them. During my observations, shop students only sat during the sanding and finishing portions of their projects. Even then, seated at workbenches, shop students were still exposed to the noise of the table saws and other fabrication machines, which (combined with noise from the ventilation fans) were loud enough to make conversation difficult.

In the Fab Lab, I saw students standing together over the laser cutter or 3D printer watching it build an artifact. Shop students do not typically stand next to each other while using machines. In fact, painted yellow lines on the shop floor indicate how much room to give the operators of machines, so they are not disturbed. These lines also protect bystanders from flying objects, though students can still get hurt. During one class period, I was observing a student use a router when a small piece of wood flew off and hit me in the arm. I was not injured, but these kinds of incidents do happen (Field notes, May 13, 2015). Another time, a student cut his finger using the drill press (luckily, the wound required only a band-aid) (Field notes, April 29, 2015).

Together, the material and social differences between the Fab Lab and the shop shape the way students with different identities will be comfortable in the learning environment. For example, when I interviewed Ms. Coleman about the Fab Lab, she mentioned how the Fab Lab has a reputation of "being very tech." However, she did not mean *any* technology, she referred to technologies like computer programming tools that a particular "super smart [student]" used to build robots and quad copters (Interview, January 14, 2016). Ms. Coleman's observation about the kinds of projects valued in the North Fab Lab is consistent with Leah Buechley's (2014) work that examined 9 years of *Make* magazine covers. She found that while the Maker Movement emphasizes that "we are all makers" (Dougherty, 2012b, p. 11), *Make* covers predominately featured "tech" projects like electronics, robotics, and vehicles. Unlike the Fab Lab, the woodworking course does not feature digital fabrication technologies or projects related to robotics and electronics. In the woodworking course, students are limited to wooden and composite materials like plywood and Masonite, and the course featured furniture projects like stools, bookcases, and benches.

Students may also feel comfortable knowing they are taking courses that are preparing them for their post-graduation plans. For example, students interested in pursuing trade work post-graduation may feel more comfortable learning in an environment like the shop that was focused on preparing students for trade work like carpentry and construction. As I mentioned before, the shop classroom was covered with posters that featured information about trade work, and when Mr. Gibson spoke about career preparation, he always referred to trade work and apprenticeship programs (Field notes, May 1, 2015). If students are planning to major in engineering at a 4-year college post-graduation, they may feel more comfortable taking Fab Lab courses where the instructors discuss preparation for engineering careers (Field notes, March 13, 2015; April 15, 2015; June 5, 2015) and where the space reflects popular images of science, engineering, and advanced technologies as discussed in part 1. In the next section, I will focus on how instructors designed the Fab Lab to align with the advanced placement coursework path to prepare students for college post-graduation and not the work-based coursework path that focuses on preparing students for technical programs and the trades post-graduation.

The Fab Lab's alignment with the advanced placement coursework path. Comparing these characteristics of comfort as they appear in the North Fab Lab and shop, especially those related to physical comfort (e.g. cleanliness, noise, risk), is important as it brings forth questions about what it means to be comfortable. For example, for whom do we expect comfortable work in K-12 settings, and was the North Fab Lab truly designed for everyone, even those students who *are* comfortable engaging in dirty, noisy, and risky work? In this section, I will show how the Fab Lab instructors effectively aligned the Fab Lab with the advanced placement and not the work-based coursework path at North High School.

Looking again at Mr. Mitchell's words concerning the design of the North Fab Lab, he said,

> One of the most important things is to have everyone feel welcome. And I don't think a noisy, dusty workshop is welcome to everybody. I'm perfectly comfortable there. I'm used to it, right? But that's not where it comes from, right? (Interview, April 17, 2015)

He ends by mentioning how he is comfortable in shop spaces because he is used to them. In my conversations with Mr. Mitchell, he often reflected on his own experiences as a shop kid who did not care for school.

> I was a hands-on kid from the get-go. I grew up next to a fix-it shop, you know just down the block. And I thought every kid got to do this as a child, but I found out that I was kind of lucky. We actually powered our wagon with an engine; you know a coaster wagon, and no brakes and just wide-open crazy thing. And we thought that was what kids did because that's what we did in our neighborhood. So that was an experience for me that I grew up next to a junkyard, I'll call it a fix-it shop you know. Now they call them recycling centers. So

> it was on the wrong side of the tracks but it turned out perfect for me. I wasn't a really good student in school. You know if I was really interested in a subject I did really well, if I wasn't, I didn't do so well. So I went to technical school as one of six kids. (Interview, April 17, 2015)

When Mr. Mitchell talked about his experiences in school, he seemed to identify with the stereotypical shop student: a male student from a low-income household, who is not good at school, and who goes into the trades post-graduation. In his previous response, Mr. Mitchell seems to acknowledge that while he is "used to" shop spaces, not all students are like him; there are students who do not feel "comfortable" in "a noisy, dusty workshop." After he says, "I'm perfectly comfortable there. I'm used to it, right?" he goes on to say, "But that's not where it comes from, right?" (Interview, April 17, 2015) He seems to suggest that his comfort in a shop is not where the design of the Fab Lab comes from. The Fab Lab was not designed for students like him who are "used to" shop spaces, but everyone else who is not.

Mr. Mitchell believes one group of students who are not comfortable is female students. When Mr. Mitchell gave Fab Lab tours to visitors from neighboring schools and industries, he often shared his desire to recruit female students.

> One of our goals is to have many girls walking into this space and falling in love with engineering and technology. We want to see more and more girls coming into this space and in many ways, we designed this space so that everyone feels comfortable walking in. It's not a traditional shop space in any sense, and that was on purpose. (Audio field notes, April 4, 2015)

Mr. Mitchell understood that female students are often underrepresented in shop courses and the engineering fields. He would often talk about his own experience working at a large engineering corporation and not seeing many female engineers (Interviews, April 17, 2015; May 27, 2015). During an interview, this understanding came up as he told me a story about taking a female student to the shop to use a sander.

> We had to go to the shop, so we put on the safety glasses, went into the shop, and I showed her how to do it… And it was noisy and dusty… There were all boys in there. She commented on that. There were no girls. I said, "That's right." "That's why we have the Fab Lab." (Interview, May 27, 2015)

In his story, he mentions qualities of the shop (noisy, dusty, male-dominated) that might make female students uncomfortable. He then suggests that the Fab Lab was designed differently to make female students comfortable. He never mentions redesigning the shop.

Female students are one group missing from many shop courses. The woodworking course I observed for this study did not have any female students enrolled. But female students are not the only group underrepresented in shop courses at North High School. In addition to attracting female students, the Fab Lab instructors hope to attract students on the advanced placement coursework path like Mr. Carson's AP Calculus students who are interested in pursuing a career in engineering, but do not feel comfortable taking shop courses. Mr. Carson explains,

> One of the benefits we realized when we were doing the Fab Lab was that it might be a way to get more students involved in doing more engineering at the high school level. As a Calculus teacher I could ask kids, for example, how many people are thinking about going into engineering, and you'd get maybe 8 or 10 students in the class of 30 that would say, "Yeah, I'm interested in going into engineering." So how many of the 8 to 10 of you have taken any classes in tech ed at our high school? And the answer is almost always zero. And now we said, we have people that want to do this for a career, but they aren't doing those courses at the high school level. (Interview, March 23, 2015)

As I previously mentioned, North high school has a technology & engineering department. This department provides courses on woodworking, metalworking, drafting, and automotive. However, when Mr. Carson mentions this department, he calls it "tech ed" instead of technology & engineering indicating that the technology & engineering department's attempt to brand itself as an engineering learning space has failed. He goes on to explain why his AP Calculus students might not be interested in taking courses in the "tech ed" department, "Well, I think there's this perception, at least there was at our school, that those classes are not for smart kids. Smart kids should be taking other classes" (Interview, March 23, 2015). Mr. Carson is aware of the commonly held assumption that "tech ed" students are not the "smart kids" who take AP and other college-preparatory courses. He is also aware that his AP Calculus students might not want to be associated with those assumptions.

Mr. Carson was not the only study participant to voice assumptions about “tech ed” courses and students. Andy, a student who has taken both woodworking and Fab Lab courses, once referred to a group of students in the shop as “hicks who don’t care about school” (Field notes, May 27, 2015). On another occasion, when we were leaving the shop, I asked him,

> Researcher: So what do you think of the shop tools versus the Fab Lab tools? Do you have a preference?
>
> Andy: I prefer the shop tools because I’m a lot better at them.
>
> Researcher: Why do you think that is?
>
> Andy: Because I’m good with my hands more than my brain (Audio field notes, March 20, 2015).

While Andy had taken several shop courses including advanced woodworking and identified as a student that is “bad at math” (Interview, May 27, 2015), he had an awareness of the negative assumptions about “shop” students and did not want to be seen by others as a hick who does not care about school (Field notes, May 27, 2015). These assumptions may be the same ones Mr. Carson’s AP Calculus students avoid by not taking shop courses.

After Mr. Carson explained why his AP Calculus students might not be taking courses in the technology & engineering department, he said,

> As a result, a lot of these kids are going into engineering and not even knowing if they like engineering, but yet they are going to a college that is good at engineering to become an engineer. And I’m sure in some cases that turned out fine; however, it would be nice if they got some exposure at this point. (Interview, March 23, 2015)

When Mr. Carson said, “It would be nice if they got some exposure at this point,” he seems to be saying that the Fab Lab can now provide that opportunity. His AP Calculus students who are interested in engineering as a career now have the opportunity to engage in engineering practices where they feel comfortable.

During this same interview, Mr. Carson mentions other groups of students who are “traditionally unrepresented” in shop courses.

> And there's also a lot of groups that are traditionally unrepresented in these type of courses anyway – female students, minority students, along those lines. We thought this might also be a good social justice sort of a thing… It would be sort of bridge into those types of courses… Now for as the amount of recruitment goes, we have not done some sort of formal push to get underrepresented people along those lines. That's actually something we're meeting about this year, is trying to come up with ways to do that. We find that, in particular, talking about female students, we find that female students who are in Fab Lab, enjoy it, and frequently take multiple levels of Fab Lab. However, as a percentage, it's still much lower than the percentage of the population in general, in our school. It's attracting them to sign up for the course in the first place that we still need to address (Interview, March 23, 2015).

In addition to his AP Calculus students, Mr. Carson also identifies other target audiences including female students and minority students. He evokes the democratizing language of the Maker Movement when he says attracting these students might be "a good social justice sort of a thing," but he then acknowledges that the North Fab Lab instructors have not taken many steps to recruit these students.

From this data, there is evidence that Mr. Mitchell and Mr. Carson hope to attract female students, advanced placement students, and students of color to the Fab Lab. However, it is unclear if they truly mean all females students and all students of color or just those students who take advanced placement courses. I believe it is the latter as the only female students Mr. Mitchell ever mentioned were former students who were majoring in engineering in college or current students who showed interest in the engineering field (Interview, May 27, 2015; Field notes, March 13, 2015). There was also no evidence of Mr. Carson or Mr. Mitchell ever mentioning the recruitment of students in special education or male students on the work-based coursework path that already take shop courses, and based on my identity observations, these students might be effectively excluded by the design of the Fab Lab.

The Fab Lab has been successful at recruiting students on the advanced placement coursework path and one reason is likely due to who teaches Fab Lab courses. At the time of this study, teachers from the science, math, and technology & engineering departments taught Fab Lab courses. The Fab Lab is the only design-based course where the instructors are able to build relationships and recruit students from courses in multiple departments. Some Fab Lab students would have recognized Mr. Kent as their iSTEM, physics, or AP physics teacher. Others recognize Mr. Carson as their AP Calculus teacher, talented and gifted teacher, or their quiz bowl club sponsor. All quiz bowl participants were familiar with the Fab Lab because they practiced there every Wednesday during lunch. Ms. Coleman, the science teacher, who was being trained to teach future Fab Lab courses at the time of this study served as a quiz bowl co-sponsor and was present at most quiz bowl meetings. Lastly, some students would have recognized Mr. Smith if they had taken drafting courses through the technology & engineering department. Students who have taken science, math, and drafting courses with these teachers may be more likely to take Fab Lab courses because they recognize and are already familiar with the Fab Lab teachers. If Fab Lab teachers are recruiting from their other courses, then Fab Lab students are also likely to recognize and be familiar with other Fab Lab students. It is likely that Mr. Gibson (the woodworking instructor) was less familiar to North High School students compared to the Fab Lab instructors because he did not teach a core subject in addition to woodworking courses. Two of the three Fab Lab instructors taught advanced placement courses in addition to Fab Lab courses. Their ability to recruit and attract students on the advanced placement coursework path helps to align the Fab Lab with this academic path.

If a goal of the North Fab Lab was to democratize access to *making* and STEM education then it would seem that the Fab Lab instructors would have been open to the idea of collaborating with the technology & engineering department. However, when I asked Mr. Mitchell about the Fab Lab students' lack of exposure to other fabrication technologies like the shop's hand-operated tools, he did not see this as a concern.

> So what I see is that the students especially the girls that are in here aren't exposed to those tools at all. They haven't been exposed to them yet. So it exposes them to some tools that they wouldn't have got otherwise. (Interview, May 27, 2015)

Mr. Mitchell suggests that female students are not going to take shop classes anyways, so if they take a Fab Lab course at least they will be exposed to some tools even if they are not hand-operated. He does not acknowledge that the Fab Lab and shop tools are markedly different and used in different sorts of ways. Mr. Mitchell's claim that girls "aren't exposed to those tools at all" is also not true as there are females students who take shop courses such as welding and car care, according to Ms. Coleman (Interview, January 14, 2016).

If we look closer at Mr. Mitchell's answer, he begins by saying "the students" and then mentions "girls" separately which suggests he had other students in mind when he answered my question. However, it is unclear who these others students are. They are not, however, students already taking courses in the shop. Mr. Mitchell never shares any concerns about the students who will choose to only take shop courses and not be exposed to the digital fabrication technologies in the Fab Lab.

Mr. Mitchell and Mr. Carson believe the Fab Lab is necessary because the technology & engineering department that offers courses in the shop is not attracting particular groups of students due its perception of being noisy, dusty, and not for "smart kids." However, this still does not explain why North High School needs a Fab Lab. If North high school already provides coursework in technology & engineering, then why not include digital fabrication technologies in the shop and work to change the perception of the shop and shop coursework by adding new technologies and updating the curricula to include science and math? Why create a completely new learning environment for "smart kids" (including female students) who do not feel comfortable in the shop?

When I asked Mr. Mitchell if there was any interest integrating Fab Lab courses with other design-based courses like those held in the art studio and shop, he mentioned integrating the Fab Lab with science, music, and art, but not the shop.

> So what we're doing this summer is starting that process. And that's bringing the art teacher. So Ms. Rhodes is getting trained and Ms. Coleman, our science teacher. So what I

> really envision… When Mr. Kent is teaching something about physics and he wants to use lasers to demonstrate something, he could bring his students in here and they could do a laser project or sound to light and light to sound project. That's what I envision. So they would use it as a lab, and then same with the music, music and art. We'll start to make musical instruments in here… [A local technical school] has a Fab Lab and they got the guitar maker. It's called guitar girl, so they have a girl's class that's sponsored by a local industry and they made 12 guitars in like three weeks. So all the girls made a guitar. So I want to bring that kind of thing to our Fab Lab… I think those kinds of things, the art and the music and the science are really going to be important to broaden our curriculum. (Interview, May 27, 2015)

From Mr. Mitchell's response, he aligns the Fab Lab with the advanced placement coursework path that includes science and not the work-based path that includes shop curricula. During an earlier interview, Mr. Mitchell shared how students should not have to use the same tools he did in his shop courses.

> I think [Fab Lab] is a new way of learning. Somewhat, I mean if I look at myself, born in the industrial age. Our learning was in that noisy and dusty shop, right? That was the learning part of it. But that's not this generation. This is the digital revolution, not the industrial revolution. I really preach that because that's the truth, that these kids aren't learning the way that I learned. They shouldn't have the same tools. It's a different world" (Interview, April 17, 2015).

Again, it is hard to know what "kids" Mr. Mitchell is referring to. Is he talking about all students or just the ones taking Fab Lab courses? Does he believe that shop courses should no longer be a part of the school curriculum or that the students he is thinking about should not have to take those courses or use shop tools? What is clear from this statement is that he does not see a need for students to learn using both hand-operated and digital tools.

When I asked Mr. Carson about integrating the different design-based courses, he referred to the Fab Lab's emphasis on digital design as a reason why the Fab Lab does not plan to integrate with other design-based courses, at least not the learning spaces.

> There's no huge benefit to tearing down the wall that I'm gesturing off to the side where all the pottery wheels are and bringing that into the same room as this because there is nothing that you would do with a pottery wheel that involves digital design. That does not mean, however, that there isn't crossover. I mean there are folks that do their ceramics that come over to our lab. They use our laser cutters to cut wood stamps that they then use in their ceramics lab, but I don't know that you gain a lot by having the actual pottery wheel here other than that forced collaboration which I think, considering it's the next room over,

> I think you still get. I mean we are still housed in the area adjacent to the art and adjacent to the traditional shop, so we still get that crossover. (Interview, March 23, 2015)

Mr. Carson begins by arguing how there is no benefit to integrating the Fab Lab with other design-based courses like pottery because pottery does not involve digital design. The North Fab Lab did not have the technology to digitally design ceramics, but there are 3D printers that can print ceramic designs. Mr. Carson goes on to use a language of theirs and ours that suggests that he is making a distinction between students who use Fab Lab tools and those students who belong to the Fab Lab. He also seems to suggest that it is enough that art and shop students are coming over to use Fab Lab technologies. This study did not examine how much crossover there is especially by the students in the shop who are not also taking Fab Lab courses. Any crossover that did exist between the Fab Lab and the shop during this study likely decreased as the Fab Lab began acquiring its own hand-operated fabrication tools. When I asked Mr. Gibson, the woodworking instructor, if he had discussed integrating his courses with the Fab Lab, he began his responses by reminding me that the Fab Lab "is not part of CTE" and then told me how district administrators "haven't really said if they would want to incorporate that" (Interview, June 3, 2015).

Mr. Mitchell and Mr. Carson believe the Fab Lab is necessary because there are groups of students who do not feel comfortable taking other design-based courses. Mr. Mitchell believes female students do not feel comfortable because shops are "noisy" and "dusty" (Interview, April 17, 2015) while Mr. Carson believes students, like those in his AP Calculus courses, do not feel comfortable because they do not want to be seen as unintelligent (Interview, March 23, 2015). Thus, the Fab Lab was designed to be comfortable, but not with everyone in mind. It was designed to make students on the advanced placement coursework path feel comfortable based on their cultural preferences, identity, and educational trajectories.

In the last section of this chapter, I will share how the design and implementation of the North Fab Lab learning environment and curriculum relates to social sorting by discussing what groups of students are taking Fab Lab and which ones are not well-represented.

Student enrollment in Fab Lab courses. At the time of this study, Fab Lab coursework did not fit into a particular department or coursework path; North High School considered it a general elective. The choice to make it a general elective was at least partly due to the instructors' teaching certification. As Ms. Rhodes mentioned during an interview, the Fab Lab 1 course is not a fine arts course because there are not any fine arts teachers teaching it (Interview, January 12, 2016). Mr. Gibson, the woodworking instructor, shared similar information, "The Fab Lab is a separate elective… It's designed that way so that you can have anyone teach it. You could have a science teacher teach it, you could have a math teacher" (Interview, June 3, 2015). By calling the Fab Lab coursework a general elective, any teacher with any state teaching certificate can teach a Fab Lab course.

At the time of this study, Fab Lab instructors included teachers from the science, math, and CTE departments who taught coursework on both the advanced placement and work-based coursework paths. With no prerequisites needed to take Fab Lab 1, the North Fab Lab (a general elective taught by teachers from across the coursework paths) appears on paper as a learning environment that would attract all students. However, after examining data from instructor and student interviews, observational field notes, and courses documents, I found that the design and implementation of the Fab Lab learning environment and curriculum and its separation from North High School's low tech, design-based courses effectively reinforced sorting practices and cultural assumptions about work and intelligence.

More than any other group of students, Mr. Mitchell hoped to recruit female students. Working from the assumption that female students do not take shop courses because they are noisy and dusty, he made sure to design the Fab Lab to be a quiet and clean lab. However, Mr. Mitchell never seemed to consider that there are female students taking courses that are messy and not clean like the art department's painting, ceramics, and woodcutting courses. If the underrepresentation of female students in shop classes was only due to the shop's cleanliness and noise, then the Fab Lab would have recruited higher numbers of female students, but they did not. In the Fab Lab 1 course I observed, there were only two female students and eleven male students, and according to the school website, where one can look at previous Fab Lab class rosters, these numbers are typical each semester.

Mr. Mitchell believed female students intrinsically prefer clean and quiet learning environments. He used this belief to explain why female students were not enrolling in shop courses. However, when I asked Ms. Coleman what design-based courses female students are taking if they are not taking Fab Lab courses, she said they are taking courses "in art, in music, in [culinary arts]" (Interview, January 14, 2016). Mr. Mitchell's explanation about female students preferring clean and quiet learning environments does not hold up if they are choosing to take messy courses in the art and culinary arts departments.

Ms. Coleman had other beliefs as to why some students were not taking Fab Lab courses. She began her explanation by explaining why she hopes Ms. Rhodes (the art teacher) can help attract more students to the Fab Lab.

> I'm hoping that [Ms. Rhodes] can really start to bring some of those kids into the Fab Lab… Because I said something that totally did not come out of my mouth right, but some kids don't see themselves as the smart kids so, they don't want to take Fab Lab because they don't see themselves as the smart kid. But they go into Ruth's area and they make these amazing things in art. (Interview, January 14, 2016)

She began her response by identifying Ms. Rhodes's art class a place where one can find non-Fab Lab students, and how she hopes Ms. Rhodes's courses that feature digital fabrication projects can expose these students to digital fabrication practices. She then repeats the same assumption that Mr. Carson shared about the "smart kids" at North High School. However, instead of discussing how the "smart kids" do not feel comfortable in shop classes, Ms. Coleman shares how this assumption keeps students who do not identify as a "smart kid" from taking Fab Lab courses. So, while the Fab

Lab instructors designed the Fab Lab to make everyone including "smart kids" feel comfortable, the decision now discourages some students from taking Fab Lab courses.

Ms. Coleman goes on make a distinction between textbook intelligence and other forms of intelligences like creative intelligence. She believes the assumption about "smart kids" is based on textbook intelligence, whereas Ms. Rhodes's courses value creative intelligence.

> We have these kids who have an intelligence that is maybe not a textbook intelligence, but I cannot teach creativity. That is an extremely hard thing to teach. But kids who excel in Ruth's area are creative and we just need to tap into that… They are creative thinkers and they have this amazing creative intelligence that they are able to utilize more in other classes. (Interview, January, 14, 2016)

When I interviewed Ms. Rhodes, she provided some insight into why some students might not be choosing to take Fab Lab courses.

> If they are constantly creating things in a two-dimensional world, I say that thinking of AutoCAD right now and Illustrator, not Solidworks, but if they are constantly thinking that way, they're not using something tangible in their hands. Some people don't think that way, and I think by offering multiple ways of doing things, you're reaching out to those higher level thinkers who might not understand and catch onto the technology of the program. You're also reaching students who can't handle the math in a program like that, but they can see it on paper and draw it, and I think you almost need both. And some students, there are a few, who can visualize something in their head and they can see it two-dimensionally and turn it into something three-dimensional, but not all students can see that. And I think that's a challenge, and I think that's probably why you don't see a ton of people in the Fab Lab. Because one they're afraid of—how am I going to do this on a computer? They understand how to do it on a piece of paper. (Interview, January 12, 2016)

Ms. Rhodes touches on several intelligences that her courses teach while the Fab Lab features a more narrow set of intelligences. She mentions intelligences like visualizing artifacts in two and three dimensions. She mentions working with your hands and drawing versus digital design using CAD programs. By featuring multiple approaches to designing artifacts, she is providing multiple avenues for participation, something the North Fab Lab lacks because it only features digital design. She also mentions how her courses are also able to reach students who have lower math skills and may struggle or be intimidated by CAD software.

During my interview with Ms. Coleman, she mentioned how female students are not the only students absent from the Fab Lab. She said there a large group of students "who don't see that they identify with the Fab Lab at all." When I asked her who makes up this group she said, "We don't have a ton of minority students, but we do have minority students and I would love to see more minority students in there" (Interview, January 14, 2016). Just like there are white students on the advanced placement coursework path who identify with the Fab Lab and white students on the work-based path that identify with the shop, it is likely that different groups of "minority students" also prefer different coursework paths.

Lastly, Ms. Coleman mentioned how students in special education and students at risk of not graduating were also discouraged from taking Fab Lab courses. When Ms. Coleman mentioned students in special education, she said, "It worries me to see kids who are students with IEPs that have more trouble reading or writing that are failing the class because they're not documenting well" (Interview, January 14, 2016). While there may be more reasons than documentation that are causing students with IEPs trouble, documentation is the main determiner of success in the Fab Lab. In the Fab Lab 1 syllabus, instructors explain the importance of reading and writing skills to be successful in the courses.

> Students who do not have these qualities rarely succeed in the Fab Lab class. Reading directions: Students are expected to read and follow the written procedural step by step directions and should not expect to have the teacher (or other students) standing next to them telling/doing/showing you what to do next constantly. Too often the question "What do I do next?" is asked in hopes to avoid reading the directions, the answer will be something to the effect "read the directions and when you have a specific question it will be answered." Directions have been written to guide you along, when you have read, understood, followed, tried, failed, retried and can or have not made positive progress then it is time to ask for guidance.

This description reads as if the instructors did not even consider that there might be students who enroll in Fab Lab 1 courses who may need help reading like students in special education, English Language Learners, and students with less access to high quality literacy support. Instead, they assume that students who are not reading directions are just being lazy. The syllabus goes on to describe the writing skills students need to be successful, "Describe clearly, adequately, thoroughly and in detail what it is that you did, accomplished, learned, skills developed and the process/procedure that got you to a final product including failures and how you overcame them."

From these descriptions, the North Fab Lab instructors define success by students' ability to read, write, and work individually. While documentation and working individually is one way to imagine defining success in the Fab Lab, there are a number of different ways that Fab Lab instructors could define success. Instead, the task of documentation and working individually favors particular skills that may keep students that struggle with reading and writing from being successful. The skills that the North Fab Lab has chosen to define success are also some of the same skills that define success in advanced placement courses. For example, Justin, a student who was also enrolled in AP Music Theory, AP Calculus, and AP Literature during the semester of this study, shared with me how he found success in the Fab Lab 1 course.

> Because the only actual way we get things graded is if we document them. I feel like actually being able to type decently quickly helped out because then I can actually document quicker, and also being able to explain things well is something that really helped out with my documentation because that's essentially what you're actually graded on. Like you have pictures of what you did, but unless you have the documentation to show for it, you get no points. (Interview, 5/20/2015)

In addition to students who need assistance with reading and writing, some students may choose to not take Fab Lab courses because they would rather not spend so much time documenting their work. Students in the woodworking course also had to document their progress, but instead of a providing a detailed, step-by-step process, they were only required to write two sentences that described what they accomplished that day. Students hand-wrote their descriptions on an 8.5 x 11 calendar. The small boxes provided for each day did not allow students to write much more than two sentences (Field notes, May 11, 2015).

The last group of students mentioned by Ms. Coleman was "at risk" students. During my interview with her, she said, "If we have some kids who are at risk, they are discouraged from maybe taking the Fab Lab because they just need to get credits to graduate" (Interview, January 14, 2016). Ms. Coleman seems to suggest that the Fab Lab does not have the reputation of being an easier course that one might want to enroll in if needing easy credits to graduate.

With these observations in mind, the design of the Fab Lab as a science and STEM learning environment and its alignment with the advanced placement coursework path offers a better explanation for who does and does not take Fab Lab than the intrinsic features of students like that female students prefer clean and quiet learning environments. Using two quotes from my interview with Ms. Coleman, I will demonstrate how the Fab Lab was not designed for all students, but instead, reinforces the social sorting practices that already exist at North High School.

When I interviewed Ms. Coleman, she shared her observation that there are two groups of girls in the Fab Lab.

> I think there is kind of like two separate groups of girls, there's girls in there because they've gotten involved in some of the tech ed classes and so they're kind of like… They're the girls who are already comfortable with doing like the welding and the car care class. And then there's… To be totally blunt, there's like the wealthy white girls who have tons of support at home, you know and everything, and are excelling in all their classes anyway. (Interview, January 14, 2016)

Ms. Coleman notes how there are female students who already take technology & engineering coursework and "wealthy white girls who have tons of support at home." From her response, she seems to imply that the female students who already take technology & engineering courses come from lower-income households and have less support at home. Her response also suggests that this group of students is already comfortable working with technological work from taking welding and car care courses in the shop. Since the "wealthy white girls" get a lot of support at home, they are most likely the same group of female students who take AP courses. They may also feel comfortable taking Fab Lab courses instead of shop courses for all the reasons previously mentioned (e.g. for "smart kids", preparation for engineering careers) not because the shop is dirty and noisy.

Ms. Coleman shared one other story about a female student who was discouraged from taking Fab Lab because it has a reputation as being hard.

> Well, I had one kid this year who said she couldn't do math… She was like, oh, my counselor told me I shouldn't take [Fab Lab] because it's hard, but I should take this other elective class instead, and I'm like I think she could do it and do really well at it. I think it's something that, I mean she needs a mentor. She has been overcoming a million other horrible things in her life and that could be really great for her. (Interview, January 14, 2016)

This example demonstrates how these assumptions about the Fab Lab being for "smart kids" because it is "hard" when repeated by school counselors can sort groups of students into different courses.

When Mr. Mitchell described the design of the Fab Lab, he was working off the assumption that girls are not comfortable in noisy and dirty shops, so he designed the Fab Lab to be quiet and clean like a lab in order to attract females students. Yet, as Ms. Coleman suggested, there a many girls who are not taking Fab Lab courses and choosing to take art, music, and culinary art courses instead, courses that can be messy. It is also worth noting that labs are not famous for being welcoming to women, so there is also this tension between what Mr. Mitchell wants to do (create a space that appeals to female students) and his claim that the space was designed to be like a lab.

There are many reasons why female students may be underrepresented in the Fab Lab, some of which were mentioned by Ms. Coleman and Ms. Rhodes. Another reason why some female students may not being enrolling in Fab Lab courses at the same numbers as the male students is that they might feel more comfortable enrolling in courses taught by women. At the time of this study, all the Fab Lab instructors were male. Ms. Coleman pointed to this issue during our interview, and how she got involved in the Fab Lab with the hope that she could teach future courses and that her presence would attract more female students.

> I talked to [the curriculum coordinator] quite a bit about the fact that we love having [Mr. Kent] in [the Fab Lab]. That's great. But we also recognize as a [science] department that half of us are women, that we were not representing women in the field at all by our [Fab Lab] staff. So I had talked to her about that. (Interview, January 14, 2016)

Unfortunately, this study ended before I was able to observe whether Ms. Coleman's presence in the Fab Lab during later semesters affected female student enrollment.

This evidence is limited to the observations of Fab Lab instructors and does not contain any actual numbers like the percentages of each student group in each Fab Lab course. However, this evidence does demonstrate how the values and assumptions embodied in the design and implementation of a Fab Lab curriculum and learning environment can reinforce assumptions about work and intelligence and sorting practices that continue to privilege middle- and upper-class, white students who take advanced placement courses. This finding is consistent with Jeannie Oakes's (1985) research on tracking in public schools where she found that working-class students and students of color were more likely to end up in lower status courses that did not provide the same educational resources and outcomes as the courses taken by middle- and upper-class, white students.

Summary. The North Fab Lab instructors provided many arguments for why North high school needs a Fab Lab. I heard arguments like that the Fab Lab provides opportunities for students to apply the knowledge they learn in their science and math courses (Mr. Mitchell, interview, April 17, 2015). The Fab Lab helps students become problem-solvers while learning the skills of digital design and fabrication (Mr. Carson, interview, March 23, 2015; Mr. Mitchell, interview, April 17, 2015). The Fab Lab motivates students to learn from their failures by encouraging them to push through them (Mr. Mitchell, interview, May 27, 2015). The Fab Lab prepares students for careers in engineering and participation in the "new economy" (Mr. Mitchell, interview, April 17, 2015). These arguments are important and can be found in the *maker* literature. In addition to these arguments, however, Mr. Carson and Mr. Mitchell shared one argument that (to my knowledge) does not appear in the *maker* literature—schools need makerspaces (in this case a Fab Lab) because "smart kids" do not feel "comfortable" taking technology & engineering courses in shop classrooms. To attract "smart kids" who take advanced placement coursework like Mr. Carson's AP Calculus course, the North Fab Lab curriculum and learning environment relied on popular images of science and STEM (e.g. clean, quiet, white lab coats, advanced technologies, intelligent work) to establish credibility and status as a science and engineering course. The Fab Lab instructors set out to attract all students at North High School. Yet, the Fab Lab's reliance on popular images of science and STEM, their intentional dissociation with popular images of craft and technical work (e.g. dirty, noisy, risky, unintelligent work), and their use of cultural assumptions of work and intelligence in the design of the curriculum and learning environment reinforced social sorting practices at North High School. Those students who identify with popular science images and high intelligence were encouraged to participate in Fab Lab coursework while those students who do not identify with them either self-selected out or were discouraged from participating due to beliefs and expectations held by their parents, teachers, and counselors.

Chapter 5: Discussion

This case study cannot provide conclusive evidence for what *making* as design-based STEM education looks like or will look like in all formal K-12 makerspaces. It can, however, provide an important story of what *making* looks like at one high school, in one Fab Lab, and the findings can be used to further unpack assumptions about what the pedagogy of *making* can look like in school settings—in particular, its ability to democratize access to and engage students in design-based STEM education.

In this case, the North Fab Lab relied on rhetorical and material symbols of science to set itself apart from other design-based learning environments and to create an image of the North Fab Lab as a space where students engage in science learning. Objects like lab coats and advanced fabrication technologies, alongside a rhetorical frame that emphasized STEM, labs, and "exactness" created a contrasting sensibility that set the Fab Lab apart from other design-based environments like the school's woodworking shop. However, when I asked the North Fab Lab instructors and students to describe how they engage in science in the Fab Lab, they provided vague and unsupported claims related to interdisciplinary STEM practices and dated descriptions of science. All the Fab Lab instructors relied upon activities that participants intuitively understood to be science-like such as building and programming circuit boards as evidence of engagement in scientific knowledge and practices when there was very little explicit evidence from student interviews or student work to suggest that students engaged in science as described in the NGSS (NGSS Lead States, 2013). For example, Mr. Mitchell and students like Nate and Justin believed the advanced technologies of the North Fab Lab provided more opportunities to engage in science and the design process than the older technologies of the shop even though projects like the EAGLE project did not require them to engage in science or the design process in order to be successful. The appearance of science in the design of the North Fab and the separation of the North Fab Lab from the other low tech, design-based courses at North high school effectively reinforced sorting practices and cultural assumptions about work and intelligence instead of democratizing access to STEM tools, activities, and identities.

Is the North Fab Lab Innovative?

At first glance, the North Fab Lab's adoption of popular images of science and STEM (e.g. clean, quiet, white lab coats, electronics) and the presence of advanced digital fabrication technologies create the impression that the North Fab Lab is an innovative learning environment where students engage in science and engineering design practices. This is especially true when you compare it to North High School's more traditional design-based learning environments like the woodworking shop. However, when I observed a Fab Lab 1 course with the NGSS framework in mind (a framework North High School has adopted) and looked past the rhetoric and cool technologies, I saw students using new technologies, but not quite in the ways proponents discuss in the *maker* literature.

The Fab Lab 1 course embraced many elements often associated with *making*. I observed students using digital fabrication software and tools like Solidworks and 3D printers. Students completed activities like building and programming electrical circuits to perform a task. Students also used resources published online by other *makers* to help them complete their projects. In general, though, the Fab Lab 1 course continued to employ teaching methods considered poor practice by supporters of *making* (Blikstein, 2013; Martin, 2015; Martinez & Stager, 2013). For example, in the EAGLE project, instead of allowing students to tinker with circuit components or hack electrical devices to figure out how they work in order to then have them build their own or make changes to an existing device (Kafai et al., 2014), Fab Lab 1 students continued to experience circuit boards as a "black box" as they built and programmed a circuit board that was designed by someone else (Resnick et al., 2000). Fab Lab instructors did not give students opportunities to define their own design problems. Instead, students followed a tutorial that resembled a traditional science "cookbook lab" in which they worked to replicate and confirm an outcome that had been determined by the instructor. As is true in many science cookbook labs, students may have been introduced to scientific concepts (such as current and resistance in the EAGLE tutorial); however, they were not required to use these concepts to develop their own models to explain how and why a circuit board works. Finally, unlike the students in Barton et al.'s (2016) study who designed, programmed, and made personally meaningful e-textile projects, Fab Lab 1 students all made the same EAGLE project; students like Justin, Nate, and Rachel eventually gave up when their circuit boards did not work. Even though they failed to create a working circuit board, Fab Lab instructors considered this outcome acceptable as long as students' documented their failures. Proponents of *making* celebrate failure as an important part of the creative process (Martin, 2015; Petrich et al., 2013); however, students like Justin did not address his failures and what he learned from them in his documentation. Instead, his documentation read more like a list of steps that resembled the EAGLE tutorial. This was in sharp contrast to the woodworking shop where student success was less about documentation and more about creating an artifact that met design guidelines.

During all the Fab Lab 1 projects, the North Fab Lab instructors relied on the tools and activities to engage students in the science content and practices that they believe were intrinsic parts of student experiences. As Mr. Mitchell said, students' experiences in the Fab Lab "developed the need to know" science and other content area knowledge and practices (Interview, May 27, 2015). However, evidence from student interviews and their documentation pages does not support this claim. Often times, the digital nature of Fab Lab projects allowed students to quickly create aesthetically pleasing artifacts with little effort (Blikstein, 2013). Many Fab Lab 1 students simply downloaded images and designs from Internet databases like Google Image and Thingiverse and printed them using the ShopBot, laser cutter, or 3D printer.

Lastly, the North Fab Lab instructors employed rhetoric of democratization. Mr. Mitchell discussed designing the Fab Lab to make everyone feel comfortable and welcomed (Interview, April 17, 2015) and Mr. Carson thought the Fab Lab would "be a good social justice sort of thing"

(Interview, March 23, 2015). Yet, the design and implementation of the Fab Lab curriculum and learning environment reinforced traditional high school social sorting practices. Students on the advanced placement coursework path took Fab Lab 1 courses, students on the work-based path took shop courses that featured the trades, and female students took feminized courses in the fine arts and culinary arts.

These findings demonstrate that a makerspace classroom, even one that includes innovative technologies, is still subject to various pedagogical interpretations, and that a more complete pedagogical transformation is required to take advantage of the opportunities presented in the research literature. Like "The Case of Mrs. Oublier" in Cohen's (1990) "A Revolution in One Classroom," the Fab Lab 1 instructors adopted "innovative" instructional tools and technologies, but they incorporated them into familiar, more traditional practices. They, like Mrs. O, believed that working with the proper activities and materials assured science learning (Cohen, 1990). Lee Martin's (2015) "The Promise of the Maker Movement for Education" cautions against the "fatally flawed conceptualization of the Maker Movement that assumes its power lies primarily in its revolutionary tool set, and that these tools hold the power to catalyze transformations in education." He argues, "A tool-centric approach to integrating making into education will certainly fail, as it will neglect the critical elements of community and mindset" (p. 37). What these examples from the North Fab Lab show is that even though the Fab Lab 1 course appeared to be innovative, the instructors still relied on traditional pedagogical practices like "cookbook labs" instead of engaging students in *making* practices like tinkering and collaboration.

Observations of the North Fab Lab including field notes, participant interviews, course materials, and student work found remarkably little evidence that students engaged in scientific practices (as defined by the NGSS) in their projects or that the Fab Lab democratized access to STEM tools, activities, and identities, making them available to *all* students. Yet, the North Fab Lab was still seen by many as a model for future educational innovation in STEM education as evidenced by its continued financial support by public and private organizations. Why was it so easy for various participants and stakeholders to believe that the North Fab Lab was successful at engaging students in science and the other STEM subjects?

The North Fab Lab's ability to appear innovative and "science-y" may be due to the rhetorical and material symbols of science and STEM that instructors used to create boundaries between the North Fab Lab and the other, more traditional design-based learning environments at North High School. Not only did these popular representations of science enable instructors and students to believe they were engaging in science when they were unable to provide explicit evidence that engagement took place, these representations also helped to establish the North Fab Lab's credibility and status as a STEM course. This credibility and status helps the Fab Lab attract students on the advanced placement coursework path and attract attention and resources from public and private organizations interested in economic and job development in the STEM and manufacturing fields.

In the following paragraphs, I discuss two claims about *making* as a learning method: (1) *Making* as a powerful method for design-based STEM education and (2) *Making* democratizes assess to STEM tools, activities, and identities. I will begin by sharing three analytical frameworks that will help me discuss the boundaries created between the North Fab Lab and the woodworking shop and how these boundaries helped to influence the presentation of science in the North Fab Lab.

Theoretical Perspectives: Boundaries

To discuss the importance of the findings of this study, I will draw upon the theme of boundaries and their social ends, specifically the boundaries between science and non-science at North High School and how these boundaries create and reinforce the categorizing and sorting of students on different coursework paths.

People create boundaries between science and non-science using both rhetorical and material symbols of science. When differences between two things such as the Fab Lab and the woodworking shop are not initially clear, these symbols can create clear boundaries that might otherwise go unnoticed. For example, the North Fab Lab instructors could only provide vague observations of how students engage in science in the Fab Lab. However, their arguments about students engaging in science in the Fab Lab may be more convincing to outsiders who notice the rhetoric of STEM and the material symbols of science such as lab coats, lab benches, and advanced technologies. The Fab Lab's use of images of science to distinguish itself from similar design-based learning environments that are also competing for recognition and resources is beneficial as science often stands for credibility, legitimate knowledge, and a trustable reality (Gieryn, 1999, p. 1). People rarely question the "epistemic authority" of science, so using symbols of science to establish credibility and status is important when funding and other forms of support are on the line. On the other hand, the presence of these symbols of science in the Fab Lab can discourage some groups of students from enrolling in Fab Lab courses. Those students who do not identify with science or being a "smart kid" may either self-selected out or be discouraged from participating due to beliefs about themselves and expectations held by their parents, teachers, and counselors.

Gieryn's (1999) "boundary-work" provides a lens to examine the rhetorical strategies used to establish the North Fab Lab as a STEM learning environment and the technology & engineering department and shop as something different. When credibility is on the line, Gieryn's (1999) work helps explain the rhetorical form of boundary-work between the Fab Lab and the other design-based environments, and the creation of the Fab Lab as a cultural space for science but not the woodworking shop (p. 5). The winners of these "credibility contests" enjoy having others act on their claims, increased influence, and the opportunities to access funding, equipment, and material resources needed to maintain their credibility and status (Gieryn, 1999, p. 1).

Winner's (1986) "politics of artifacts" conception reminds us that the technological artifacts we interact with everyday are not neutral tools; they change the way we think and live. The political nature of technological artifacts is a useful lens when reflecting on the power and authority embodied in the material design of the North Fab Lab and how the flexibility in its design changes students' learning experiences. I will use this lens to examine the physical boundary created between the Fab Lab and the woodworking shop and the conceptual boundary between Fab Lab tools and woodworking tools and how these boundaries change the kinds of skills and practices students learn, the guidelines for judging their work, and how students view each other's work and intelligence. Gieryn (1999) and Winner's (1986) work help me examine how rhetorical and material boundaries were used to establish the credibility and status of science in the North Fab and their social ends—attracting recognition, funding, and students on the advanced placement coursework path.

Lastly, Dorothy Nelkin's (1987) study of the imagery of science in journalism will provide an important framework for examining the imagery of science in the North Fab Lab that results from its rhetorical and material symbols of science. Nelkin's (1987) work illustrates how people understand science more from language and imagery than from direct experience and past education, that "imagery often replaces content" (p. 6). These theoretical perspectives will be used to explain why the Fab Lab instructors and students saw themselves engaging in scientific practices when there was no explicit evidence that they did and why the North Fab Lab was not the democratizing learning environment that the instructors set out to create.

Together these perspectives will help push the *maker* research beyond the definitions and goals of *making* and STEM education to considering how the structural tensions in public education can change those definitions and goals and reinforce social sorting practices that have been shown to discourage the participation of girls, students of color, and low-income students in STEM education.

Making as a Powerful Method for STEM Education

Educational supporters of the Maker Movement believe the design process is central to STEM education (Honey & Kanter, 2013; Martinez & Stager, 2013; Quinn & Bell, 2013). Similar support has also existed in science education for some time (Fortus et al, 2005; Kolodner et al, 2003; Krajcik et al, 1998; Schwartz et al., 2001); however, *making* now has the support of national standards like the *Framework for K-12 Science Education* (NRC, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013).

While the research literature on *making* as a vehicle for STEM education is still in its early stages, this work is promising (Blikstein, 2013; Brahms, 2014; Peppler & Glosson, 2013; Sheridan et al., 2014). Researchers have found that *making* can engage students in scientific concepts and practices as they design and build objects using various materials and tools (Blikstein, 2013; Kafai et al., 2014; Peppler & Glosson, 2013; Sheridan et al., 2014). *Making* can also promote other important elements of learning not often seen in public education like how design iteration helps students learn from their failures (Martin, 2015).

In this study, the Fab Lab 1 course engaged in *making*, at least on the surface. However, there is no explicit evidence that students engaged in *making* as defined in the research literature. Yet, Fab Lab instructors, students, and visitors believed they were—a belief I argue stems from the images of science and STEM reflected in the Fab Lab. On the other hand, they did not believe the same opportunities to engage in design-based STEM education existed in the shop. In the following paragraphs, I will illustrate how the Fab Lab instructors engaged in rhetorical and material boundary work to separate itself from the shop and to gain the credibility and status of science needed to secure funding and materials from public and private organizations.

Gieryn (1999) notes how boundary-work occurs when credibility is on the line. During my interview with Mr. Mitchell, he spoke about approaching the North School District, not yet retired from engineering, about why they needed a Fab Lab. He mentioned how the school district was concerned about funding and sustainability (Interview, April 14, 2015). To get the school district to give $40,000 and building space to house the Fab Lab, Mr. Mitchell had to convince district administrators that a Fab Lab is different from the other design-based courses at North High School. He had to convince them that the Fab Lab was not going to be another technology & engineering shop. To do that, he and future Fab Lab instructors like Mr. Carson began by stressing the name "lab," a name adopted from MIT's Fab Lab. The name and its association with MIT reflect images of the epistemic authority of science. The person or people who designed the North Fab Lab website and course materials also used the language of STEM and interdisciplinary education like the Fab Foundation does on its website. The Fab Lab instructors could just as easily applied this rhetoric to coursework in the technology & engineering department.

Boundary work is never finished though. Even though the school district agreed to the project, boundary work continues as long as credibility, recognition, and funding are on the line. When I asked the Fab Lab instructors how students engage in science in the Fab Lab, they told me how they believed the EAGLE project engaged students in scientific practices more than any other Fab Lab 1 project. Ms. Coleman believed this "electronics" project exposed students to scientific concepts related to circuitry and engaged students in the "iterative process" (Interview, January 14, 2016). Mr. Mitchell compared the EAGLE project to similar projects taught at MIT and believed the project "developed the need to know" scientific concepts like Ohm's Law (Interview, April 17, 2015). When I asked Mr. Mitchell how he thought making a circuit board helps students develop scientific knowledge and skills, his initial reaction was to use the EAGLE project to create a boundary between the Fab Lab and the other design-based learning spaces at North High School.

> Well, we're the only ones doing it. [laughs]… We're going to keep doing circuit boards because it's a difficult thing to do. It's a master's level course at MIT that teaches circuit boards. To make the circuit board isn't easy. (Interview, May 27, 2015)

He begins by sharing how the Fab Lab is the only space were students engage in circuit boards. He then goes on to argue how the EAGLE project is intellectually hard like similar courses taught at

MIT. In just these few sentences he creates a boundary between the Fab Lab and other learning spaces by drawing upon rhetorical and material symbols of science that establish the Fab Lab as a STEM learning environment and the other learning environments as something else.

The rhetoric and material culture of the Fab Lab effectively gave the Fab Lab the credibility and status of science needed to secure funding and materials from public and private organizations. The imagery of science as a result of the rhetoric and material culture of the North Fab Lab also helped convince instructors and students that the North Fab Lab provided opportunities to engage in science that were not found in similar design-based learning environments like the shop. Lastly, the imagery helped support the instructors' and students' beliefs about their engagement in science in the Fab Lab when there was no explicit evidence that suggested that engagement in science (as defined by the NGSS) was taking place.

It is important to note that the North Fab Lab does not claim to engage students solely in the subject of science; it claims to teach "science, technology, engineering, art, and math" (School website, n.d.). Since the beginning of this research study and as I read the first research articles on *making*, I was struck by the idea of interdisciplinary STEM or STEAM education and how people defined science within STEM or STEAM education. For instance, is STEAM simply an acronym for five different subject areas that are taught together or is something added when these five subject areas come together to create interdisciplinary learning experiences? Does technology mean the subject of technology or just the use of technology in science, engineering, art, and math activities? What does science engagement look like in a STEM or STEAM learning environment where instructors also teach technology, engineering, art and math? When I examined how the Fab Foundation and the Teaching Institute for Excellence in STEM (TIES) understand student engagement in science within a STEM learning environment, I found that both organizations provide only a vague description of STEM education. Neither organization actually mentions what engagement in science looks like beyond referencing the NGSS, so it may not be coincidental that the North Fab Lab does not emphasize scientific practices. However, I argue that the Fab Lab still benefits from the vagueness of STEM or STEAM, and that this study illustrates how instructors can use rhetorical frames like STEM and STEAM to accrue the resources and credibility associated with science even when science is not obviously involved.

In Nelkin's (1987) *Selling Science*, she notes how the "public communication of science is shaped by the cooperative and collaboration of several communities, each operating in terms of its own needs, motivations, and constraints" (p. 11-12). Several communities were present in some form at all times in the North Fab Lab. There were the North High School Fab Lab instructors including a retired engineer. There were six other Fab Labs in the USFLN broadcasted from around the world on the North Fab Lab's teleconferencing screen. There were banners on the wall representing the local corporations that had donated money and materials to the North Fab Lab. Occasionally there were government officials touring the Fab Lab to promote job training for manufacturing jobs (Fabrication Laboratories Grant, n. d.). All of these communities are shaping what STEM education looks like at North High School, each operating in terms of its own needs, motivations, and constraints. For some communities, STEM may represent preparing students with the skills to work in STEM jobs. For others, STEM may represent interdisciplinary, problem-based learning.

I worry how easy it is to create an image of science in learning environments where there is no explicit evidence that engagement in science is taking place. I worry that the North Fab Lab's image of science and perhaps other subject areas (e.g. engineering and math) may provide cover for a curriculum that does not have intellectual depth. Lastly, I worry that the Fab Lab's image of science is only attracting and providing white males on the advanced placement path access to STEM tools and identities and not girls, students of color, low-income students, and other students who have been historically absent from STEM education.

These findings should be read with the following limitations in mind. In this study, I observed a Fab Lab 1 course. I did not focus my attention on the Fab Lab 2 and 3 courses though there were two Fab Lab 3 students in the Fab Lab 1 course I observed. One could read my findings and argue that perhaps Fab Lab 1 is just for skill building and Fab Lab 2 and 3 are the courses that are more open-ended where students engage in science and engineering design practices. Certainly observing all three Fab Lab courses would make this study more complete. However, while all the Fab Lab instructors mentioned the EAGLE project as a project that engaged students in science concepts related to circuitry, I observed no evidence of Fab Lab instructors providing direct instruction or "just-in-time" learning resources to help students engage in STEM knowledge and practices that may have helped them answer their questions and complete their projects.

There is also the possibility that students may be engaging in science and engineering design practices even if they could not describe them during interviews. There may be science practices students have learned in their science coursework that they are applying in the Fab Lab. However, many of the science and engineering design practices outlined in the NGSS are not being taught in most traditional science classrooms like "developing and using models" and "constructing explanations (for science) and designing solutions (for engineering)" (NGSS Lead States, 2013), so students would be unlikely to use these practices in the Fab Lab. If students were engaging in these then they would have likely shown up in students' documentation as instructors told students to document every step of their process. These kinds of practices would have also not been required in Fab Lab 1 because students simply followed tutorials, so did not plan and carry out their investigations.

The North Fab Lab instructors' inability to teach the science and engineering design practices outlined in the NGSS may be due to their lack of training in the design process and interdisciplinary STEM education. All of the Fab Lab instructors besides Mr. Mitchell were certified teachers who had been trained to teach their subject area. None of the teachers had been trained to teach multiple subjects areas in one course. Had I been able to observe Ms. Coleman teach a Fab Lab 1 course, I may have observed students engaging in science practices because Ms. Coleman is a trained science teacher; however, this would not change the observed reality that there were no such practices which suggests that they are not intrinsically part of the Fab Lab.

This research is significant because it examines how the teaching and learning of STEM through design-based practices and digital fabrication technology can play out in a formal K-12 Fab Lab when instructors incorporate a packaged Fab Lab with tools and activities instead of placing more focus on their pedagogical decisions. Secondly, it demonstrates how rhetorical and material symbols of science and STEM can create images of student engagement in science and STEM learning experiences when engagement might not be taking place.

If one were to observe the curriculum of the introductory woodworking courses and the Fab Lab 1 course, it would not be initially clear to the observer how these two courses differ beyond the tools used to build artifacts. Like the Fab Lab 1 course, woodworking students built projects using plans designed by the instructor. Both courses emphasized learning how to use fabrication technologies instead of engaging students in creative, design-based experiences that were personally meaningful to the students. To create a clearer boundary between the Fab Lab and the other design-based environments at North High School, the Fab Lab instructors relied on rhetorical and material symbols of science and STEM. This boundary work established the Fab Lab as a STEM learning environment and the woodworking shop as something different. The credibility and status that comes with science allowed the Fab Lab to access recognition, funding, and material resources from the school and community, things the technology & engineering department has struggled to access.

In the next section, I will share how the boundaries between the North Fab Lab and the other design-based environments does more than give the Fab Lab credibility as a STEM learning environment, but also keeps particular groups of students and important learning practices out the

Fab Lab. I will examine the claim that *making* is a democratizing practice that includes everyone and all *making* tools and activities. When schools feel pressure to appeal to the epistemic authority of science and STEM to gain status, credibility, and financial and material support, this appeal does not just affect the students who take Fab Lab, but the ones who do not.

***Making* as a Democratizing Practice**

Before peer-reviewed literature on *making* was available, many early supporters of the Maker Movement wrote about *making* as a universal, democratic activity that expands access to STEM tools, activities, and identities to everyone including students in K-12 school settings (Anderson 2012; Dougherty, 2012b; Hatch, 2014; Martinez & Stager, 2013). These early adopters wrote how *makers* are "regular folks," "kids," and "amateurs" (Anderson, 2012, p. 20). Dougherty (2012b) described *makers* as "each one of us, no matter how we live our lives or what our goals might be. We all are makers: as cooks preparing food for our families, as gardeners, as knitters" (p. 11). Martinez & Stager (2013) wrote how *making* "obliterates the distinction between a vocational and academic education" because "when the same hardware and process skills are required in the physics lab as the art studio as the auto shop, schools need to no longer sort students into imaginary tracks for jobs that no longer follow those arbitrary rules" (p. 3). Dougherty (2012a) wrote, "We are re-thinking the shop class and re-inventing the computer lab, and combining both of them. The makerspace should be like a library, available for use by anyone in the school to make things for a variety of purposes" (p. 14). In these idealist visions, *making* and makerspaces are inherently democratizing because they break down the boundaries between subjects like science, technology, engineering, art, and math. When implemented in schools, the tools, practices, and identities that have been kept separate as parts of different tracks in the school structure are now available to all students.

When research on *making* in both informal and formal settings began appearing, educational researchers did not presume that *making* in itself is democraticizing. Instead, they shared how they intentionally designed learning spaces and activities to democratize access to *making*—including STEM-related resources, activities, and identities—to students who do not often have access to *making* or to STEM experiences (Barton et al., 2016; Blikstein, 2013; Kafai et al., 2014). For example, Barton et al. (2016) created a makerspace at a Boys and Girls club that offered underrepresented students access to STEM tools, activities, and identities. They may have been successful, in part, because they were not working within the constraints of K-12 education.

While some research supports *making* as a democratizing practice, this study found that the North Fab Lab did not achieve their goal of designing a learning space where everyone feels “comfortable,” and, in fact, they may have set even firmer boundaries between those students who have access to STEM tools and identities and those who do not. This study’s findings are more consistent with Leah Buechley’s (2014) analysis of 9 years of *Make* magazine covers where she found that *making* participants, as they were represented in the magazine, were predominantly white males who engaged, not in art and craftwork, but robotics, electronics, and vehicles. North Fab Lab students do not represent all groups of students at North High School, nor does *making* in the Fab Lab feature a wide range of creative activities (such as more traditional craftwork). The North Fab Lab students fit more of Anderson’s (2012) and Dougherty’s descriptions of *makers* when they compare *makers* to Steve Jobs and others who helped start the computer industry in Silicon Valley (Larson, 2014). The North Fab Lab students were predominantly white males interested in electronics.

If *making* has the potential to break down the walls that separate academic and vocational education and give underrepresented students access to STEM tools, activities, and identities, why were these goals not achieved at North High School? I believe the North Fab Lab instructors believed the Fab Lab would be that place in the school where everyone felt “comfortable,” a place where all students could experience design-based STEM education. However, in the process of designing the Fab Lab to appeal to female students and advanced placement students who were not known to take other technology & engineering courses held in the shop, they designed a curriculum and learning space that did not democratize access to STEM. Instead, it reinforced boundaries that already existed between students on advanced placement and work-based coursework paths. To illustrate the social consequences of material and rhetorical boundary work in the North Fab Lab's attempts to establish credibility and status, I will draw upon one incident that involved the ShopBot CNC router.

Building the ShopBot room. During my interview with Mr. Mitchell, he described to me how the shop originally housed the ShopBot. As part of the shop, the ShopBot would have fit right in with the shop's hand-operated tools. Of all the digital tools in the Fab Lab, the ShopBot most closely resembles tools currently in use in the wood shop. Just like the table saws and planers, the ShopBot is loud, produces a noticeable amount of dust, and students must wear safety glasses when it is in operation. When the school designed the Fab Lab, it was not initially obvious where they should house the ShopBot.

When the first group of students took Fab Lab courses, they had to walk to the shop and use the ShopBot in that space. Rather than pressing "print" on the ShopBot computer and leaving the shop, students would have been required to stay in the shop. One of the safety guidelines of the Fab Lab is that students who are operating the ShopBot or a laser cutter must stand near the machine while it is in operation in case it needs to be shut down for safety reasons.

As Fab Lab students operated the ShopBot, they would have observed woodworking students using their knowledge and skills using hand-operated tools to build artifacts. There would have likely been times when a shop student showed a Fab Lab student how to operate tools like the belt sander to smooth edges left by the ShopBot bit. If the Fab Lab students were on the advanced placement coursework path, these opportunities may have been the first time they were exposed to the knowledge and skills of students on the work-based coursework path who were planning to purse a trade job after graduation. The presence of the ShopBot in the shop may have also piqued the woodworking students' interests in digital design and encouraged them to sign up for a Fab Lab 1 course. When Fab Lab instructors housed the ShopBot in the shop, students may have seen this tool as both a shop and a Fab Lab tool.

Instead of keeping the ShopBot in the shop with the other noisy and dusty tools, the Fab Lab instructors decided that a separate room off the computer lab needed to be built to house the ShopBot. If the Fab Lab instructors believed that the ShopBot needed to be with the other digital tools of the Fab Lab then building a separate ShopBot room would have been necessary. The noise and dust produced by the ShopBot would have affected the Fab Lab's ability to maintain its clean and quiet, science lab image.

When they built the ShopBot room, they equipped it with a large set of windows so Fab Lab instructors and students could observe what was going on in the ShopBot room without exposing themselves to the noise and dust. This renovation also allowed the North Fab Lab to cut all obvious ties with the woodworking shop. There was now longer a need for Fab Lab students to visit the shop. During an interview with Mr. Mitchell, he described how this renovation was done to make Fab Lab students more "comfortable" using it.

> We brought the ShopBot over, but when we did that, we wanted to make sure that it wasn't noisy. So you can run this noisy machine and still see it running and kind of contain the dust and that kind of thing. So that's our biggest gig, but the students can work around it without… They're comfortable doing it. (Interview, April 17, 2015)

Mr. Mitchell suggests that there were students who were uncomfortable around the ShopBot because it is loud and dusty. They built the ShopBot room so students can still see the ShopBot working without exposing themselves to noise and dust.

When they moved the ShopBot into the Fab Lab, the opportunities for Fab Lab and woodworking students to interact and share creative ideas, skills, and practices were lost. The ShopBot was no longer a shop and Fab Lab tool, it became exclusively a Fab Lab tool. While there may still be some potential for shop and Fab Lab crossover, the building of a ShopBot room makes this more difficult. The ShopBot room creates a physical separation between the Fab Lab and the shop and this boundary makes it even harder for Fab Lab students on the advanced placement coursework path to observe and engage with the skills and intelligences of the shop students. Mr. Mitchell mentioned how they had the ShopBot room built to contain the noise and the dust of the ShopBot so that the Fab Lab students were comfortable working around it; however, he never mentions how all students (including shop and art students) may be uncomfortable working around noise and dust not just Fab Lab students.

His ability to create a boundary between the Fab Lab and the shop also segregates the tools, practices, and students that occupy those spaces. In an interview, he assumed the students who take shop courses were like him when he was in school, not a great student and "used to" shop spaces (Interview, April 17, 2015). He would go on to share how the Fab Lab was not designed for students like him, but everyone else including female students and students on the advanced placement coursework path. Mr. Mitchell's and presumably others' assumptions about the comfort and work ethic of Fab Lab students compared to shop students help to explain why the school district was willing to fund building renovations in the Fab Lab, but would not give Mr. Gibson money to install sawstops on the table saws to prevent student injuries. Examining the history of manual labor and vocational education and the perceptions about the intelligence of the people that engage in that work can provide some insight into why the school district may have chosen to fund the Fab Lab, but not the shop.

Mr. Carson mentioned how people do not typically consider students who take shop courses the "smart kids" (Interview, March 23, 2015). While I do not think Mr. Carson agrees with the way that other people evaluate this set of students, he understands that this assumption exists and that some of his students might believe it. Judging people's intelligence based on their job is part of our cultural history (Rose, 2004). We base these judgments on distinctions we make when comparing job-related qualities like cleanliness, physical risk, and education requirements. These qualities of a particular job are both real and symbolic. These symbols can cause us to assume that the qualities of the work reflect the qualities of the worker. For instance, when Andy referred to shop students as "hicks who don't care about school" (Interview, May 27, 2015), he was repeating a cultural assumption about the intelligence of students who engage in low-tech, hands-on work.

The North Fab Lab instructors designed the Fab Lab to be quiet and clean like an imagined science lab and not a shop. It features objects that are symbolic of science and intelligent work like lab coats, lab benches, and advanced technologies that are not neutral objects. They are symbolic and can change the way we think about the people who interact with them. They can cause us to assume that the qualities of the learning environment (e.g. clean, quiet, intelligent) reflect the qualities of the learners. When we compare qualities of an imagined science lab (e.g. clean, quiet, intelligent, high status) to the shop, a noisy and dusty environment that does not contain cultural symbols of science and intelligent work, these distinctions can cause us to see Fab Lab students as the "smart kids" who engage in science. Therefore, they deserve a learning environment that reflects their intelligent work.

While these assumptions about intelligence and who belongs in what learning spaces are often hidden in the design of learning environments and curricula, they do not go unnoticed. Rose (2004) writes, "curricular options are built on terribly diminished, and self-fulfilling, assumptions about the cognitive capacity of large numbers of students. After a while, young people figure this out" (2004, p. 190). This was true at North High School.

The Fab Lab instructors set out to attract all students at North High School. However, their reliance on popular images of science and STEM, their intentional dissociation with popular images of craft and technical work (e.g. dirty, noisy, risky, unintelligent work), and their use of cultural assumptions of work and intelligence in the design of the learning space and curriculum reinforced social sorting practices at North High School. Those students who identified with popular science images and "smartness" were encouraged to participate in Fab Lab coursework while those students who do not identify with them either self-selected out or were discouraged from participating due to beliefs and expectations held by their parents, teachers, and counselors.

Unlike Barton et al. (2016), who used *making* to provide underrepresented students access to STEM tools, activities, and identities, the North Fab Lab used the rhetoric of science, STEM, democratization (e.g. The Fab Lab was designed to make everyone "comfortable) to give already privileged students even more access to STEM tools and identities even if it is unclear whether there were STEM activities in this context. They did this by appropriating educational modalities already common in the shop class (e.g. hands-on learning, using powerful fabrication technologies) and re-casting them as innovative and "comfortable" for students already classified as future engineers.

The research findings are troubling because the design and implementation of the North Fab Lab reinforced social sorting practices that are widely understood to be problematic, and they did this despite the rhetoric of democratization that goes along with the Maker Movement. Additionally, the North Fab Lab appropriated a set of practices that are already present in other, low-status contexts in the school—further obscuring the power of that low-status educational work and its salience to the explicit goals and objectives of the Maker Movement. We should also consider the possibility that the separation of *making* coursework and digital technologies from more traditional forms found in CTE and art classrooms further conceals the skills and intelligences of students and people who work with more traditional technologies.

As a reform movement, *making* offers one path for introducing STEM/STEAM education into formal education. However, like all reforms, *making* can reinforce or diminish established inequities. Scholars like Barton et al. (2016) and Kafai et al. (2014) have shown how the latter is possible. They may have been successful democraticizing access to STEM education to underrepresented students because they provided a learning environment that featured a wide-range of tools, skills, and *making* possibilities. They showed students how they could pair traditional crafting practices with more contemporary digital programming practices, and by doing so, they worked to bridge the gap between arts, crafts, and digital fabrication practices and highlight different skills and intelligences.

We are currently investing a fair amount of *maker*-style learning experiences under the assumption that these experiences can provide students with new and exciting opportunities to develop disciplinary ideas and practices, but we should not be too quick to assume that this happens. *Making*, in its various forms, does not necessarily offer rich science learning experiences. If we want it to introduce makerspaces in K-12 settings, we must take more care in the design and implementation of curricula and learning environments including shaping students' learning experiences with an "equity-oriented lens". As Barton et al. (2016) warn, "If makerspaces are made accessible or attractive only to those who already have the social and cultural capital for success in STEM, then gaps in access and opportunity may increase as a result of the maker movement" (p. 26).

These findings should be read as an instructive cautionary tale, how one Fab Lab's attempt to democratize access to design-based STEM education actually reinforced the school's social sorting practices that have kept students from accessing STEM tools, activities, and identities in the past. Instead of designing the Fab Lab around the curricular goals of *making*, the Fab Lab instructors focused on the fabrication technology and creating a cultural space of STEM. While images of science and STEM were present, the Fab Lab did not engage students in the scientific practices described in the NGSS (NGSS Lead States, 2013).

One could read these findings and think that the North Fab Lab just represents bad teaching, that the instructors did not design and implement a *making* curriculum that promoted the skills and practices discussed in the *maker* literature. While that may be true, their instructional decisions were not socially inert. The Fab Lab instructors' efforts to attract recognition, funding, material resources, female students, and students on the advanced placement coursework path effectively created boundaries between the Fab Lab and the other design-based learning environments and the students who have been historically left out of STEM education.

This research is significant because it is one of the first to examine how K-12 teachers and formal makerspaces can use the epistemic authority of science and STEM in ways that ultimately exclude students who choose or who are encouraged to learn in more traditional design-based settings (e.g. woodshop). This study also provides a greater awareness of the politics of artifacts that make up learning environments. As a movement that highlights the use of technologies in students' learning experiences, we need to pay greater attention to how these technologies can encourage some skills and practices while discouraging others.

Maker Movements

When I began this research study, I set out to understand how the promises of the Maker Movement can play out in a formal K-12 setting, specifically what student engagement in science looks like in a learning environment that promotes design-based STEM education. I also went into this study with the idea that the Maker Movement may actually be several movements just as the progressive movement a century ago was not one movement but several movements with "diverse and contradictory expressions of support" (Kliebard, 2004, p. 282).

Some supporters see *making* as a learning process that can empower students by providing them access to STEM tools, activities, and identities when they solve personally meaningful problems (Blikstein 2008; 2013; Barton et al., 2016; Halverson & Sheridan, 2014; Kafai et al., 2014). Others look to *making* for its entrepreneurial opportunities and to prepare students for jobs in the STEM fields (Anderson, 2012; Hatch, 2013), and others are trying to bring both worlds together (Dougherty, 2012a). I went into this research study concerned that if the Maker Movements played out like the progressive movements did a century ago that the Maker Movement's success would not be remembered for its ability to provide all students with a hands-on, design-based STEM education, but its ability to "act as a kind of magic mirror in which the powerful interest groups [could] see their own reflected ways of reforming" (Kliebard, 2004, p. 128). I worried that behind that mirror would be little intellectual depth.

While the goal of this study was not to distinguish the different interest groups that have shaped the North Fab Lab, as I analyzed the data, I found that the North Fab Lab set out to achieve many important, but different goals. Some of these included providing opportunities for students to apply the knowledge they learned in their science and math courses (Mr. Mitchell, interview, April 17, 2015), to have students engage in personally meaningful problems while learning the skills of digital design and fabrication (Mr. Carson, interview, March 23, 2015; Mr. Mitchell, interview, April 17, 2015), and preparing students for careers in the STEM fields (Mr. Mitchell, interview, April 17, 2015). These goals are similar to the ones in the *maker* literature.

Unfortunately, I found that the North Fab Lab might have lost sight of some of these goals. I believe the North Fab Lab has focused so much of its time designing and implementing a curriculum and learning environment that reflects a cultural space of science, in order to appeal to corporate and government interest groups, female students, and advanced placement students, that their other goals have been neglected. They have used the epistemic authority of science and STEM to gain status and credibility in order to recruit advance placement students who identity with science, STEM, and advanced technologies and to access money and resources through corporate sponsorships and public and private grant organizations. I believe their focus on creating images of STEM and *making* instead of student engagement in design-based STEM education is influenced by these interest groups. For example, the "Fabrication Laboratories Grant" they recently received from the state's Economic Development Corporation stated that qualifying schools must provide students with opportunities to "practice concepts they have learned in science, technology, engineering, art and mathematics (STEAM) courses." Other than that one sentence, the grant does provide any information about what student engagement would look like in this kind of learning environment. Like the Fab Foundation and TIES, STEM or in this case STEAM remains vague and up for interpretation. The grant goes on to say that "increasingly, this type of learning requires equipment such as 3D printers, laser engravers, computer numerical control routers and plasma cutters." Qualifying schools must also have "business and community partnerships" already in place ("Fabrication Laboratories Grant," n. d.). While the North Fab Lab may not be successful yet at engaging students in STEM or STEAM, they have been successful at creating an environment that evokes engagement in STEM, creating business and community partnerships, and using resources from those partnerships to acquire digital fabrication technologies.

What this research demonstrates is that the North Fab Lab has been successful at appealing to those interest groups despite not accounting for/incorporating other things like engaging students in science content and practices, democratizing access to STEM education, and providing students with creative and empowering learning experiences. If educational reformers and instructors do not have a clear sense of what engagement in science looks like in a STEM learning environment then science could become an assumed feature of an environment that really just features cool technologies, and *making* could be another opportunity to maintain the status quo in formal K-12 settings. We cannot expect the Fab Foundation and the USFLN to help Fab Lab instructors figure out how to integrate science practices into their Fab Lab pedagogy.

There are various definitions in play concerning what constitutes what science is and looks like in *making* experiences. Some educators may focus on creating *making* experiences around science concepts and practices like building a rollercoaster to learn about friction and energy. Others may use students' personal projects like creating an Anti-Rape Jacket and supporting students with "just-in-time" resources to help students deepen their understanding of science knowledge and practices (Barton et al., 2016, p. 20). Either way, STEM learning environments should pay attention to at least one of these ideas in the design of student learning experiences.

Lastly, as a field that continually benefits from its linkage to economic and vocational agendas (Donnelly, 2009), research that addresses the social aims of *making* and STEM is one area where science education researchers can deepen their understanding of science education and vocationalism.

Future Work

While the NGSS provides a list of science and engineering design practices that science educators should make a part of their STEM learning environments, there is still little research on what science learning should look like in design-based STEM education. There is a growing body of research on how students develop understanding of science through practices like creating, testing, and revising explanatory models (Windschitl, Thompson, & Braaten, 2008); however, there is a need for research on how students use their scientific models alongside their engineering models as they engage in the design process. Additionally, if science education is moving towards STEM education, there is a need for research that examines how we prepare teachers for interdisciplinary work when university programs train them to teach one subject area. Lastly, there is a need for more work on understanding what the social aims of design-based STEM education should be and how STEM practices contribute to these aims. With a clearer vision of our social aims, we can work to design STEM curricula and learning environments that overcome the structural tensions of public education (e.g. separation of disciplines, categorizing and sorting students) that have historically kept girls, students of color, and low-income students from accessing STEM education.

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Appendices

Appendix A: Interview Protocols

Student Interview Script

Thank you for agreeing to be interviewed today. The information you share will help me understand how students learn through making. Audio taping this interview will help me remember what you share with me today. I will type up our conversation and include portions in my research, but I will not include your name on the transcript.

Do I have your permission to audiotape?

I am going to be asking you some general questions about your experience as a student in a Fab Lab/Woodworking course, but you may also ask questions of me at any time. Do you have any questions before we begin?

Making Background

1. Before participating in the course, what experiences did you have that involved designing or making?
2. What skills do you feel you bring to the Fab Lab/Woodworking course?
3. Have you taken other courses that involved making or design?

Reflections on your participation in the Fab Lab/Woodworking course

1. What do you feel you learned by participating in a Fab Lab/Woodworking course?
2. What kinds of skills do you feel you developed by participating in this course?
3. How was this learning experience different from other learning experiences (Fab Lab/Woodworking/Art) you have had?
4. Why did you decide to take a Fab Lab/Woodworking course and not another making course like those taught in the Fab Lab/shop/art studio/etc?
5. The Fab Lab website says, "Science, technology, engineering, art and math all come together in our state-of-the-art digital fabrication laboratory (Fab Lab)." How do you think you used science in the Fab Lab? What scientific knowledge do you think you have learned? What kinds of scientific practices did you use? Math? Engineering?
6. It has been mentioned that students engage in science during the circuit board project. Can you explain to me how a circuit board works?
7. Do you think you would have learned the same things in a traditional course on science? What about a shop/Fab Lab class? Why or why not?
8. Would you consider taking another course like this one in the future? If so, why? What about a different making course like one found in the Fab Lab/Woodworking Shop/Art Studio?
9. Has this course had an effect on your plans after high school?

Post- Interview

Is there anything else you would like to tell me about your experience in the Fab Lab/Woodworking course?

Thank you again for your participation in this interview.

Instructor Interview Script

Pre-Interview

Thank you for agreeing to be interviewed today. The information you share will help me understand how teaching and learning take place in design-based learning environments. Audio taping this interview will help me remember what you share with me today. I will type up our conversation and include portions in our research, but I will not include your name on the transcript.

Do I have your permission to audiotape?

I am going to be asking you some general questions about your experience as an instructor in the Fab Lab course, but you may also ask questions of me at any time. Do you have any questions before we begin?

Background

1. What is your background and how did you become involved with the Fab Lab/Shop?
2. What other courses do you teach at [X] High School?
3. What is your day-to-day role as an instructor at [X] High School?
4. What do you think are the goals of the Fab Lab?
5. How do you use the Fab Lab?
6. Do you consider yourself a maker? Why or why not?
7. What are some examples of things you have made?
8. What has been your most rewarding making experience?

Reflections on your/students participation in the Fab Lab/Woodworking course

1. How is this teaching experience similar to other experiences you have had?
2. How is this teaching experience different from other experiences you have had?
3. How do you think the Fab Lab is different from other design-oriented spaces like the woodshop and art studio?
4. How do you think students learn differently in the Fab Lab compared other learning spaces?
5. What kinds of knowledge and skills are students learning by participating in the Fab Lab? Can you give me an example?
6. The Fab Lab homepage says, "Science, technology, engineering, art and math all come together in our state-of-the-art digital fabrication laboratory (Fab Lab)." How do you see students engaging in science in the Fab Lab? Knowledge? Practices? Skills?
7. Do you think students would learn similar things in a traditional science course? Why or why not?
8. What are some pedagogical challenges you have faced as a Fab Lab/Shop instructor? How have you tried to resolve them?
9. What do you hope students walk away with after participating in the Fab Lab?
10. Is there any interest in integrating other design-based courses (woodworking/art) into Fab Lab courses?
11. Why use digital fabrication technologies and not the technologies found in the woodshop or the art courses?
12. How do you see students using their knowledge and skills in the future?
13. Did you attend the FabLearn conference at Stanford? FAB conference at MIT? Did those experiences change the way you think about teaching? Teaching science?
14. Why is the Fab Lab/Woodworking experience important for a student's education?

15. Has the Fab Lab changed the way you teach your other courses?

Post- Interview

Is there anything else you would like to tell me about your experience as an instructor in the Fab Lab course?

Thank you again for your participation in this interview.