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Schooling Makerspaces: On the Promises and Tensions of Implementing this Much-Touted Innovation in a High School

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Schooling Makerspaces: On the Promises and Tensions of Implementing this Much-Touted Innovation in a High School

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Dedication

To Eliza and Carrie – I love you both so much! Without you two, I couldn't have done it.

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Abstract

Schooling Makerspaces: On the Promises and Tensions of Implementing this Much-Touted Innovation in a High School

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This dissertation explores the tensions and contradictions that manifest when implementing a makerspace in a high school. This writing is the result of a two-year ethnographically informed study of a makerspace housed on the high school campus of a K-12 independent school located in Austin, Texas. My goal was to provide a rich and detailed account of how the makerspace changed over the years, in response to the various 'forces' that impinge upon the system, and to triangulate these observations with issues of educational relevance that have animated discussions about the benefits of making activities. I draw on Activity Theory (Engeström, 1999b) to help focus these efforts, in particular in following how tensions and contradictions in the various elements of an activity system drive changes to the environment and its culture. While this account is by no means generalizable to other settings, this analytical strategy can help articulate themes that are likely to be manifested (in one way or another) across various other implementations of school makerspaces.

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Chapter 1: Introduction

This ethnographically informed research study was designed to explore the educational realities of implementation and daily use of a makerspace housed on a high school campus. In the past decade, schools and libraries around the world have built makerspaces in connection with a larger societal movement, referred to as the maker movement. As the maker movement is a relatively new phenomenon, there is little research into the educational realities of makerspaces on school campuses, including the unique challenges that arise in the process of conceiving, establishing, and operating a makerspace within school grounds.. This study hopes to develop the educational connection from makerspaces to formal institutions of schooling by focusing specifically on the potentialities, tensions, and contradictions that emerge as a result of implementing a school makerspace – that is, the schooling of the makerspace.

1.1. Problem Statement

Making is an emerging form of educational practice that involves designing and constructing a wide variety of artifacts using old and new forms of tools and technology, integrating art, science, engineering, and mathematics. The Maker Movement was borne of making, and represents the growing movement of makers and tinkerers who creatively design and build objects for both playful and utilitarian needs (Lee Martin, 2015). Although the name and the idea of the maker movement can be traced back to the founding of *Make* magazine in 2005 and the first Maker Faire in 2006 (Dougherty, 2012), the principles of making are related to well known hobbies and crafts like woodworking, sewing, and electronics (Lee Martin, 2015, p. 30). Sheriden et al. (2014) describe makerspaces as a key component of the maker movement, "where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" (p. 505).

Making and makerspaces promise to change the way people learn (L. Martin & Dixon, 2013; Sylvia Libow Martinez & Stager, 2014). Maker activities are argued to provide multiple starting points and pathways for student learners (Resnick & Rosenbaum, 2013), and provide learners across all ages to engage in playfully and creative ways in order to develop their own ideas and build on what they know (Shirin Vossoughi & Bevan, 2014). The inherent *tinkering* nature of making is seen as a natural foundation for students to engage in feedback loops while learning, allowing learners the space to try again, encouraging the potential for sustained engagement in the practice (DiGiacomo & Gutiérrez, 2016).

Making is also poised to enhance opportunities for K-12 students to engage in design and engineering practices at the granular level, and STEM practices more broadly (Lee Martin, 2015). The interest-driven nature of making positions it as a strategy for broadening participation in the STEM disciplines (Resnick & Rosenbaum, 2013). Making is argued to align with K-12 science standards (Quinn & Bell, 2013) and promises to deepen students' understanding of STEM concepts, phenomena, and practices (Bevan, 2017).

The introduction of makerspaces within school grounds promises to transform education and schooling by changing the very nature of teaching and learning, by broadening access to STEM content and practices to all students, and by fostering student creativity and entrepreneurship (Bevan, 2017; Kylie Peppler & Bender, 2013). The problem is that we know very little about what actually happens in school makerspaces, the processes that shape the creation and functioning of the space, how different stakeholders (students, teachers, administrators, makerspace personnel/staff, and even parents) participate in the space—all of which mediate the learning that ultimately takes place within the space.

As Paulo Blikstein (2013) puts it: "Schools manifest how they value a particular activity by building a space for it" (p. 6). Callaghan (2013) describes makerspaces thusly: "Maker-spaces can be regarded as a type of informal learning environment, as the group support is often focused on instructive advice, resulting in learning, especially by less knowledgeable members" (p. 2). Makerspaces vary in their inventory from location to location, with the theme of creating, building, and crafting running common. Makerspaces are largely associated with specific forms of technology and tools like 3D printers, laser cutters, microcontrollers, power tools, and crafting supplies and instruments (Kurti, Kurti, & Fleming, 2014a). With a relatively inexpensive build-out budget, schools can create makerspaces using existing classrooms, which might account for the rise in makerspaces on school campuses (Kurti et al., 2014a). As the inventory of tools and expertise varies from location, makerspaces have come to be defined not based on specific tools or hardware, but on the community and shared vision for what a makerspace is (Horvath, Cameron, & Adrianson, 2015, p. 59). Since makerspaces serve a community and an ideal, it is necessary to determine what makes up the educational basis of the Maker movement, and contrast this with any basis in educational theory.

The growth in makerspaces on school campuses and in libraries (Dougherty, 2012; Yasmin B. Kafai, Peppler, & Halverson, 2016; Lou, 2016; Strycker, 2015) over the past decade necessitates research into the educational backbone of the maker movement and makerspaces in general. Educators have established makerspaces on campuses, and in many places, have also developed new departments and positions to accommodate these makerspaces seemingly based on the hope that the maker movement holds educational merit, and that students will learn as a result of maker activities. Due in part to the relative newness of the maker movement in education, there is very little empirical research to be found in the literature into the learning activities in makerspaces, with much of the research into makerspaces concerning the establishment and design of makerspaces. According to Sheridan, Halverson, Litts, and Brahms (2014) "Despite a flurry of interest and activity around designing and creating makerspaces, we still know little about the content and processes of learning in makerspaces" (p. 506). This imbalance in the educational literature leaning heavily towards designing and constructing makerspaces and away from understanding the learning implications of makerspaces definitely warrants consideration.

The popularity of the maker movement in schools is extraordinary considering the modern maker movement was established a little over a decade ago with the publication of MAKE magazine (Dougherty, 2012). The popularity of the maker movement as a educational reform is due to its grassroots nature, spreading at a local level due to its accessibility and potential (Peppler & Bender, 2013). With the aid of the Internet, this grassroots movement has spread across the globe, for as Dougherty (2012) suggests, "today's makers enjoy a level of connectedness that has helped to build a movement out of what in the past would have been simply a series of microcommunities defined by a particular hobby or activity" (p. 12). For many educators, the maker movement holds the potential for paradigmatic change to our educational system, and these educators have become advocates for building makerspaces for students to learn through making and infusing maker activities into traditional schooling. The founder of MAKE magazine and Maker Faires, Dale Dougherty, described spreading the maker movement into schools, saying "Our first wave has been to find teachers who are themselves makers. They understand the relevance and importance of making things and are able to act on it, and also to connect with their students as mentors" (2012, p. 13).

Within the educational literature and popular writings regarding the design of makerspaces in schools, there is a surprising lack of discussion regarding the theoretical assumptions inherent in makerspaces and how they align with the theoretical assumptions of formal institutions of learning. It must be stated again that the maker movement did not originate as an educational reform; the maker movement is a popular movement that has become the basis for an educational reform. The educational research community that has embraced the maker movement has attempted to define its educational forefathers, overwhelmingly favoring John Dewey and Seymour Papert (Halverson & Sheridan, 2014; Y. Kafai, Fields, & Searle, 2014; Sheridan et al., 2014). However, neither Dewey nor Papert conceived of the maker movement in schools, and thus attributing their theories to the maker movement provides a theoretical grounding for the movement, which also serves as justification for the interest in makerspaces and the maker movement. It is necessary to not just attribute theoretical grounding to the maker movement in education, but to examine and explicate the theoretical assumptions of the maker movement, by exploring the nature of participation in a school makerspace.

1.2. Research Question

This is a study of the challenges and promises that emerged during the conception, implementation, and operation of a makerspace installed within the grounds of a private high school. To do so, I take a broad sociocultural lens to the problem and analyze the *tensions* and *contradictions* (Engeström, 1999b) that played out in the daily functioning of the space over a period of 24 months. Following activity theory (Baek, Evans, & Barab, 2013; Engeström, 1999b), tensions and contradictions are inherent in the practices of groups or communities, and they may manifest themselves in different ways (e.g., in the evolving rules/norms of operation of the space/community, in open negotiations among its participants, in various forms of conflict and/or breakdowns in work flow, and so on). Simultaneously, tensions and contradictions embody the potential to transform the practices from which they are borne. While the tensions and contradictions highlighted in my analysis are clearly specific to the case I studied, they share many substantive themes with commonly reported challenges in the adoption of classroom/technological innovations and add important empirical details on how makerspaces are appropriated into school environments—that is, the schooling of a makerspace.

Furthermore, in line with the broader sociocultural framework that informs my study, I also attend to the different *forms of participation* that users of the makerspace (teachers, students, and others) took on, as well as the relationships of power that developed over time within the space (Lave & Wenger, 1991). For example, as students frequent the space and learn about the various technological tools available in the community, they may take on more *peripheral* or *central* forms of participation in the makerspace (Lave & Wenger, 1991). Alternatively, some students may choose to completely withhold participating in the space whereas others may elect to participate, yet actively *resist* the culture of the space (Norton, 2001; Roth, Hwang, Goulart, & Lee, 2016). By mapping out the various forms of participation that developed in the makerspace, my analysis seeks to highlight broader aspects of the culture of schooling and STEM, such as gender inequities and identity politics (Beede et al., 2011; Côté & Levine, 2002; Holland, 1998; Wang & Degol, 2017).

While the study does not address student learning directly, forms of membership and participation in any community or practice are directly linked to what people might learn in such practices. By revealing how various constituencies came to inhabit (or not!) and participate (or not!) in the makerspace, therefore, I also speculate on what students may or may not have learned through their experiences in the makerspace. This speculation comes in the form of addressing the potentialities embedded in the activity system.

1.3. THEORETICAL FRAMEWORK

This study of a makerspace is a study of culture, community, hierarchies, power, and activity within a complex environment. As such, I required a multilayered theoretical framework that will allow for the analysis of varying forms of participation and activity within the sociocultural contexts of the school makerspace. I selected the Communities of Practice theoretical framework based on the work of Lave and Wenger (Lave, 1988; Lave & Wenger, 1991; Wenger, 1999, 2009) for its emphasis on the social dimensions of learning that were inherent in the makerspace. Lave and Wenger's theory of learning - Legitimate Peripheral Participation - serves as "an analytical viewpoint on learning, a way of understanding learning" (1991, p. 40), and serves as a basis for my research study in order to "raise questions about the social organization of schools themselves into communities of practice, both official and interstitial, with varied forms of membership" (p. 41).

Legitimate Peripheral Participation describes a mechanism whereby newcomers to a community of practice constantly move between peripheral, or tangential, and more central forms of participation (center and periphery do not refer to physical locales but rather to relations of production and accountability crucial for the community's function). Therefore, learning is seen in the different roles progressively taken on by a newcomer, who in the process becomes accountable to more central aspects of the practice.

I borrow from Legitimate Peripheral Participation the idea that forms of participation (namely the norms of the culture of the community; and, access to tools and equipment) are mediated by the environment. Thus, power relations are seen in the forms of participation that are afforded to some, or withheld from others. Take the case of Vai and Gola tailors in Liberia (Lave & Wenger, 1991, pp. 69–72). Neophytes entering communities of tailors are apprenticed through a process that guarantees their continued access to resources in the community (which is critical for the newcomer's performance of any task), as well as an overall understanding of the process of garment production. As newcomers are assisted by more capable peers in working with various aspects of garment making, they take on new responsibilities in the production process and develop into more mature forms of practice participation.

The framework of Communities of Practice has been used to situate other research studies into learning in the makerspace (Halverson & Sheridan, 2014; Sheridan et al., 2014), with Sheridan et al (2014), claiming that the framework was selected for their comparative case study of three makerspaces because it helps to delineate "how the shared use of space, tools, and materials; shifting teaching and learning arrangements; individual and collective goals; and emergent documentation of rules, protocols, and processes for participation and action work together to form each Community of Practice with its own particular features" (p. 509). In a similar vein, I used the Communities of Practice framework to better understand the various forms of membership and participation that emerge in the makerspace, the group/individual interactions and relations of power that develop over time, and how these dynamics are mediated by resources and infrastructure.

In order to further develop a framework of participation, I draw from Activity Theory (Engeström, 1999b), as it makes these categories of mediational means (tools, artifacts, materials, division of labor) more obvious. Consider Engeström's model of the activity system (Engeström, 1992; Engeström & Escalante, 1996). Figure 1.1 depicts the model.

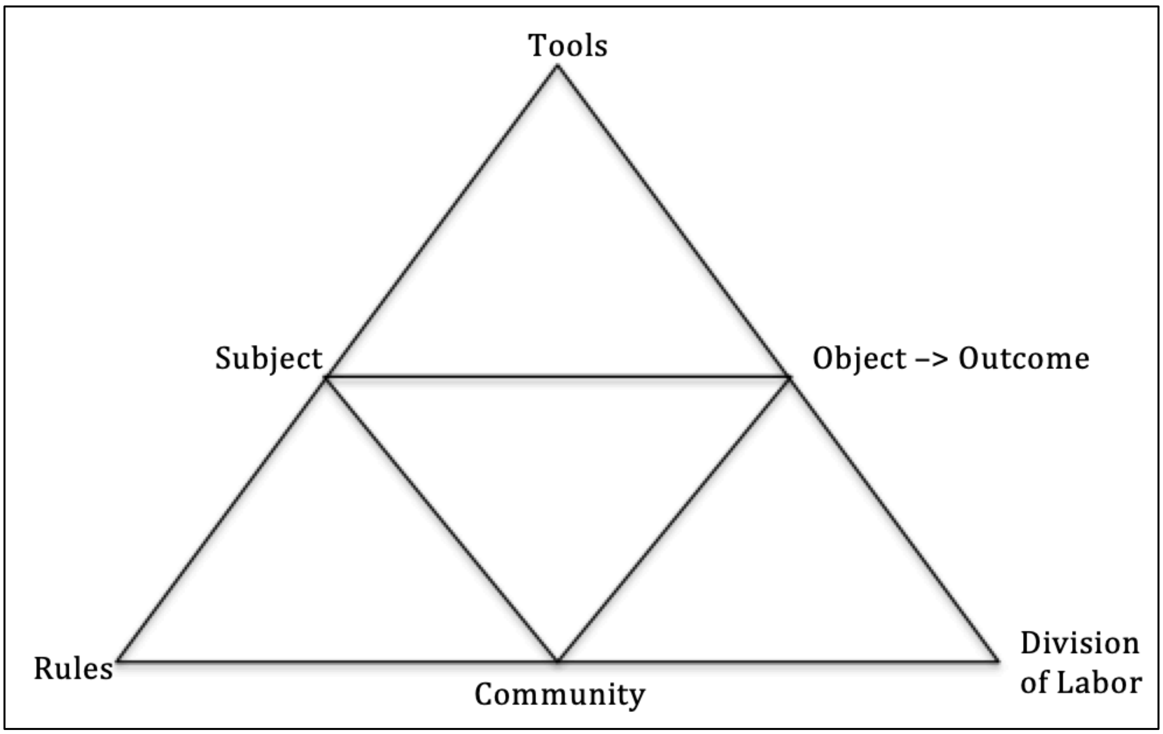


Figure 1.1. Activity system model as adapted from Engeström Engeström (1999)

Engeström's activity system model consists of subject, tools, object, rules, community, division of labor, and outcomes. Subjects are the participants of the activity, and tools represent the tools or resources these participants use in pursuit of the object, or the goal of the activity. Within an activity system, the subject's participation is regulated either formally or informally by the rules of the activity system, with the division of labor serving as the shared responsibilities determined by the community, or the overarching group(s) that the subject belongs to. Given this activity system model, one can see that the relationship between the subject and the community is mediated by both explicit and implicit norms of participation. Meanwhile the relationship between the subject and the object of the activity is mediated by tools or resources, and then further shaped by the division of labor across participants in the activity system.

Activity theory has been used in research covering a wide variety of topics (Baek et al., 2013; Lisa C. Yamagata-Lynch, 2010b; Lisa C. Yamagata-Lynch & Smaldino, 2009). Although here I do not add specifically to the development of activity theory, many aspects of the theory permeate the approach that I have used in my research. Activity theory is fundamentally concerned with the evolving structure of activity, the historical development of activity over time, and the inherent social nature of human activity. The inherently social nature of human action embodied in the concept of activity provides an inspiration for the study of student participation in a setting that can be seen as intrinsically social especially so when one contrasts the school makerspace to formal classrooms. Additionally, Activity Theory is fundamentally committed to the historical development of activity over time. An account of the history of the developing activity system is therefore a key component of activity theoretical analysis. Most important for this research, however is Activity Theory's use to identify tensions and contradictions in activity systems. In fact, Engeström developed activity theory "in order to explore and document the sources of tensions in human individual or collective activities" (Lisa C. Yamagata-Lynch & Smaldino, 2007, p. 366). In the following section, I will explicate this application of activity theory in understanding the various tensions and contradictions in activity systems by first exploring the methodological and analytical approach, then extrapolating the formal definitions of tensions that I used for analysis.

1.4. Delimitations

This study limited its focus to understanding systemic tensions in a makerspace on a secondary school campus. The decision to focus on tensions was based on my interest in understanding how tensions and contradictions in the various elements of a makerspace-based activity system drove changes to the environment and its culture.

The decision to focus on makerspaces aligned with formal institutions of learning was based on my connection to a makerspace on a secondary school campus. The site was selected purposefully given that I served as the director of the makerspace used for the study and thus had unfettered access to the site, and the underlying principles, equipment, and tools of the makerspace align with those suggested by Horvath and Cameron (2015), Kurti, Kurti, and Fleming (2014a, 2014b), Range and Schmidt (2014), and Strycker (2015).

To better understand experiences of participants working in a makerspace, I recorded observations in field notes, highlighting such things as who visited the makerspace and for what reasons, the projects attempted in the makerspace and the general activities it afforded, how visitors to the space interacted with the space and its infrastructure, and how the makerspace changed over time. In addition to field notes, I conducted interviews with 12 makerspace users. These interviews were meant to scope out students' individual motivations for attending the space, and to better understand the relevance of learning to their interactions within the makerspace and in school.

The participants were limited to students and teachers who used the makerspace on a secondary school campus. Interview participants were selected purposefully in order to compare and contrast formal school activities to interest-driven activities, and individual projects to group projects.

Chapter 2: Review of the Literature

The maker movement in education is a relatively new phenomenon, and as such there are seemingly few educational researchers writing about the topics of the maker movement in education, and makerspaces in schools. A review of literature which relates to this study of participation in a makerspace consists of the following topics: (a) makerspaces, (b) the maker movement, (c) design and construction of makerspaces, (d) history of makerspace and the maker movement, (e) the theoretical foundations of the maker movement in education, (f) the Constructionist foundation of the maker movement in education, (g) the maker movement and learning by doing, (h) makerspaces as learning environments, (i) the maker movement and STEM education, (j) participation in makerspaces via communities of practice, and (k) activity theory analysis in educational research.

2.1. Makerspaces

Makerspaces vary in their inventory from location to location, with the theme of creating, building, and crafting running common. Makerspaces are largely associated with specific forms of technology and tools like 3D printers, laser cutters, microcontrollers, power tools, and crafting supplies and instruments (Kurti et al., 2014a). With a relatively inexpensive build-out budget, schools can create makerspaces using existing classrooms, which might account for the rise in makerspaces on school campuses (Kurti et al., 2014a). As the inventory of tools and expertise varies from location, makerspaces have come to be defined not based on specific tools or hardware, but on the community and shared vision for what a makerspace is (Horvath et al., 2015, p. 59).

The number of makerspaces have increased over the past decade, with online websites like makerspace.com cataloging all known makerspaces across the world, estimating almost 600 makerspaces as of this writing ("Directory of Makerspaces," 2017). Although there are attempts at cataloging the number of makerspaces around the world, these directories do not include school-based makerspaces. The increase in the number of school-based makerspaces can be evidenced by the number of articles published in the last four years that describe how schools can design makerspaces (Fleming, 2015; Preddy, 2013; Rivas, 2014; Strycker, 2015) and by the steady increase in published articles and books published on the subject of making over the past decade.

2.2. The Maker Movement

The maker movement can been defined as "the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forms to share their processes and products with others" (Halverson & Sheridan, 2014, p. 496). The maker movement has also been described as a burgeoning culture of creating, designing, and innovating, usually with a do-it-yourself, or DIY mentality (Peppler & Bender, 2013, p. 23). The maker movement's greatest impact so far in the field of education would be the establishment of makerspaces in schools and libraries. As Paulo Blikstein (2013) puts it: "Schools manifest how they value a particular activity by building a space for it" (p. 6). And schools seem to have found a lot of value in making as an educational activity based on the rise in the number of makerspaces found in schools across the country (Lou, 2016) and internationally (Peppler & Bender, 2013, p. 5). Halverson and Sheridan (2014) point out that the excitement concerning maker culture "has led to an explosion of makerspaces around the United States (and the world) across a range of instructional environments, including libraries, museums, independent nonprofit and for-profit organizations, K-12 schools, and institutions of higher education" (p. 495).

2.3. Design and Construction of Makerspaces

Much of the early literature regarding makerspaces deals with the designing and building of makerspaces, including equipment that allow for students to make. Range and Schmidt (2014) summarize the wide variety of tools and equipment one can put in a makerspace by saying, "taking into account several factors – students' interest, projects, budget, space, and storage – every makerspace's collection of tools and equipment is unique" (p. 10). While there is not a universal agreement on what tools and equipment that a makerspace must have, but there are several pieces of equipment that many authors of makerspace design and construction publications suggest for a makerspace.

3D Printers

In terms of hardware, many researchers suggest that 3D printers have become a staple tool in makerspaces (Fleming, 2015; Kurti et al., 2014a; McDermott, 2012; Range & Schmidt, 2014; Strycker, 2015) . 3D printers, sometimes referred to as "additive machines" (Straub & Kerlin, 2014) are machines that convert digital 3d files into physical objects, using plastic filament material such as PLA or ABS to build the object one layer at a time (Straub & Kerlin, 2014, p. 76). The popularity of 3D printers in makerspace is a consequence of the availability and increasing affordability of 3D printers (Saorín, Melian-Díaz, Bonnet, & Carbonell-Carrera, 2017).

2.3.1. CNC Machines and Laser Cutters

According to the research, another popular form of hardware, akin to 3D printers, would be CNC routers or laser cutters (Halverson & Sheridan, 2014; Kurti et al., 2014b; Range & Schmidt, 2014; Strycker, 2015). CNC routers and laser cutters are computer-controlled routers and cutters used to engrave and cut into materials such as woods, acrylics, and metals. CNC routers and laser cutters, along with 3D printers, have become increasingly more popular in schools, as Blikstein (2013) points out that "in the 2000s, prototyping equipment, such as laser cutters and 3D printers, dramatically dropped in price, and Open Source hardware further popularized these technologies" (p. 4).

2.3.2. Microprocessors and microcontrollers

Microprocessors are defined by Cleveland (2014) as “a type of computer architecture based on a general-purpose central processing unit (CPU) on a single microchip (chip)” (p. 380). According to McDermott (2012), microprocessors allow students to create interactive objects that take environmental input such as temperature, light, or movement, and respond by performing a function that the students can program

(p. 8).   Microprocessors have become commonplace in makerspaces due to their inexpensive cost and powerful, yet simple features (Kurti et al., 2014b; McDermott, 2012; Preddy, 2013; Range & Schmidt, 2014). The most common microprocessor used in the maker community is called an "Arduino" (McDermott, 2012) an open-source microprocessor that was created in 2005 by Italian researchers (Grimmett, 2014). In addition to Arduinos, microcomputers such as the popular Raspberry Pi microcomputer, are suggested as basic technologies for a school or library makerspace (Kurti et al., 2014b). Finally, tools associated with microprocessors, including soldering irons, have been suggested as basic tools for makerspaces (Kurti et al., 2014b; Rivas, 2014).

2.3.3. Software

The powerful machines one may find in school makerspaces are powered by software, and research suggests that the use of open source software is both unique to the maker community and possibly one of the reasons why makerspaces have quickly spread in schools and libraries (Kurti et al., 2014b). McDermott (2012) summarizes the effect of open source software in the maker community by saying "makers power their magic machines with open source software and patterns from these sources" (p. 10).   Types of software, either open source or not open source, that researchers suggest for school and library makerspaces include CAD (computer aided drawing) solid modeling software for creating 3D designs (Haug, 2014; Kurti et al., 2014b; McDermott, 2012; Saorín et al., 2017), artistic mesh modeling software for artistic 3d modeling (Haug, 2014; Kurti et al., 2014b) and a wide variety of other software specific to 3D printers and CNC machines (Haug, 2014; Kurti et al., 2014b; McDermott, 2012; Saorín et al., 2017).

2.3.4. Arts and Crafts

Far from innovative technology, traditional arts and crafts materials are also suggested as essential equipment in makerspaces (Preddy, 2013; Range & Schmidt, 2014; Strycker, 2015). Some researchers do not include arts and crafts materials in their list of essential makerspace materials, but they allude to the relationship between the arts and crafts and making (P. Blikstein, 2013; Y. Kafai et al., 2014)

Although some researchers claim that there are a fundamental tools and equipment that one might find in a makerspace, there are many researchers who eschew the necessity of any equipment at all in order for a school to create a makerspace. Martinez and Stager (2014) suggest “even if educators don’t have access to expensive (but increasingly affordable) hardware, every classroom can become a makerspace where kids and teachers learn together through direct experience” (p. 15). Many researchers echo this belief that any classroom can become a convincing makerspace (Jarrett, 2016; Sylvia Libow Martinez & Stager, 2013, 2013). Range and Schmidt (2014) summarize the approach to finding equipment and tools for turning any classroom or library into a makerspace thusly: “A combination of tactile, low-tech materials, and high-tech digital tools offers students a variety of exploratory challenges and styles of making” (p. 10).

2.4. History of Makerspaces and the Maker Movement

The origins of makerspaces can be traced back very far, as the act of "making" or being a "maker" is in some ways synonymous with being a human (Halverson & Sheridan, 2014). The act of making, in other words, has been a necessity of life, but the modern makerspace, and more broadly, the maker movement, are modern inventions whose history is relatively brief (Halverson & Sheridan, 2014). Although this history is brief, makerspaces are not entirely unfamiliar to schools, as makerspaces "share some aspects of the shop class, home economics class, the art studio, and science labs" (Quinn & Bell, 2013, p. 25). Relating makerspaces to shop classes is not an uncommon theme throughout the literature, as many scholars have made this connection (Horvath et al., 2015; Jarrett, 2016; Quinn & Bell, 2013; Slatter & Howard, 2013), which in many ways extends the history of makerspaces in schools, but the emphasis on makerspaces representing a new sort of shop class in schools indicates that makerspaces are a new phenomenon, related to established educational spaces, but not so closely related that they are simply extensions of these spaces.

Makerspaces are related to digital fabrication spaces (Paulo Blikstein, 2013), whose history is also brief, with the first known fabrication studio on an academic institution suggested by Slatter and Howard (2013) as the fabrication space on the MIT campus established in 2001 known as "the Center for Bits and Atoms." In 2001, Neil Gershenfeld and other researchers at MIT used the success of the "Center for Bits and Atoms" and created the "Fab Lab", which packaged low-cost fabrication equipment in a standardized lab that could be deployed in community centers, and universities (Paulo Blikstein, 2013, p. 4).

Scholars claim the maker movement owes its origins to the late 1800s' Arts and Crafts Movement (Herther, 2015), the hobby movement of the mid-20th century and the early computer industry pioneers of Silicon Valley (Dougherty, 2012; Herther, 2015). Whether these movements indeed paved the way for the maker movement or not, one can argue that the maker movement is a relatively new phenomenon based on the fact that for many, the maker movement is a reaction to a relatively new phenomenon, the consumerist technology culture (Dougherty, 2012; Fourie & Meyer, 2015; Halverson & Sheridan, 2014). These authors point out the democratizing nature of the maker movement with its emphasis on inexpensive tools, open source software, the sharing of ideas and the showcasing of inventions and failures, and designing technology versus consuming technology.

The modern maker movement has grown in popularity since the 2005 publication of MAKE magazine (Lee Martin, 2015), thus the maker movement is a relatively new phenomenon, finding its way into schools and libraries only in the last few years (Fourie & Meyer, 2015). The maker movement's increasing popularity in the past decade is sometimes attributed to the popularity of Maker Faires, annual events in which makers showcase their inventions and collaborate with other makers (Dougherty, 2012; Halverson & Sheridan, 2014; K. Peppler, Halverson, & Kafai, 2016). Herther (2015) reported that the first Maker Faire event was "created and controlled" by the MAKE magazine company in order "to celebrate arts, crafts, engineering, science projects, and the Do-It-Yourself mindset" (p. 45). MAKE magazine trademarked the term Maker Faire (Herther, 2015) which is indicative of the magazine's control over content and marketing of Maker Faires.

Maker Faires attendance has been shown by Herther (2015) to be comprised overwhelmingly of college-educated males (p. 42), which aligns with the male-dominated trend in the maker movement suggested by Bean and Rosner (2014), Halverson and Sheridan (2014) and Kafai et al (2014). A range of authors use the White House hosting a maker Faire in 2014 to support the argument that the maker movement has garnered wide scale attention (Halverson & Sheridan, 2014; Honey & Kanter, 2013; Lee Martin, 2015). At this first ever Maker Faire hosted at the White House, President Barak Obama addressed the grassroots popularity and appeal of Maker Faires in his address to those invited, saying "across our country, ordinary Americans are inventing incredible things, and they're able to bring them to these fairs like Maker Faires" (p. 2).

2.5. Theoretical Foundations of the Maker Movement in Education

The maker movement in education can be seen as having theoretical grounding in experiential learning (Dougherty, 2012; Blikstein, 2013), constructivism and constructionism (Paulo Blikstein, 2013; Kurti et al., 2014c). It seems clear that the theory of constructivism, in which students "construct knowledge from their experiences in the world" (Rusk, Resnick, & Cooke, 2009, p. 33) would be a basis for the maker movement in which emphasis is placed on constructing and building. With Seymour Papert's addition to Jean Piaget's constructivism that learners will learn more effectively if they are constructing something personally meaningful (Rusk et al., 2009), one can also see the direct connection of constructionism to the maker movement. Blikstein (2013) contends that experiential education, constructionism, and critical pedagogy serve as the theoretical bases for the modern digital fabrication and 'making' movements (p. 4), spending a considerable amount of writing detailing the educational lineage from Papert to the maker movement (pp. 5 – 6).

Martinez and Stager (2014) describe the foundation of the maker movement in education as another form of a "learning-by-doing approach" whose precedents in education they believe include project-based learning, Piagetian Constructivism, and Papert's Constructivism (Martinez & Stager, 2014, pp. 13-14). According to Halverson, Kafai, and Peppler (2016), the maker movement emphasizes learning via engagement through design and "making learning visible and tangible" (p. 24), and thus they suggest the predecessors of the maker movement to include Froebel, Dewey, Montessori, and Papert. In particular, Halverson et al suggest that the emphasis on artifacts attributed to these educational pioneers, including Froebel's building blocks, Dewey's emphasis on real-life experiences, Montessori's letter planes, and Papert's LOGO turtle, are the real predecessors of the maker movement (2016, p. 24).

There is ample evidence within the literature that suggests that although the popular notion is that the maker movement originated outside of schools and then was adopted by schools, the reality might very well be that the maker movement is a byproduct of the work of the educational research community and several educational theorists. The literature suggests that the recent popularity of the maker movement in schools is due primarily to Papert and Dewey.

2.6. The Constructionist Foundation of the Maker Movement in Education

Makerspaces are primarily for making, which is described by Sheridan, Halverson, Litts, and Brahms (2014) as "developing an idea and constructing it into some physical or digital form" (p. 507). This simple description of making emphasizes how closely related the maker movement is to Seymour Papert's Constructionism, with its emphasis on learning as a result of taking an idea and making a physical representation out of the idea (Y. Kafai & Resnick, 1996; Y.B. Kafai, 2006) Many researchers have suggested various underlying theories to the maker movement, but overwhelmingly agree Seymour Papert's Constructionism provides the dominant foundation for understanding the learning that occurs in a makerspace (Blikstein, 2013; Dougherty, 2012; Halverson & Sheridan, 2014; Kurti et al., 2014c; S. L. Martinez & Stager, 2013; Sylvia Libow Martinez & Stager, 2014; Quinn & Bell, 2013; Resnick & Rosenbaum, 2013; Rusk et al., 2009; Sheridan et al., 2014).

Many researchers that assert that Constructionism provides the theoretical basis for the maker movement point out the emphasis on building an artifact to share within both the maker movement and Constructionism (Halverson & Sheridan, 2014; Sylvia Libow Martinez & Stager, 2014). Halverson and Sheridan (2014) connect the emphasis within maker communities on building something to share to the central tenet of Papert's constructionism. Martinez and Stager (2014) also explicitly connect the emphasis on building a shareable artifact within the maker community to Papert, saying "Papert's theory of learning provides the theoretical basis for making, which is a stance towards learning that is predicated on the active construction of a shareable artifact" (pp. 13 – 14).

Other than the connection to a shareable artifact, researchers who claim that Seymour Papert's Constructionism provides the theoretical basis for the maker movement in education describe many different ways in which Constructionism paved the way for the maker movement in schools. Halverson and Sheridan (2014) point out that making activities are adaptable both in setting and design, and making activities can be designed to achieve a variety of learning goals. The authors assert that this adaptable approach is in line with the constructivist and constructionist tenet "that focuses on engaging participants in learning content and process" (p. 501). Adding to their connection between Constructionism and the maker movement in regards to the emphasis on shareable artifacts, Martinez and Stager (2014) point out that Papert's metaphor of "computer as material" aligns with the materials and philosophy that support makerspaces (p. 14). Blikstein (2013) also connects Papert's emphasis on using computers in the classroom as a vehicle for learning. Blikstein argues that "Papert advocates technology in schools not as a way to optimize traditional education, but rather as an emancipatory tool that puts the most powerful construction materials in the hands of children – again, another idea that inspired the resurgence of the 'maker' sensibilities" (p. 5). This emancipatory tool that Papert was advocating for, can be seen in the maker movement's emphasis on the democratization of technology.

Another indicator of the Constructionist foundation to the maker movement can be evidenced by the absence of something, actually. When researching for maker curriculum, one finds that there is virtually no published curriculum for makerspaces, and this absence of fixed curriculum is another connection to Constructionism, as Blikstein (2013) says “in a typical Constructionist environment, there is rarely a fixed curriculum. Children use technology to build projects, and teachers act as facilitators of the process” (pp. 5–6). Blikstein further connects Papert’s Constructionism to the maker movement n education by describing the evolution from the Logo programming language through the Lego mindstorm robotics kits to the microcontroller and sensors that makerspaces rely on. Blikstein’s journey through the technologies that allow for creating shareable artifacts is a solid attempt at directly relating Papert’s theory of Constructionism to the maker movement in education.

A review of all available literature regarding the theoretical basis of the maker movement in education suggests that the maker movement in schools is Papert’s Constructionism come to life. It is no wonder that Martinez and Stager (2013) refer to Seymour Papert as "the father of the maker movement" (p. 31). The two authors allude to Papert creating a makerspace of his own as his last research project:

> During Papert’s last institutional research project he created an alternative learning environment to support constructionism inside a prison for teens. It was during this project that constructionism was expanded to include a wide variety of non-computational materials, often in concert with computers to create handcrafted classical guitars, ultra-light airplanes, films, telescopes, photography,

animal habitats, publications, and more. The continuum of low- and high-tech materials allowed for learning through the construction of shareable artifacts not normally associated with school. (p. 22)

One can find research relating the creation of many of the artifacts within a makerspace that Martinez and Stager list as being made in Papert's learning environment at the teen prison, including creating a musical instrument (Blikstein, 2013, pp. 16–17)and publications (Halverson & Sheridan, 2014, p. 499).

Finally, the maker movement in education might claim Papert, and his theory of Constructionism, to be the "father of the maker movement" by reflecting on what Papert himself wrote about Constructionism and relating it to the modern maker movement. Almost as if he knew that his theory of Constructionism would one day be recognized within an educational reform that was not planned, Papert (1980) writes in *Mindstorms: Children, Computers, and Powerful Ideas* "educational innovators must be aware that in order to be successful they must be sensitive to what is happening in the surrounding culture and use dynamic cultural trends as a medium to carry their educational interventions" (p. 181). Papert almost presages the maker movement in education in that statement, a statement he delivers after describing how it is necessary for educators to be anthropologists. Another hint that Papert would be pleased with the maker movement in education emerging "out of the mathetic computer culture" (p. 181) is his admiration for Brazilian samba schools, small social clubs that serve the purpose of educating large numbers of community members in their unique Carnival parade dances. Papert describes these community schools as "real, socially cohesive, and where experts and novices are all learning" (p. 179). Papert describes the attributes that the samba school possesses and which Papert believes all learning environments should have as: "Learning is not separate from reality. The samba school has a purpose, and learning is integrated in the school for this purpose. Novice is not separated from expert, and the experts are also learning" (p. 179). This connection between Papert's own words regarding samba schools and complex learning spaces like makerspaces has been made by other researchers (Zagal & Bruckman, 2005).

2.7. THE MAKER MOVEMENT AND LEARNING BY DOING

Many scholars who write about the maker movement attribute its acceptance in schools based on its relationship to the educational philosophy of John Dewey, and the *learn by doing* summary of his philosophy of experiential education (Paulo Blikstein, 2013; Paulo Blikstein & Worsley, 2014; Dougherty, 2012; Halverson & Sheridan, 2014; Lee Martin, 2015; Sylvia Libow Martinez & Stager, 2014; Regalla, 2016; Rusk et al., 2009; S. Vossoughi, Hooper, & Escude, 2016). This is not too surprising, as Dewey's philosophy of learning has been widely used by educators to provide a seemingly firm theoretical basis to reforms (Tanner, 1997). However, much like Papert's Constructionism, Dewey's theory of experiential education is unique in that is widely regarded as a theoretical basis for the maker movement in education.

Many researchers attribute Dewey's theory of learning directly to an inherent theoretical basis of the maker movement (Blikstein, 2013; Dougherty, 2012; S. L. Martinez & Stager, 2013; S. Vossoughi et al., 2016). Dougherty (2012) ties the learning by doing approach of Dewey to the “importance of tactical engagement and of using our hands in the learning process” (p. 12), a characteristic of the maker movement. Vossoughi et al (2016) elevate the Deweyan emphasis on using ones hands, and its associated importance within the maker movement, saying, “Dewey sought to cultivate communal forms of pedagogical activity that connected the hand and the mind” (p. 211). These authors broaden Dewey’s pedagogical influence greatly, as now one can associate many educational reforms based on tactical engagement to Dewey. Given the number of researchers who attribute educational reforms to Dewey’s “learning by doing” phrase, it comes as no shock for educators to correlate the tactical engagement inherent in Dewey’s philosophy with educational reforms in which students use their hands to make things. Martinez and Stager (2013) do not mention Dewey specifically, but make many references to learning by doing and its inherent place within the maker movement philosophy, “the maker movement overlaps with the natural inclinations of children and the power of learning by doing” (p. 12). The two authors allude to Dewey’s philosophy by directly relating the popular activity of “tinkering” inherent in the maker movement to learning by doing, saying “tinkering is a powerful form of learning by doing” (p. 15).

There are other researchers who claim that Dewey’s philosophy paved the way for other theories that are more closely related to the theories underlying the maker movement in education (Blikstein, 2013; Blikstein & Worsley, 2014; Halverson & Sheridan, 2014; Sylvia Libow Martinez & Stager, 2014). According to Halverson and Sheridan (2014), “Deweyan Constructivism” paved the way for Papert’s Constructionism, which the authors regard as the theory of learning that is the basis of the maker movement (p. 497). Although they do not mention Dewey directly, Martinez and Stager (2014) also assert that the learning by doing approach set the stage for Piagetian Constructivism, and thus Papert's Constructionism.

Dewey's connection to the maker movement can be evidenced as well by the connection of Dewey to the "maker mindset" (Lee Martin, 2015; Quinn & Bell, 2013; Regalla, 2016). Dougherty (2013), Martin (2015), and Regalla (2016) all cite Dewey's theories of learning as grounding influences to the maker mindset. These researchers are not merely suggesting that acceptance of Dewey's theory of learning by doing allows one to practice a maker mindset, but also that Dewey's influence in schools allows for the discussion of the maker mindset within schools. Finally, as one last maker movement connection to Dewey's theory of learning, Blikstein and Worsley (2014) and Peppler et al. (2016) allude to Dewey's Lab school as a precursor to makerspaces in schools.

2.8. Makerspaces as Learning Environments

In comparison to traditional classrooms, makerspaces "may appear to be simply a chaotic melee of students, tools, and strange creations" (Kurti et al., 2014c, p. 8). Callaghan (2013) describes makerspaces thusly: "maker-spaces can be regarded as a type of informal learning environment, as the group support is often focused on instructive advice, resulting in learning, especially by less knowledgeable members" (p. 2). Makerspaces as informal learning environments are unique in that their underlying purpose is not for learning, per se, but more so for designing and building individualized creations. Some researchers contend that learning is not a central goal of makerspaces, although learning clearly occurs within makerspaces (Halverson & Sheridan, 2014, p. 502; Sheridan et al., 2014). Lee Martin (2015) claims that research from learning sciences and engineering education support the claim that learning occurs in a makerspace, provided that the making activities are playful, asset-and growth-oriented, failure-positive, and collaborative (pp. 35-36).

In 2014, Sheridan, Halverson, Brahms, Jacobs-Priebe, and Owens performed a comparative case study to explore makerspaces as learning environments. Exploring three different makerspaces, Sheridan et al determined that through cross-case analysis, although the three makerspaces varied across participants, and length of participation, one could conclude that the makerspaces served as "blended formal learning environments and informal communities of practice, and as being focused on learning as production rather than as master of a composite set of skills" (p. 526). In addition, Sheridan et al. join Brahms and Crowley (2016) in describing makerspaces as learning environments in which participation varies based on the participant, with multiple inroads into the community of practice and many different combinations of disciplinary knowledge and skill available to each participant.

A theme found in the literature regarding learning in a makerspace suggests that, contrary to formal institutions of learning, when students are engaged in an activity in a makerspace, there is more emphasis into continual self-reflection and metacognition (Dougherty, 2012; Quinn & Bell, 2013; Sheridan et al., 2014). This can be explained by considering that by making and building things, students are creating a physical object that represents their learning. As Dougherty (2012) point out "the opportunity to talk about that object, to communicate about it, to tell a story about it is another way we learn at the same time we teach others" (pp. 12-13). In "Invent to Learn: Makers in the Classroom" Martinez and Stager (2013) describe the way students use real-life experiences to provide contexts for understanding science and math concepts that are otherwise considered abstract by the students.

Although there is some research into the process of learning in a makerspace, the researcher joins Sheridan et al (2014) in their conclusion that "despite a flurry of interest and activity around designing and creating makerspaces, we still know little about the content and processes of learning in makerspaces" (p. 506). The lack of empirical research into the maker movement in education is certainly a theme that one finds in the prevailing literature regarding makerspaces and the maker movement in education (Brahms & Crowley, 2016; Lee Martin, 2015; Sheridan et al., 2014; Slatter & Howard, 2013).

2.9. The Maker Movement and STEM Education

The maker movement in education has been discussed as a possible means for teaching content from STEM disciplines either directly using maker activities or by adopting a similar mindset to the maker movement mindset (Blikstein, 2013; Brahms & Crowley, 2016; Halverson & Sheridan, 2014; Honey & Kanter, 2013; L. Martin & Dixon, 2013; Sylvia Libow Martinez & Stager, 2013, 2014; Peppler & Bender, 2013; Sheridan et al., 2014). Martin and Dixon (2013) point out that educators are excited about relating the maker movement in education to STEM, but they warn that by doing so, these educators are trivializing making as a set of component skills and knowledge, and thus limiting the potential of the maker movement (p. 3). Halverson and Sheridan (2014) speak about the potential benefit to STEM learning of the maker movement: "learning through making, most notably with digital technologies, has the potential to help us reach institutional and policy goals for STEM learning for a range of students" (pp. 500-501). Blikstein (2013) also emphasizes the connection of the maker movement to STEM disciplines, by connecting the maker movement to its digital fabrication beginnings, saying "digital fabrication is typically associated with the learning and practice of STEM disciplines" (p. 13). Blikstein goes so far as to suggest that making activities allow for students to explore STEM content "in a highly meaningful, engaging, and contextualized fashion" (p. 18). Martinez and Stager (2013) posit that the maker movement could revitalize STEM curriculum, relating the importance of direct experience and interaction with materials to STEM subject learning (p. 12). Martinez and Stager (2014) suggest that the benefits of maker activities are not limited to students only, and that STEM teachers are also benefitting, "perhaps the best educational outcome of the maker movement is the new ways that project-based learning can come to life, especially in STEM subjects" (p. 15). Finally, Brahms and Crowley (2016) summarize the allure of viewing making as a way to enhance STEM learning: "consequently, as a multidisciplinary endeavor, making may have the potential to render STEM experiences more accessible, interactive, and motivating for the community of makers, as well as for individuals and communities seeking to integrate making into their own community practice, such as teachers and informal educators" (p. 42). Brahms and Crowley, through their research into the learning practices found in MAKE magazine, did not find evidence to suggest expertise in making correlates to expertize in STEM disciplines (p. 42).

Some researchers suggest that adopting a similar mindset to the maker movement mindset will result in benefits to STEM programming (Honey & Kanter, 2013; Martinez & Stager, 2013, 2014; Peppler & Bender, 2013). Peppler and Bendler (2013) claim that the maker mindset will transform STEM education, and also claim "the maker mindset empowers people not just to seek out jobs in STEM or creative fields, but to make their own jobs and industries" (p. 23). Honey and Kanter (2013) describe the connection of STEM learners to the maker mindset, or the maker sensibility as they refer to it, by characterizing the essential characteristics of the maker sensibility – "deep engagement with content, experimentation, exploration, and learning to learn" as the "very ingredients that make for inspired and passionate STEM learners" (pp. 20-21). Although not directly relating STEM to a maker mindset, Martinez and Stager (2014) describe "the key to making" as "using authentic tools to create something meaningful," which they believe is a natural fit" for STEM subjects (p. 14).

2.10. Participation in Makerspaces via Communities of Practice

There is little research into the learning that takes place in a makerspace or while engaged in maker activities, but the research that does exist (Brahms & Crowley, 2016; Halverson & Sheridan, 2014; Sheridan et al., 2014) examines learning through the lens of participation in communities of practice (Lave & Wenger, 1991; Wenger, 1999). Adopting this theoretical stance regarding participation is necessary according to

Halverson and Sheridan (2014) as "learning through making reaches across the divide between formal and informal learning, pushing us to think more expansively about where and how learning happens" (p. 498). Using the lens of communities of practice, Halverson and Sheridan (2014) define makerspaces as "the communities of practice constructed in a physical place and set aside for a group of people to use as a core part of their practice" (p. 502), making as learning activities, and makers as "the identities of participation that people take on within the maker movement" (p. 502). According to these researchers, learning happens in makerspaces thusly:

> In these spaces, learning happens as a consequence of individuals beginning as legitimate peripheral participants and moving toward becoming full participants. But learning is not guaranteed; nor is it regulated. This is crucial from an institutional perspective that takes the education of all kids as a core part of the mission of schooling. A makerspace approach values individuals moving in and out of a space freely. As a result the unit of analysis is not necessarily individual learners over time but, rather, what happens in the space and how to design the space to enable distributed expertise and open configurations of learning. (p. 502)

This description of learning in a makerspace is shared by Sheridan et al (2014), and suggests a reason for why much of the research into makerspaces and the maker movement centers on the design of makerspaces.

Sheridan et al. (2014) echo the definition of learning through making that is expressed by Halverson and Sheridan (2014). Sheridan et al. discuss the reasoning behind using a communities of practice framework in which learning is viewed as an ongoing part of social interaction in their comparative analysis of three makerspaces. The researchers suggest several reasons for using the communities of practice framework. First, viewing learning through a community of practice lens helps frame how variables such as “the shared use of space, tools, and materials; the shifting teaching and learning arrangements; individual and collective goals; and emergent documentation of rules, protocols, and processes for participation” (p. 509) result in unique communities of practice. Second, Sheridan et al. posit that the shared domain of making can be viewed when using the communities of practice framework (p. 509). Third, the authors suggest that the communities of practice frame allows one to highlight “how the environment promotes a sense of identity as a member of the community” (p. 509) so one can attempt to understand the appeal of maker communities, its participants, and why they choose to participate in these communities. Fourth, Sheridan et al. observed that most of the activity in the makerspaces they researched could be considered “peripheral to making” but they found these activities to be central to learning and important for ideation (p. 509).

In “Makers in the Making: defining learning practices in MAKE magazine” Brahms and Crowley (2016) position their research into the making activities described in MAKE magazines using a communities of practice framework. Their research into the making activities in MAKE magazine resulted in a set of seven core learning practices they associated with recognizable participation in a maker community of practice: explore and question; tinker, test, and iterate; seek our resources; hack and repurpose; combine and complexify; customize; and share (p. 33).   Although the authors did not find a correlation between expertise in making activities and expertise in STEM disciplines, they suggest that as STEM disciplinary practices are used in the making communities, “making may promote an understanding, and the purposeful use, of specific facets of disciplinary knowledge and skill that inform and extend making community participation” (p. 42). To summarize, the authors suggest that facets of STEM disciplinary knowledge and skill allow for a greater involvement with and understanding of making community practices, which in turn promotes greater involvement with STEM disciplines.

2.11. Activity Theory Analysis in Educational Research

Central to this dissertation’s analysis is using Activity Theory to identify tensions and contradictions within a system. Activity theory analysis has been used by educational researchers since the publication of Engeström (1999). The analytical method suggested by Engeström became popular amongst educators due to its usefulness for analyzing complex human interactions from qualitative datasets (Lisa C. Yamagata-Lynch & Smaldino, 2007). Although Engeström originally intended for activity systems analysis to center upon identifying tensions within activity systems, many researchers have applied activity theory as a descriptive research tool not focusing on sources of tensions. Beyond using activity theory for analyzing sources of tensions, educational researchers have applied activity theory analysis to understand and summarize organizational change within educational contexts (Baek et al., 2013; Engeström, 2004), to identify guidelines for designing learning environments (Jonassen & Rohrer-Murphy, 1999), and to demonstrate the evolution of organizational learning (Lisa Catalina Yamagata-Lynch, 2001). Across all of these studies, researchers have used activity theory to better understand how individual and group activity affects, and is affected by, the social contexts the activity is embedded within.

There are many educational researchers who have used activity theory as Engeström (1990) intended: for identifying sources of tensions within activity systems.

Barab, Barnett et al. (2002) used activity theory to understand the systemic tensions that characterized a technology-rich astronomy course. Through their analysis, the researches identified two systemic tensions that illuminated the classroom activity. The first tension concerned the use of 3-D modeling software that students used in the class, and the limitations of this software actually highlighted inconsistencies that supported a rich appreciation of certain astronomy content. The second systemic tension identified by the researchers indicated that rather than teacher-directed instruction or student-directed learning serving as the motivator for learning astronomy content, it was the rules, norms, and division of labor that was required for building and sharing 3-D models that did so.

Barab, MaKinster, and Scheckler (2003) used activity theory to characterize the design of an online learning environment created to support in-service and preservice mathematics and science teachers focused on inquiry-based pedagogical practices. The researchers discovered that their design for the online learning environment was based on a tension characterized by the "schism" between the online community the learning environment was designed for, and the community of designers who developed the environment.

Yamagata-Lynch and Haudenschild (2008) used activity theory to identify inner contradictions in a teacher professional development program. The researchers enlisted teachers engaged in a joint professional development effort between a suburban Utah school district and a large university. Using semi-structured interviews of teachers and administrators, Yamagata-Lynch and Haudenschild identified several tensions that affected the quality and effectiveness of the professional development program. The tensions identified by the researchers suggested that the professional development program competed with teachers' value systems, and did not adequately account for the multiple regulations and requirements teachers had to follow. In addition, the researchers determined that the program was not adaptive for teachers who completed the program and were forced to accommodate new approaches to teaching.

Chapter 3: Research Design and Methodology

In this chapter, I discuss the methodology used for my research and analysis. To begin, I provide an overview of the use of activity theory for defining and analyzing tensions. Then, I describe the design of the study, and the methods of collecting and analyzing my data.

3.1 Using Activity Theory to Define Tensions

As a post-Vygotskian theoriest, Engeström (1999) saw the basic internal contradiction of human activity as related to production, claiming, "within the structure of any specific productive activity, the contradiction is renewed as the clash between individual actions and the total activity system" (p. 118). He believed that the fundamental contradiction of human activity arises from the division of labor, meaning that the basic internal contradiction of human life stems from the competing interests of individuals working independent of, but also in a subordinate fashion to, the total societal production.

Engeström believes activity system models can be used to identify tensions and internal contradictions within a given activity system, and that an expansive system is one that addresses and eliminates these contradictions over time (Barab, MaKinster, & Scheckler, 2003). Contradictions and tensions play a crucial part in evolving activity systems, which is why, in order to better understand the complex processes involved in the learning process, Engeström (1999b) identified that "the concept of learning activity can only be constructed through a historical analysis of the inner contradictions of the presently dominant forms of societally organized human learning" (p. 127). To understand how I used the concept of tensions, both for purposes of documentation and analysis, I will break down Engeström's definitions of the inner contradictions of activity systems.

According to Engeström (1999), there are four levels, or layers, of contradictions within any activity system. The primary contradictions within an activity system are defined as the inner contradictions within each component of the central activity. The secondary contradictions exist between the components of the central activity. The tertiary contradictions are found between the object of the dominant form of the central activity and the object of a more culturally advanced form of the central activity. Finally, the quaternary contradictions reveal themselves between the central activity and its neighbor activities. Figure 3.1, taken from Engeström (1999), graphically elaborates the four levels of contradictions within an activity system, with numbers representing the said levels within a central activity. The number "1" at each node implies the primary contradictions, which for a class visiting the school makerspace might arise due to a visiting teacher in many ways becoming a student in the space. The number "2" between the nodes indicates the secondary contradictions between elements, which can be exemplified by the conflict experienced by the students in the visiting class before they've internalized the new rules for behavior in the makerspace. The number "3" denotes the tertiary contradiction, which could be seen in a student's resistance against accepting a project in the school makerspace with all of the new technology and tools that need to be learned, whereas previously all of their projects took place in their classroom, which didn't require learning new tools. Finally, the number "4" in the figure marks the quaternary contradictions, e.g. a student who is part of a class visiting the makerspace realizing that they would need to learn CAD software in order to a 3D-print a custom part for their project. In this instance, the activity of learning CAD software would be an instrument-producing activity.

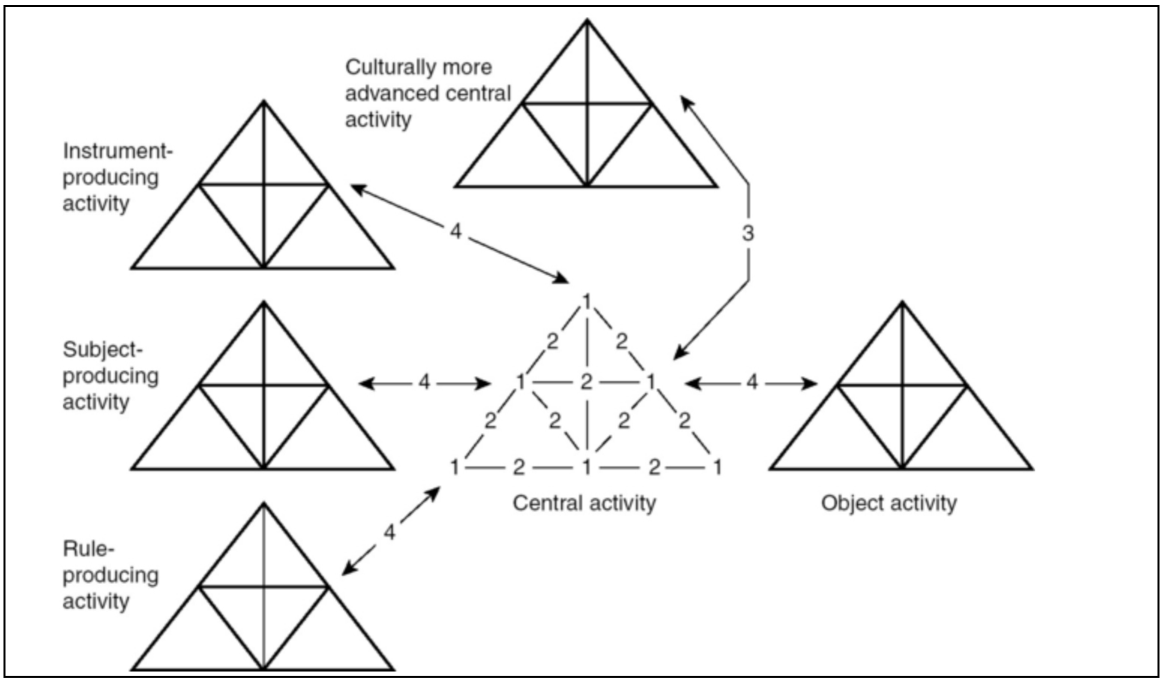


Figure 3.1. Four levels of inner contradictions within activity systems.

Activity theorists believe that by analyzing the various levels of contradictions within an activity system, researchers might better understand the evolving nature of the central activity. Many researchers have utilized this approach for analyzing qualitative datasets (Baek et al., 2013; Siyahhan, Barab, & Downton, 2010; Lisa C. Yamagata-Lynch & Haudenschild, 2009). Yamagata-Lynch & Smaldino (2007) used this approach to identify persistent institutional tensions in a partnership between K-12 schools and a university in order to develop strategies to overcome the tensions. The researchers actually had the participants themselves use an activity systems model in order to guide participants' discussions and aid in their analyses of the institutional tensions they believed were evident in the K-12 school and university partnership. In another study, Yamagata-Lynch and Haudenschild (2009) developed activity system models based on teacher professional development programs, and explored the inner contradictions within each activity system model in order to understand systemic tensions. They identified the following tensions that teachers perceived in professional development: (a) continuing professional development with competing value systems, (b) continuing professional development while juggling multiple regulations and requirements, (c) continuing professional development after undesirable outcomes, and (d) adjusting overall instructional practices in the classroom while accommodating new approaches to teaching (p. 513).

In the available research studies that utilized an activity theory approach to understanding tensions, contradictions and tensions are defined in various ways, though at the heart of each definition lays the concept of conflict. In fact, in Yamagata-Lynch and Haudenschild's (2009) research, they include descriptions of Engeström's (1987) four levels of contradictions, with each level of contradiction related to conflict in varying ways. Table 3.1 reproduces Engeström's levels of contradictions as presented by the researchers.

Contradiction level	Engeström’s definition
Primary Contradiction	When activity participants encounter more than one value systems attached to an element within an activity that brings about conflict
Secondary Contradiction	When activity participants encounter a new element of an activity, and the process for assimilating the new element into the activity brings about conflict
Tertiary Contradiction	When activity participants face conflicting situations by adopting what is believed to be a newly advanced method for achieving the object.
Quaternary Contradiction	When activity participants encounter changes to an activity that result in creating conflicts with adjacent activities

Table 3.1. Engeström's (1987) levels of contradictions as presented by Yamagata-Lynch & Haudenschild (2009)

Although I do not utilize the identification of the four levels of inner contradictions in my analysis (instead opting to focus on the signs of tensions that exist between the nodes of the activity system model), I have included the discussion of the layers of inner contradictions as it demonstrates the theoretical grounding of Engeström’s (1999) concept of tensions within activity systems. It seems appropriate to bring in Engeström once more to summarize the concept of tension that I use for my research. Engeström (1999) uses the term *double bind* frequently to describe the character of tensions within activity systems. A *double bind* refers to a situation in which a person is confronted with two conflicting demands, or messages. With this in mind, I can formalize the concept of a tension to arise from conflicting situations, messages, and demands, and search through my data for evidence of double binds.

3.2. Research Design

Given my interest in understanding aspects of the culture of a school makerspace, I used an ethnographically-informed approach for this research study (Glesne, 2010; Merriam, 2014). Ethnographies emphasize the description, analysis, and ultimately the understanding of a culture or group (Glesne, 2010), and given the societal and cultural characteristics of the makerspace as a research setting, the choice of ethnography seemed appropriate. The primary data source consists of interviews and observation data of both students and teachers participating in a school makerspace.

3.3. Setting

The makerspace is housed on the high school campus of a private K-12 school located in an affluent neighborhood of Austin, Texas. Approximately 400 students attend the high school, which is known for its open campus and professional-quality fine arts facilities, with the entire K-12 population hovering near 900 students across two campuses. The school (referred to using the pseudonym SAS here) recently marked its 65th anniversary, although the high school is relatively new, established sixteen years prior to this research study. The student population of SAS is a homogenous one, with the vast majority of its students identifying as white and Christian. The faculty is more diverse, however the majority of teachers are white.

The 1500 square-foot school makerspace was originally an elevated stage in the high school's cafeteria and thus it looms over rows of tables and chairs. Fifteen-foot tall glass walls enclose the original 650-square foot makerspace, called the "lab side" of the makerspace. In Figure 3.2, a picture of the makerspace taken from the floor of the cafeteria, one can see the glass walls that split the old stage into two spaces.

Figure 3.2. Image of the makerspace from the cafeteria

The makerspace is well equipped with worktables, storage for tool and materials, and sitting areas and tables used for studying and collaboration. Equipment in the school makerspace also includes a rotating assortment of 3-D printers, CNC machines, a laser engraver/cutter, two virtual reality platforms, and four desktop computers for running the machines. The makerspace opened to students in the 2015-2016 school year without a formal name, instead being referred to as the "innovation center" for its first few months of existence. Student assistants eventually renamed it, and throughout the rest of this document I will refer to it by its pseudonym, the LAB, or the school makerspace, or the makerspace, depending on the context.

As the director of the LAB, the setting seemed like a natural fit for an autoethnographically-informed research study. As a full-time educator at SAS, I had to be carefully attuned to unique ethical issues. According to Glesne (2010), conducting a research study at the institution with which the researcher is associated is considered *backyard research*, which "can create ethical and political dilemmas" (p. 42), as well as issues that will need to be addressed in the design of the research study.

Ultimately, the setting was an obvious site for data collection, given my unique position within the system. On the one hand, my proximity to the setting could *taint* data collection, but conversely it provides me with phenomenal insights into the culture of a school makerspace. I decided that the phenomenal benefits of my perspective outweighed the concern about my relationship tainting the data. In fact, in order to account for my unique position within the system, I approached the collection and analysis of data through an autoethnographic lens.

3.4. Statement of Positionality

When engaging in qualitative research, it is crucial for researchers to unpack their positionality, i.e. the ways that their race, background, and culture shape how they engage in, and write about, research (Glesne, 2010). Much of the literature around researcher's positionality is related to the ways their positions of power as a result of their backgrounds and types of privileges influence their research (Glesne, 2010; Merriam, 2014; Roegman, 2018). It is critical that researchers reflect on their background and experiences, identify their privileges, and examine their positionality in comparison to their research participants.

I was born a member of most dominant groups – white, male, heterosexual, upper class. I have found that as a result of this, I approach interactions within academic settings with care. I try not to overwhelm classroom discussions, and interactions with students and fellow educators, and I am always vigilant when I engage in academic argumentation that my dominant perspective does not blind me. I have found that accepting the fact that many different types of privilege (white, male, straight, Christian just to name a few) exists has helped me to be more aware of the many ways I benefit from my dominant member status in multiple groups.

For the past two decades, I have worked as an educator in different contexts (teacher, administrator) and in different settings (college-level, K-12, private schools). As a young student, I was interested in mathematics and felt successful when studying mathematics and other STEM subjects. I am certain that members of other cultural groups, specifically girls and non-whites, did not share my experiences in math classes growing up in an urban Texas environment. I recall instances when my secondary math teachers allowed me to blurt out answers to questions in class, or cut the line for help with a problem, actions that non-white and female students might have been penalized for. At the time, I thought it must have been due to my facility in math that teachers would sometimes allow me to skirt the rules. Upon reflection I believe that my interest and success in STEM subjects, especially math, was encouraged by my status as a dominant member.

I graduated with a master's degree in mathematics before I was ever exposed to critical theory that allowed me to better understand the privileges I benefitted from in and out of schools. While pursuing my masters degree in mathematics education and later when I entered into a doctoral program, I learned more about Critical Race Theory and Critical Gender Theory, and with this newfound understanding, I began to see educational institutions in a different light. As an adherent to the tenets that undergird Critical Race Theory and Critical Gender Theory, I acknowledge that there is systemic racism and sexism in education, the legal system, housing, and government.

As a researcher, I must always be conscious of the many benefits my privileges have provided me, and in fact, continue to provide me. In daily activities, privilege can play its way out in many insidious ways, affording me protection while at the same time degrading those non-dominant group members. While researching, my privilege might blind me to non-dominant actions and attitudes while performing fieldwork, and when analyzing data. Thus, throughout my research study, I have had to continually reflect upon how my positionality in relation to social and political contexts affects my data collection and analysis.

3.5. Data Collection

I collected a variety of data through an assortment of instruments, including (1) field notes and ethnographic observations, (2) artifact collection, (3) interviews, and (4) video-recorded observations. The data for this dissertation was ethnographically informed with the primary source of data collected coming from fieldwork. My interest was in the varying forms of participation that occurred in the makerspace, paying careful attention to the culture of the makerspace, and its norms, values, and shifting participant makeup.

Following ethnographic methods, I took on the role of participant observer (Glesne, 2010) during data collection. At its most basic interpretation, participant observation consists of "establishing a place in some natural setting on a relatively long-term basis in order to investigate, experience and represent the social life and social processes that occur in that setting" (Atkinson, 2001, p. 352). My role as participant observer thus allowed me a greater understanding of the tensions inherent in the high school makerspace.

My dual role as director of the makerspace and researcher allowed me to co-develop the norms and routines of the makerspace, observe any visitors to the makerspace, assist visiting students and teachers as they participated in the makerspace, and collect field notes and other forms of data, such as artifacts, formal interviews, and video observations of participants.

The fieldwork for this study took place formally between early-fall 2016 and late-spring 2017. Prior to officially engaging in fieldwork, I created the makerspace, between May 2015 and August 2016, and served as its director henceforth. During this time, I procured grant money, purchased core equipment and tools, and developed the makerspace's mission, systems, and protocols. On a daily basis, I oversaw students and teachers as they participated in the LAB, which allowed me to collect observations and reflections to ready myself for the formal fieldwork phase. The formal phase of my fieldwork took place over the 2016-2017 school year, after obtaining IRB approval to observe, interview, and video record subjects.

In developing this ethnographically informed study, I aspired to document everything that happened in and around the LAB, as well as everything ever said about it (e.g. in informal conversations with students in the hallway, or in a formal meeting with the principal). I did this with an eye towards identifying tensions across various elements of the LAB and school activity system. The tensions were not immediately obvious; the only became apparent after repeated analysis. I will describe my analysis technique in a later section.

3.5.1. Field notes and ethnographic observations

My primary method of data collection for this ethnographically informed study was the use of field notes. Given my theoretical framework and its emphasis on the participatory nature of learning, I was primarily concerned with participation. Thus my fieldnotes provided me a forum to attempt to understand the answers to the following questions: Who visited the makerspace? How often did they visit? What did they do in the makerspace (i.e., were they there for a purely social visit, or were they working on a project, and if so what type of project)? What roles did visitors to the makerspace take on? In simplest terms, I was concerned with understanding: How was the space used?

As Atkinson (2001) reports, "field notes are a form of representation, that is, a way of observing just-observed events, persons, and places to written accounts" (p. 353). I tried to keep my research notebook with me at all times, but occasionally I had to rely on memory until I could jot down observations and reflections. As the director of the makerspace, I would sometimes repair or maintain equipment, organize tools and supplies, help students with equipment, meet with teachers and students about projects, and perform myriad other tasks which made contemporaneous note-taking burdensome. During times when immediate note taking was not possible, I would jot down rough notes at the earliest opportunity (which was sometimes the end of the day) in order to remember key events. Usually on a weekly basis, I would process some of these rough notes into more cohesive notes.

The majority of my fieldnotes were descriptive accounts, in which I tried to record information about participants and their activities, scenes and interactions, and bits of dialogue that resonated with me as a participant-observer. In addition, I committed to journaling my own personal experiences, reactions, and reflections. Sometimes, I would intentionally reflect in writing over a specific event or interaction in the makerspace in my fieldnotes. My process for taking notes alludes to the selective nature of fieldnotes in general. As Atkinson (2001) points out "the ethnographer writes about certain things that seem 'significant', ignoring and hence 'leaving out' other matters that do not seem significant" (p. 353). Of course, I would never suggest that my fieldnotes provide a complete record of the culture of the makerspace. For nearly two years I engaged in informal and formal fieldwork, I collected over 400 pages of observations and reflections in the form of field notes. My fieldnotes accumulated over time, and much like Atkinson's description of fieldnotes, the resulting corpus of notes had little to no overall coherence or consistency (2001). Like Atkinson, I viewed the collection of notes as "a loose collection of possibly usable materials" (p. 353), the majority of which will have not been incorporated into this dissertation.

3.5.2. Artifact collection

Another form of data collection in which I engaged for this ethnographically informed study was the collection of artifacts. By doing so, I was extending the practice of anthropologists and archaeologists, for whom collecting objects or artifacts bestowed with meaning and history by their subjects would allow them to hypothesize about cultural norms and practices (Glesne, 2010). Like Glesne, I believe that the artifacts I collected during the gathering period would represent the culture of the people and the setting of the study, in this case the school makerspace. (p. 88). Examples of artifacts I collected during the study include: written communication between myself as director of the makerspace and students and teachers who frequented the makerspace, archived messages from the SLACK messaging platform that was used for internal communication, and student work in the form of photos, drawings, and writings. Additionally, there were other documents that I used for creating and running the makerspace, such as minutes from meetings, budget sheets, visitor statistics, written communication about policies, etc. To ensure confidentiality, I first photocopied or saved as screenshots any materials I used for analysis, and then redacted any identifying information in the artifacts, before finally saving the resulting document in a digital format.

3.5.3. Interviews

In addition to fieldnotes and artifact collection, I collected interview data from eleven participants split into four groups, in order to better understand the culture of the makerspace and to encourage triangulation of my findings. I grouped each of the interview subjects in order to compare and contrast participation in different contexts (Merriam, 2009; Stake, 2013). I utilized this approach in order to determine a shared central meaning regarding participation in the school makerspace. I grouped the interview subjects thusly: (1) one student working on a project in the makerspace for a class, (2) one student working in the makerspace on a project not related to a class, (3) one group of students working on a class project, and (4) one group of students - not aligned with a class - collaborating on a shared project.

I opted to perform in-person, open-ended interviews because the primary motivation of this research study was to better understand learning in a makerspace, and according to Simons (2009) one of the benefits of an open-ended interview is the "active engagement and learning it can promote for interviewer and interviewee in identifying and analyzing issues" (Simons, 2009, p. 43). In order to ensure accuracy and reliability (Merriam, 2002), I first recorded the interviews, then transcribed them, and finally reviewed the interview data with the participants. Each of the two interviews consisted of five questions with three sub-questions to guide the open-ended discussions.

Interviews with participants typically occurred during the participants' "free" periods, before school, or after school.

Questions in both interviews were designed to prompt interview subjects to gradually bring focus to their role as a member of the makerspace community of practice, especially regarding specific activities and forms of participation in the makerspace. During the interviews, I asked the interview subjects to reflect on their personal approaches to learning both in and out of school, in STEM classes and in the makerspace up to that point, and regarding the projects on which were working in the makerspace. Questions in the interviews were guided by the principle that "learning is an issue of engaging in and contributing to the practices of their communities" (Wenger, 1999, p. 13), and thus I guided the participants to describe the relationships and communities in which they engaged when learning in their classes, outside of school, and in other informal environments, such as the makerspace. Allowing participants to describe how they believe they learn was important, as Wenger (1999) explains that learning is so embedded in our everyday lives that "we do not have very systematic ways of talking about this familiar experience" (p. 14). Therefore, allowing the participant to describe their learning processes in their own words allowed for unique declarations of activities and participation. The interview data allowed me to triangulate my findings, along with my fieldnotes and collected artifacts.

3.5.4. Video-recorded observations

Between interviews, I observed the participants in the makerspace as they worked on their projects. These direct-observations allowed me to witness the unique forms of participation in the makerspace. I took fieldnotes of the participants as they worked in the makerspace, and in addition, each participant observation was video-recorded. I used an observation protocol that consisted of a document with two columns: one column for recording descriptive notes of the session, and one column for recording reflective notes of the session. I video-recorded each participant session partly to view each session again for reflection, but also to account for any distractions that might have occurred during the observation due to my participant observer role.

I had hoped that the video-recorded observations of the study participants would provide insights into unique forms of participation in the makerspace. However, the two video-recorded observations were simply not enough to provide me with further understanding of the nature of long-term participation in the makerspace. Unfortunately the data collected from the two video-recorded observations paled in comparison to the rich descriptions of participation that I obtained from my fieldnotes, interview data, and artifacts collected throughout the entire length of my research study.

3.6. Data Analysis

In setting up this research study, I was interested in understanding the varying forms of participation and learning within the sociocultural makeup of the school makerspace. I came to focus on the tensions, given how they affect participation. The work of Philip and Garcia (2015) informed my pursuit to understand tensions. The researchers analyzed the effect of an educational reform in which mobile phones were given to students attending seven urban high schools across Southern California. The results of their research demonstrated that the meaning of the mobile phones shifted as the schools institutionalized them. The researchers showed through their analysis how "assumptions about the proximal benefits of new technologies, particularly the belief that these devices effortlessly generate interest in students, are misguided and essentialize youth interest" (p. 700). Given that a "tension" within an activity system can occur when there is a misalignment of goals and intentions (Lisa C. Yamagata-Lynch & Haudenschild, 2009), it can be seen that Philip and Garcia's analysis centers upon a massive tension between students and schools concerning the institutionalization of mobile phones. Philip and Garcia's analysis was based on focus group interview data alone, however, and given my ethnographic exploration of the makerspace and the myriad data I collected, I attempted a broader analysis strategy to understand tensions.

My method of analyzing tensions was informed by the analytical strategy used by Yamagata-Lynch and Haudenschild (2009), and Yamagata-Lynch and Smaldino (2007) . According to Baek et al. (2013), the analytical model has three phases, carried out in a semi-sequential manner: (1) characterize components of activity, (2) structure levels of activity, and (3) locate points of contradiction. In the following paragraphs, I explain in detail the phases of the analytical model and how it applied to my data corpus.

For the first phase of the analytical model, the researcher must attend to the primary components of Engeström's (1987) activity system triangle – Subject(s), Tools, Object(s), Outcome(s), Rules, Community, and Division of Labor (Baek et al., 2013).

Before categorizing the data into the components of the activity triangle, it is recommended that the researcher determine the unit of analysis, or grain size, and I determined that my unit of analysis was the individual tension/contradiction that affected participation in the LAB. In addition to determining the grain size, and before I could begin the first phase of my analytical strategy, I transcribed all interview data, and organized all of my fieldnotes and artifacts along a timeline.

After selecting my unit of analysis, I began mining my data to determine what content I would consider as different components of activity systems triangles, a process which Baek et al. describes thusly: "components may be used as "buckets" for arranging data collected" (p. 207). I used NVIVO qualitative software to code my collected data into different buckets that represented components of the vast activity system models that constituted countless forms of activity and participation in the makerspace. I also constructed a timeline using this arranged data.

The second phase of the model is attention to the hierarchical structure of activity. During this phase, "the analysis is interested in discovering and constructing the motives of the overall activity system, the needs associated with the actions of individual participants and users, and the conditions that enable or inhibit accompanying operations" (Baek et al., 2013, p. 208). Baek et al. (2013) suggest, "attention to the hierarchical structure of activity provides 'depth' to the initial 'breadth' gained from the activity triangle orientation" (p. 208). For this phase, I used my own reflections, memories, and associations to provide depth and context to the initial coding of data. I employed this technique of autoethnographers because, according to Ellis, Adams and Bochner (2010):

“autoethnographers must not only use their methodological tools and research literature to analyze experience, but also must consider ways others may experience similar epiphanies; they must use personal experience to illustrate facets of cultural experience, and, in so doing, make characteristics of a culture familiar for insiders and outsiders” (p. 3). In this way, I used my personal experience to attend to the hierarchical structure of activity in the makerspace.

The final phase of the analytical model is to “identify contradictions within and between nodes in the central activity system as well as across entire activity systems” (Baek et al., 2013, p. 208). This phase is important as it allows the researcher to identify discordance within the activity system, which further allows the researcher to validate the tensions within the activity system (Lisa C. Yamagata-Lynch, 2010a). Engeström (1999) describes the analytical reason for identifying contradictions thusly: “the analysis functions as the midwife for bringing about the double bind, or at least an anticipatory grasp of the double bind in the form of intense conceptual conflict” (p. 289). As a participant of the makerspace under study, it is my job to reflect upon these double binds, with the goal of developing the makerspace activity system into an expansive activity system.

Through my analysis, I was able to uncover several examples of systemic tensions that I could corroborate with empirical data. The last step for my analysis, then, was to reflect upon these tensions as a participant within the system. I accomplished this by writing narratives that allow me to discuss these tensions, which are included as the next chapters in this dissertation. These recountings allow me to describe the connections among my fieldnotes observations, collected artifacts, and interview transcript data, make inferences and interpretations, and most importantly, show in detail the various tensions within the school makerspace.

3.6.1. A note about promises

> An activity system is by definition a multivoiced formation. An expansive cycle is a reorchestration of those voices, of the different viewpoints and approaches of the various participants. Historicity in this perspective means identifying the past cycles of the activity system. The reorchestration of the multiple voices is dramatically facilitated when the different voices are seen against their historical background as layers in a pool of complementary competencies within the activity system.
>
> (Engeström, 1999a, p. 35)

Activity theory analysis, as suggested by Engeström (1999) does not stop at identifying inner contradictions in order to understand systemic tensions. Engeström (1999) writes, "the ultimate aim of the analysis is not just to reveal the inner contradictions and developmental logic of the activity to the researcher. The aim is to make the participants, the potential subjects of the activity themselves, face the secondary contradiction (p. 290). He contends that the aim of activity theory analysis is to have participants identify the inner contradictions of an activity system so that they can develop new models that address these tensions in future activity. The participants would then face the secondary contradiction, which is the contradiction that occurs when participants are forced to assimilate a new method for doing something in their activity system. Engeström even suggests that participants may reconstruct the analysis in order to develop new models for resolving tensions. Given that my data collection ended over two years ago, engaging participants in the reconstruction of analysis would be a fruitless task, as all of the participants have already graduated.

Engeström's concern with developing what he called "expansive solutions" to contradictions inherent in the activity system is related to his contention that the activity system under analysis is continually evolving. The dialectical lens allows one to search for different voices, or viewpoints in order to establish truth. With respect to identifying tensions and contradictions within activity systems, the dialectic method suggests that in addition to the tensions, there exists promises, or potentials. Since the dialectical method is at its base a discourse around a central subject, these promises are related to the tensions. In order to understand the activity systems as multivoiced formations, I will present promises and potentials of the activity system that relate to the internal contradictions that I identify throughout my analysis. For example, if a tension were to relate to a group of students co-opting some space in the makerspace, a promise is surely that the group of students saw such potential in the space that they hoped to co-opt some of the area, or that they were comfortable enough in the space to participate without the pretense of formality.

The promises and potentials I will present are attempts at representing an expansive activity system, using the dialectic method, by acknowledging that the inner contradictions and tensions do not represent the entire story.

3.7. SUMMARY

In conducting my research, I used an ethnographically informed methodology in which I analyzed data collected over a period of almost two years. The study took place in a makerspace called the LAB, on the campus of an affluent private Episcopal high school in central Texas. I served as a participant-observer for this research study given that I created the makerspace and served as the director of the makerspace. The collected data included fieldnotes, artifacts, and interview transcriptions. My analysis strategy was to identify tensions within the makerspace, using the analytical strategy described by Baek et al. (2013) and Engeström (1999). My objective was to understand the tensions that are inherent when a high school establishes a makerspace on its campus.

Chapter 4: Conflicting Visions for the School Makerspace

In this narrative, I will discuss the tensions that resulted from different stakeholders having competing visions for the school makerspace. To understand these tensions, I will explore the different visions that users held for the makerspace during its establishment along with my vision for the LAB. I will then inventory the nature of class projects undertaken in the makerspace, exploring one class project in particular. Finally, I will analyze the evidence presented to better understand the various tensions that manifested in the LAB from these conflicting visions.

4.1. The Establishment of the "Innovation Center"

After being hired as the Curriculum/Technology Innovator for the high school in March 2015, I met in early April with its principal, Stephen. We walked the campus, checking out the few unused office spaces and empty rooms that I could possibly use as my office. Before beginning our walk on campus, I mentioned that my dream scenario would be to build a small makerspace either adjacent to or within my office, depending on the sizes of the spaces available. Stephen was unfamiliar with the term 'makerspace,' so I explained what type of equipment was found in makerspaces, and that I would need very little money to build a small makerspace if my office location would allow it. After I declared my intention for a makerspace, he led me to the cafeteria, where an old stage was half-enclosed by 15-foot tall glass walls. The school had built the walls the previous year to enclose a school shop where, for two hours each afternoon, volunteers from the

Parent's Association sold clothing and gear emblazoned with the school logo, as well as snacks and drinks. When I first saw the space, I was reminded of MIT's Media Lab, a laboratory that I had visited a few months prior, and whose glass walls allowed visitors to view inside the lab. I showed Stephen some photos of the Media Lab on my phone while he informed me that the Parent's Association was unhappy with the space because their inventory was not large enough to fill its 1500-square feet, and because they wanted to be in a more central part of campus. Stephen told me that if I could find money for a makerspace, he would have the Parent's Association move their shop to a small, unused classroom in the center of campus. [FN; 4/16/2015]

After that initial meeting in April, I met again with Stephen and we talked about makerspaces. I talked with him about how a small makerspace could cost less than $10,000 to build. During this meeting, Stephen was hopeful that the makerspace would elevate the school's STEM status, sharing with me his viewpoint that the school was associated more with the humanities than STEM. [FN; 4/30/2015]

The makerspace became a reality once I was connected with a set of parent-donors: an inventor / entrepreneur (Jake) and his wife, who wanted to donate to the school for the establishment of something "innovative." During our first meeting in late May 2015, I described how I was hoping to build a makerspace. Jake was familiar with the phrase, and thought that it was "innovative" and could be used by "budding inventors and entrepreneurs" [FN; 5/27/2015] After this first meeting, the parents wrote a check for $50,000 to the school, writing in the memo line "Innovation Center." On June 2nd, I was informed via email that the school's business manager had received the donation check seven days after the meeting with the donors.

On June 15, 2015, I met with Stephen over lunch. At this meeting, we discussed my plans for purchasing equipment, the timeline for me accessing the stage to begin building the makerspace, and how he was going to talk with the Parent's Association about moving the school shop. At this time, Stephen was excited about the technology of the makerspace being used to improve our school's STEM programming. Because of his association with the makerspace and STEM, he worried about girls not accessing the makerspace as much as he thought boys would, and he wanted me to be deliberate about reaching out to girls. [FN; 6/15/2015]

In early September 2015, only a few weeks after the makerspace opened, a second set of parents Sam and Kathy (again, the husband was a very successful inventor and entrepreneur) - approached me because their son was an early and frequent visitor to the space who had spoken with me about getting a mixed-materials 3-d printer. I had told him that those types of 3-D printers were too expensive, and he apparently spoke with his parents about this conversation. Sam and Kathy invited me to a Virtual Reality demonstration hosted by a startup company in which Sam was investing. At the demo, Kathy told me that she wanted to help me get more innovative technology in the makerspace, and she asked me to make a "wish list" for the makerspace. [FN; 9/9/2015] I created the list and emailed it to Kathy in the span of a few days, excited to take advantage of her generosity. Kathy communicated to me via email only once about the list I made, asking me if I would rather buy cheaper 3-D printers instead of one expensive printer, and I explained in a reply that I would rather get quality over quantity. Within days of emailing Kathy my wish list, she dropped off a donation check at the school for a very large sum of money (more than the original donors) in order for me to buy more innovative technology, including the mixed materials 3-d printer that was requested by their son, VR equipment, a commercial drone, and the most expensive item in the makerspace: a laser engraver/cutter with a fume filter that would allow us to use the laser cutter indoors.

Sam and Kathy were hands-off after making their donation. I invited them many times to meet after their donation, and they declined each invitation. They did not push an agenda or suggest that the makerspace was to be used for a specific purpose. Conversely, the original donors were direct with me in their desire for the makerspace to support inventors and entrepreneurs.

The original donor (Jake) met with me several times over the course of the first two years, and each time he would push me to use the makerspace to improve our school's focus on entrepreneurism, suggesting that students should use the makerspace to develop patents and pursue business ideas and inventions. On a couple of occasions, Jake even requested to use some of the makerspace equipment to build a prototype of one of his own inventions. [FN; 4/4/2017]

After the first donation was given to the school, I met with Jake for dinner, where O jotted down notes about his desire for the makerspace to have comfortable chairs, which he said was crucial for invention and innovation, and for me to attend an entrepreneurial educators workshop put on by a business school. [FN;6/11/2015] During this second meeting with Jake, he asked me to attend an entrepreneurship education workshop at a well-known business school in the Northeast United States because he wanted entrepreneurism to be a focus of the makerspace. He suggested that the makerspace could nurture the students who had business ideas by helping them to create prototypes, and even get their inventions patented. I attended the 5-day workshop, using the makerspace budget, between January 10, 2016 and January 15, 2016, a little over five months after the makerspace's opening. I returned from the workshop and met with the donor over dinner during that same month to discuss the workshop, and he asked me to talk with the high school principal about approving a yearlong class intended for entrepreneurship. However, there was already a trimester-length entrepreneurship course that the principal suggested was sufficient given the school's history with low student interest in yearlong electives.

The people that were most instrumental to the establishment of the makerspace held competing visions for it. The high school principal, Stephen, envisioned the makerspace as a STEM learning space. The original donors envisioned the makerspace as a place devoted to business and entrepreneurism. My vision was for an open makerspace not solely connected to STEM or entrepreneurism, because I believed that an open makerspace would allow everyone to use it for their own purposes, be it STEM, or invention, or a myriad other purposes.

4.2. The Mission and Maintenance of the Makerspace

Because the makerspace funding and approval happened in early June of 2015, when teachers were on summer vacation and the high school administrators were focused on other matters, I was left to make major decisions about the makerspace inventory, mission, and operating principles by myself. Given full control of the makerspace mission and its maintenance, I wanted to define the space as a makerspace discussed in the maker movement literature, which is how I devised the mission: for students to make anything they wanted, whether related to school or not.

On the fifth day of school – September 4, 2015 – I addressed the entire school community during chapel, and I chose to talk about how I believed learning occurred and how students might use the makerspace. I referenced the makerspace as "the innovation center" because I had not decided on a name yet, telling the students that I had pushed to develop the space "So that you, students, and teachers, would have a space to work on something that is not just an objective from an essential list. You *can* do that- I don't want you to think that is not something the space would be good for. I want you to think about how you could work on a project that would integrate concepts and goals from subjects, but you are not going to place the learning of these concepts as the goal." I also mentioned that the idea behind the makerspace was "for you to make anything you want, whether or not it is related to school." In my address to the school, I was attempting to convey the openness of the school makerspace as compared to a classroom, in which learning was primarily directed by teachers, and in which activities and participation served the goal of learning.

Due to my establishing an open mission and staffing the makerspace with students, I believe that many students viewed the makerspace as an unconstrained area, with regard to what they could do in it. During my interviews with students, I wanted to understand their perceptions of the makerspace, including its purpose. Dallas, one of the students who worked on a group Physics project in the LAB, shared my vision for an open makerspace. Discussing his perception of the makerspace's purpose, Dallas said "You're supposed to be creative, you're supposed to go in there and have these tools-- if you have a thought, or an idea, you can make it, because... no one told you to make that, it's--you're going in there and you're finding your own purpose for it, and you have the tools to make anything happen, essentially. So I think it's like a purpose-- it's like, purpose is to make your purpose. (Laugh)" [Interview Data with Dallas; 12/7/2016]

There were many who believed that the makerspace held a promise of innovation, especially related to technology. The second set of donors, Sam and Kathy, viewed the makerspace as a place where students at the school, their son included, could explore innovative technology. Many students shared this vision of the makerspace as a space for innovation. Consider this excerpt from an interview with a senior who was working on a group project in the makerspace when I asked him about his initial reaction to visiting the makerspace:

> Billy: Oh I mean, I thought it was really cool. There were like, all these things that -- all of these tools there that I didn't have at home and I, personally I saw it like, hey I can use these things and I don't have to buy one. That's like exactly my first thoughts of it and, and then there was all this new stuff that I could learn about too and there is like, I definitely haven't learned about everything in there for sure but, I learned some about 3D Printing which was cool and a little bit about the laser printing machine and the milling machine and that kind of stuff." [Interview data with Billy; 12/13/2016]

There were many who viewed the makerspace as a place to augment the STEM programming at the school. Stephen consistently envisioned the makerspace as a STEM learning space, and many students shared his vision, even though I never designated the makerspace as a place for STEM learning. When asked about his initial perceptions of the makerspace, Colby, a senior who worked in the LAB on a Physics group project, said:

> So first I – it was a little scary, but I knew I wanted to get involved with it, 'cause I've always been sort of a STEM guy, but it was definitely a little intimidating and I wasn't sure how any of the tools worked, like the 3D Printer, Laser cutter, any of that, and I was just kind of afraid to just try things, but I definitely saw it as a place where a lot of students could come in and work on stuff for other classes, or just stuff on their own outside of class, 'cause they're interested in it, and I can see teachers coming in or whole classes coming in even.
> [Interview data with Colby; 2/2/2017]

I shared Colby's vision of entire classes utilizing the LAB for multiple projects, although in reality this occurred less frequently than I envisioned. The following table (Table 4.1) lists class projects that took place in the makerspace over the course of two years. The table displays the name of the project and the class to which it was connected, the dates of the project's activity, and the number of students who were involved in the project. Over the course of two years, only five faculty members, representing 4 distinct classes, had their classes work on a project in the makerspace, and out of just over 400 students at the high school, only 55 students worked on class projects in the first year, and only 53 students worked on class projects in the second year.

Project (Class)	Dates of Activity	Number of Students
3-d printing Artifacts (Latin 2)	11/10/15-11/12/15	11
"DNA" Milling Project (Biology)	12/7/15-12/17/15	32
Sound Explorations (AP Physics)	4/4/16-4/12/16	12
"Applied Choice Project" (Advanced Calculus)	9/17/16-4/21/17 (every other Friday)	9
Rube Goldberg (AP Physics)	12/5/16-1/10/17	30
Sound Explorations (AP Physics)	4/11/17-4/20/17	10
Roman Board Games (Latin 3)	5/2/17-5/10/17	4

Table 4.1. Class projects that took place in the LAB during the 2015-2016 and 2016-2017 school years.

The scarcity of class projects taking place in the makerspace was noticeable not just to me. I asked Johnny, a junior who worked on building a video arcade machine in the LAB between January 2016 and May 2017 about his perceptions of the makerspace and he said:

> I guess I honestly expected and I know "Mr. W" implements it, but – some other teachers to utilize it more, because now, at least in my math and chemistry class, the [LAB] is never mentioned or we never do any projects involving the [LAB], that's kind of a shame. And it is – and the one thing that frustrates me is that I don't know if this is like something you would write down, because I don't know if that's part of the question, but as I've gotten – as I've progressed into like Junior year and stuff I still want to go to the [LAB] just as much as I did sophomore year, but then I always find, like, on no, I have this or that. And because I think it has to do with the fact that teachers don't utilize it and make it a part of their class – I feel like that's something

> extracurricular. That my other classes take priority in and I don't want it to be that case, that's just what happens because of the school you know.
> [Interview data with Johnny; 2/6/2017]

There are many possible reasons why teachers did not utilize the space more. For starters, I was not able to involve any teachers in the establishment of the makerspace, given that the makerspace was approved in the summer when teachers were not on campus, then opened on the first day of school in the fall. Further, I was new to the high school, and still perceived as an outsider, thus the makerspace reflected my vision alone. To better understand the tensions that resulted from me establishing a vision for the makerspace without strategically involving members of the faculty, I examine one of the class projects that took place within the makerspace's first year.

4.3. THE DNA PROJECT

During the 2015-2016 school year, Roger, one of the 9th grade Biology teachers, wanted to have his class do a project in the makerspace. On November 23, 2015 Roger and I met to brainstorm project ideas. He told me that he had a good friend who worked for the company that manufactured the milling machine, and that he was inspired by this friend to have his class learn to use the milling machine, and he wanted them to use it for a project related to DNA. I felt constrained by his insistence on using the milling machine because the milling machine was quite slow and also relatively small, and I could not picture how we would get 2 whole classes of almost 20 students each to meaningfully engage with it. During our initial brainstorming session, I tried to get him to think about using other equipment, but ended our first brainstorming session with both of us agreeing to think more about project ideas related to DNA and the milling machine. [FN; 11/23/2015]

We met again on November 27, 2015, and during this meeting he told me about his idea to have his students use the milling machine to create 3-D models of a DNA double helix. At this meeting, I explained that such a project would require his students to learn a lot about 3-D rendering on a computer, and that it would take longer than the one-week he allocated for his students to learn this skill. I wanted to make the project idea work, so we spent the rest of the meeting looking online for easy 3-D rendering software, but found none that would work for us. Again, we left our brainstorming session without a project, and at that time, I thought that we would likely not go through with a project during the time period he wanted because it was 2 weeks until the anticipated start date of December 14th and we didn't have a solid idea yet. [FN; 11/27/2015]

Through an email exchange on November 30, 2015, Roger decided that his students would design a 2-dimensional model of the DNA double helix that would be milled into PCB boards and connected with LED lights to represent the connections between base pairs. The project coalesced because my search for CAD software to design 3-d models led me to different, free software to design circuit boards, and Roger thought the idea of having base pairs light up to model their connections would be an effective application of the knowledge about DNA that he wanted students to learn. As an added bonus, since the project would take place during the last week of school before the holiday break, Roger thought that the students could take their projects home and use them as ornaments.

In a whirlwind of activity, I ordered PCB boards, battery holders, LED lights, resistors, and solder – enough for each student to make their own circuit board. According to my invoices from these purchases, I received the last of the necessary supplies on December 10, 2015, four days before the project was to begin in the LAB. With the remaining time before the Biology classes started working in the LAB, I developed an example for the students to be able to see the software rendering and the milled-out PCB board. During the time I worked on the example, my hesitation to use the milling machine was confirmed, as it took almost 30 minutes to mill out my simple DNA circuit board. After I shared this with Roger via e-mail on December 11th, he reached out to his friend at the milling machine company to inquire if there was a way to speed up the milling, and he was told that there was a limit to how fast it could mill items without breaking the cutting bit.

During the four days that the two Biology classes worked on their project in the LAB, students worked on designing their DNA model on their laptops, and also learned the basics of soldering by using a kit that allowed them to solder a battery holder and two LED lights on a pre-milled PCB button. Out of the 32 students in 2 classes who worked on the project, only 1 student successfully designed and milled out a working circuit board model of a DNA double helix, and only finished due to working on it outside of class. Figure 4.1 is an image of the almost-completed student project alongside the software design.

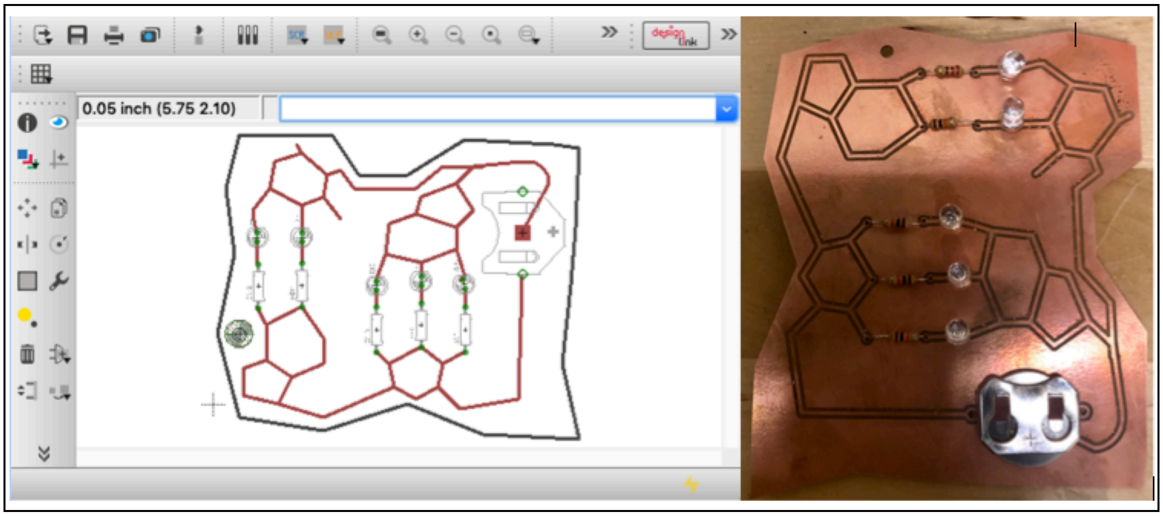


Figure 4.1. An example of student work from the "DNA Project" comparing the software rendering to the completed project

During the first two days in the LAB, Roger told his classes that he expected them all to complete the project. However, by the last day of the project, we had determined that it wouldn't be possible for everyone to complete their DNA model, he told his students that it was okay to not finish the project. [FN; 12/17/2015]

At our first brainstorming session, Roger confided in me that he wanted to do a project in the makerspace during the last week before the holiday break because he didn't want to begin a new unit of study right before students left for a 2-week break [FN; 11/23/2015]. I was happy to accommodate his classes because only one class had used the makerspace for a project up to that point; however, as I worked with Roger on developing the project, I was concerned that the time he devoted to the project would not be enough, and that there would not be many students who would finish. After the Biology project, I wrote a reflection in my field notes that the project was frustrating for me from the very beginning when I was brainstorming with Roger because I found that we had overemphasized one particular piece of technology, the milling machine. We had also deemphasized what students would need to learn, meaning our project did not account for the learning curve related to soldering, and circuit board design. [FN; 12/18/2015]

4.4. Analysis of Tensions and Promises

Having explored some of the evidence that suggests tensions within the LAB activity system, I now turn to taking a final analytical pass of this evidence in order to better understand these tensions. Most appropriate for this chapter, Engeström (1999) defined an activity system as "a multivoiced formation" (p. 35) and implored researchers to focus on the different voices in order to understand, and then overcome internal contradictions. As I mentioned in Chapter 3, tensions in activity systems are marked by conflict, either conflicting situations, messages or demands. I will analyze the conflicting visions first, and then discuss the resulting conflicting messages and demands.

The first donor, Jake, was overt in his desire to have the LAB be a space devoted to invention and entrepreneurism. He stipulated that I attend an entrepreneurial educators workshop with part of this donation, and he requested dedicated sitting space in the makerspace devoted to invention. Although I did not consider him overbearing, his vision for the space drove changes to the environment and the culture in measurable ways, including the initial naming of the makerspace as “the innovation center.” I admit that the name wasn’t important to me in the beginning, as I wanted students to come up with the name, but this initial branding of the makerspace as the innovation center caused the school community to associate the LAB with innovation before engaging with it themselves. I encouraged this association by embracing the name of the innovation center in my first address to the school community.

The association with innovation led the second set of parent-donors to want to support the makerspace in an effort to make it more inventive, which shows that the association itself is not negative. In fact, the association with innovative technology promised by makerspaces, and in particular this makerspace, helped me to attract more students to participate in making activities.

Jake's vision for the LAB to be a place where students could hone their skills as entrepreneurs was also not entirely negative. In fact, makerspaces seem ideal places for invention and creating prototypes for entrepreneurial endeavors. However, my vision for the LAB was for it not to be solely devoted to invention and entrepreneurism, because I thought that would limit the participation of students. This conflict between Jake's vision and my own speaks to the inherent contradiction that Engeström (1999b) believed is at the heart of activities in capitalist socioeconomic formations: "the inner conflict between exchange value and use value within each corner of the triangle of activity" (p. 123). Jake saw the LAB as a means for students to become entrepreneurs, and to patent inventions and learn how to start a business [FN; 6/11/2015], but the LAB served a variety of purposes beyond making money, thus we have a conflict between its usefulness and its value.

In looking back at the establishment of the LAB, I also must analyze Stephen's vision for the makerspace to be a STEM learning space. Again, this represents a promise of school makerspaces, discussed widely in maker education literature (see Chapter 2 for my review of the literature relating makerspaces to STEM), so the principal's vision is understandable. However, just as in Jake's case, the inherent contradictions reside in the conflict between the siloed value of Stephen's vision and the true utility of the space beyond serving the STEM disciplines.

It can be seen how my vision for the LAB conflicted with Jake and Stephen's, as I envisioned a makerspace that was open to all pursuits, and whose value and usefulness would be determined by participants. Given that I developed the vision for the LAB without input from teachers, it is likely that there are numerous competing visions. These competing visions for the LAB certainly resulted in conflicting messages sent throughout the student community.

These conflicting messages can be evidenced by the different visions that the students held, examples of which I cited in this chapter, including envisioning the LAB as a space for STEM, for innovation, or for serving individual pursuits no matter their connection or nature. Teachers also received conflicting messages about the purpose of the LAB. These conflicting messages can be best understood when you consider the definition of a double bind in which the conflicting messages, demands, or choices lead to undesirable outcomes.

When analyzing the DNA project, the tension that resulted from the competing visions can be marked by conflicting demands for the LAB, several of which confronted me when working with the biology teacher. Initially, he demanded a specific tool (the milling machine) be used, and this led to undesirable outcomes for the speed of workflow for the project. He further demanded that students learn how to use a specialized form of CAD software, as well as learn how to solder, and that students should finish their models during a shortened timeline. Each of these demands led to undesirable outcomes, and taken altogether, further define tensions manifested by the conflicting visions that were held for the LAB.

The DNA project helped me to better understand why so few teachers used the LAB for long-term projects. It is my assertion that the many conflicting demands placed on the LAB were due to the many different visions that were held for the LAB. In other words, each of the conflicting demands placed on the students and on the LAB itself can be seen as a consequence of the lack of a unified vision for the LAB. Were Roger and I able to find that common ground, I think that there would have been less conflict during the project.

In terms of the model activity system (Engeström, 1999b), the tension manifested in the competing visions for the LAB is a tension over the *object* of the activity—that is, the very reason for the existence of the makerspace and its specific educational purposes and affordances. Given the centrality of the object for defining the overall functioning of the space, it is no wonder that the space has yet to live up to its full potential. There are only a few classes that use the makerspace for projects to this day, usually spending only one class period in the LAB. This is a loss to the school community because the makerspace does not enrich students' academic pursuits and limits the reach of the makerspace and its population of users. The students hold different visions for the LAB, and the teachers who brought their classes to the LAB developed their own visions for the space, as evidenced by the DNA project explored in this section.

Even though it would seem that the tension still remains, promises abound as well. Donation money was secured for the makerspace through the promise that it would serve as a place for innovation. The vision of the makerspace serving as a STEM learning space provides great promise for reimagining STEM in high schools as integrated and related to individual pursuits. The notion that teachers and students held competing visions could ultimately be a good thing because it shows that my fear – that the LAB would become a siloed space not open to individual pursuits – has not come to pass. A further promise is that makerspaces might serve a function for unifying visions of learning and work activity within a school community. Finally, and most notably, the fact that I was given a budget and creative control of the makerspace provides great promise for other educators to develop non-traditional learning spaces at school.

Chapter 5: "It's a Sausage Fest"- the gendering of the LAB space

We have already seen how the tensions and promises related to the competing visions of the school makerspace drove changes to the environment and its culture. The tensions manifested over time with evidence that these conflicting visions were primarily borne from the different promises that the makerspace held. In this chapter, I will analyze the various promises and tensions that related to the dynamics of gender.

I will analyze these promises and tensions by first examining the inherent contradictions and tensions related to gender that were evident in the activity system during the establishment of the school makerspsace. Then, I will present a narrative about a female LAB manager who founded a club and developed a campaign in response to these inherent contradictions, followed by another narrative about a female visitor to the LAB whose participation provides more context for understanding the entire activity system, its tensions, and its potentials. Finally, I will evaluate the trends and patterns observed during the research study, which bring even more context to the issues of gender in the makerspace.

5.1. Gender Issues During the Establishment of the Makerspace

A tenet of Activity Theory analysis holds that it is important to analyze the broader activity context (Engeström, 1999b) in order to understand the tensions that manifested as a result of said activity. The LAB was situated within the broader socio-political system of the educational experience of girls. Over time, the influence of this broader system and the inherent contradictions therein manifested tensions, thus in order to analyze the experience of girls in the LAB, I will first discuss the evidence of the inner contradictions inherent in the activity system during the establishment of the makerspace, between the spring and fall of 2015.

The pattern of girls participating in lower numbers than their male counterparts in STEM disciplines (Beede et al., 2011; Viadero, 2009; Wang & Degol, 2017) might be due to the pattern of girls experiencing STEM (in both classes and career-wise) different than boys (Cheryan, Plaut, Davies, & Steele, 2009; O'Brien, Garcia, Adams, & Villalobos, 2015), and these patterns have become well known to educators. As a result of their ubiquity within the world of schools, the issues related to the "gender gap" in STEM have become common to the general public.

Perhaps due to this unfortunate and omnipresent cultural phenomenon, there was a hope not just to include more girls, but also to improve their anticipated experience in the makerspace, even before the makerspace was established. During my initial meeting with the first set of donors, they expressed their desire to make the makerspace "available for all students, especially girls" [FN; 5/27/2015]. During an early meeting with Stephen, the high school principal, he worried that the makerspace would become a "boys club" and asked me to reach out to girls to ensure that there was equal representation. [FN; 6/15/2016] It would seem that to both the donors of the makerspace and the high school principal, the makerspace held potential for addressing the lack of female involvement in STEM.

I was also concerned about the potential dearth of participation from girls, and given the concerns from the initial donors and the high school principal, I decided to address the issue soon after the makerspace was opened. During the second week of school (September 4, 2015) I addressed the entire school community during the daily chapel assembly period (the chapel assembly period is used for addressing the entire school community and these assemblies are not always liturgical in nature). During my talk to the students, I mentioned how there were very few girls who signed up to be makerspace assistants, and I made a plea for more girls to sign up. [Artifact – "Chapel Talk"; 9/4/2015]

The day after my chapel talk, Karen (a junior) visited the makerspace during her free period and signed up to be an assistant. At that point, fewer than a dozen out of the approximately 100 visitors had been girls, and only 4 girls had submitted an application to become a student assistant while 45 boys had done the same. [FN; 9/2/2015]

5.2. The "Women in Tech" Club and Campaign

After Karen became a student assistant in early September 2015, I quickly promoted her to a manager when she asked to be one, and she became a fixture in the makerspace: cleaning, organizing, and assisting student visitors during her free period and lunch. At the end of September 2015, I began hosting weekly manager meetings with the 8 students who had asked to be managers (6 boys, 2 girls). These meetings took place Wednesdays during lunch, and I would share the agenda for meetings with the managers on Mondays so that they could add agenda items to the meeting.

In November 2015, Karen added the topic "Girls in the LAB" to the agendas for two separate manager meetings. The notes added to the agenda from the first meeting on November 4, 2015 included "If there are too many boys hanging around, girls won't come in" and "Invite more girls." [Artifact – "Managers Meeting Notes"; 11/4/2015] The next meeting, on November 18, 2016, the notes I added included just one bullet point: "Boys need to clean up." [Artifact – "Managers Meeting Notes"; 11/18/2015] My memory from both of these meetings was that Karen wanted to draw the male managers' attention to the ways that girls were experiencing the LAB differently than boys.

In January 2016, a little over a month and a half after Karen had added the "Girls in the LAB" agenda items, Karen and I met to talk about how to increase girls' participation. In this meeting, Karen described wanting to create a club/campaign called "Women In Tech"; she needed me to be a sponsor, to which I agreed. [FN; 1/21/2016]

Karen started a "Women in Tech" SLACK channel for planning the club/campaign, and she posted the following message in her first post as a way to set the purpose of the SLACK channel: "Let's be real, the LAB is a sausage fest. Like, it's impossible to even breathe through the testosterone. This feed is to discuss the problems we face as women in tech and how to get more women at SAS to feel comfortable coming into the LAB." Karen's desire to start the club/campaign was two-fold: she wanted to provide a forum for girls that regularly participated in the LAB to discuss the issues they encountered as a result of being a female in a male-dominated space, and she wanted to encourage more girls to participate in the LAB.

Karen made 6 posters for the "Women in Tech" campaign in which she used photos of girls in the makerspace alongside slogans such as “Women in Tech: Hide your husbands we’re stealing everybody’s jobs up in here” and “Women in Tech: Sawdust covered pants are the new black” and others. All of the posters, presented below in Figure 5.1, teased the gendered notions of participation in technology. In this way, she was being provocative by juxtaposing the call for more female participation in the makerspace against historical associations with women’s capabilities and interests. The posters, printed on standard-sized copier paper, were primarily taped on doors around campus, a popular location for student announcement posters due to the open campus and the myriad doors that students must pass through on any given day.

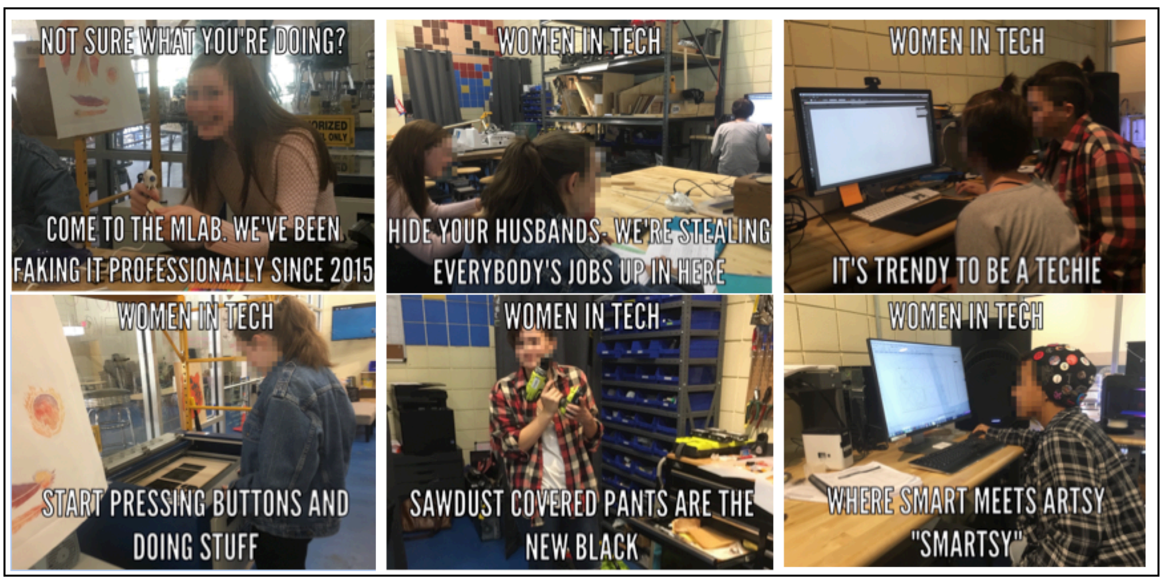


Figure 5.1. All six “Women In Tech” Posters

In total, Karen posted about two-dozen posters around campus, and most of them remained posted throughout the rest of the school year. Anecdotally, I recall when Karen showed me the first few posters in the LAB that she thought they were clever, and she was hopeful that the "Women In Tech" posters would generate interest among girls in visiting the LAB.

During the same period in which Karen was making and hanging posters around campus, she also focused on addressing some of the issues that she believed were contributing to the "sausage fest" internally in the LAB. One facet she wanted to address was the gender of an automated "bot" that was used in our SLACK messaging app. This "Phil-bot" was used to automatically respond to users in the SLACK app, usually with a meme or GIF based on what the user's query contained. Karen convinced the student manager in charge of the SLACK channel add-ons and bots, Mack, to rename "Phil-bot" as "Jamie-bot," announcing the change in SLACK thusly: "Phil is now Jamie because Jamie is a robot and has no gender, so a gender neutral name is fitting." [FN; 2/3/2016]

In terms of the club aspect of the "Women In Tech" club and campaign, Karen and 4-5 other girls met once a week during lunch for 5 meetings on February 9th, February 23rd, March 1st, March 22nd, March 29th [FN; 4/11/2016]. Although I was the sponsor of the club, I did not attend the meetings, as I did not want my positionality as a male, and the director of the LAB, to limit their conversations. From my conversations with Karen about the meetings, I believed that the club meetings were used for discussion about "how to improve the climate of the LAB for girls." [FN; 2/18/2016]

Starting in early April 2016, Karen turned her attention towards working on creating an add-on for the Jamie-bot for the SLACK application that would display different memes relating to feminism when one types "Jamie feminism me." Karen worked with

Mack, the student manager who was in charge of add-ons and bots to learn how to customize the Jamie-bot. At the same time that Karen began working on the SLACK bot, she stopped scheduling the regular lunch meetings.

Two months after Karen and I met to talk about the "Women In Tech" club/campaign, no more "Women In Tech" club meetings had been scheduled to take place during lunch in the makerspace. Karen confessed in a manager meeting on April 27, 2016, that she saw no progress in recruiting girls to the makerspace [Artifact – managers meeting notes; 4/27/2016]. Then privately she told me that she was losing interest in the makerspace herself. I asked her if there was anything I could do, and she said that there was nothing I could do because she was getting more involved in theater and singing [FN; 4/29/2016]

A few weeks later, Karen auditioned for a select school choir into which she was accepted for her senior year. She invested herself in the choir the next year, rarely visiting the makerspace during her free period, although she was the only student manager that visited the makerspace over that summer, spending a day with me as we organized the hand tools.

5.3. A "MONSTER" PROMISE

Karen's story represents the resistance that manifests within a system due to its inherent internal contradictions, but to analyze the experience of girls in the LAB, it is necessary to discuss the experience of another girl in the LAB in which the resistance to the tensions is less overt. Take the case of Priya, who was a LAB assistant during all three years that the LAB existed during her tenure at SAS and who worked on a Physics group project between November 2016 and February 2017, during the second year of my research study. During the time she worked on the project in the makerspace, Priya was highly regarded by her group members (3 boys and 2 girls) for her intellect, abilities, and work ethic. One of her male peers described Priya as a "monster" during his interview with me after he told me about how Priya had learned CAD software for their project in order to give her group's presentation a boost: "Priya's just a monster and she just like did it all, all of that without us saying anything." [Interview with Billy; 2/15/17]

The "monster" that was Priya (which as a descriptor is ironic given her slight stature and shyness) led her group during their time working on the Physics group project. Priya no doubt earned the "monster" monster for the work she did beyond learning CAD software for this group project. As an example of her prowess, during Priya's senior year (and after my research data collection period) she used the LAB to build a *knitting robot* for a month-long independent project. She was regularly busy with everything in her life, including knitting hats for premature babies as both a hobby and for her ongoing personal commitment to community service (hence the *knitting robot*), but she still made time to participate in the LAB as much as she could.

At first glance, Priya' involvement in the makerspace might provide a counterpoint to the experience that led Karen to develop the "Women In Tech" club. But, Priya was one of the few girls that attended Karen's "Women In Tech" club meetings [FN; 2/18/2017], which suggests that Priya was just as aware of the tensions around gender that manifested in the LAB as Karen was. Further, Priya's standing in her group project as a "monster" reifies the notion that in order for girls to be treated as equals in STEM learning environments (which the LAB can be considered), they must be better than their male counterparts, which is a troubling internal contradiction.

5.4. ANALYZING THE GENDERED PATTERNS OF PARTICIPATION IN THE MAKERSPACE

In order to provide more context to the broader activity system in which the LAB operated, I present analysis of the quantitative data connected to issues of gender collected during my research study period. This data prompts an interesting discussion of the promises of makerspaces and the tensions that manifested as a result of the makerspace's existence within the school system. Table 5.1 is a list of "extended projects" (projects that lasted for more than 2 days) attempted in the makerspace over a 24-month period, organized by gender. The big takeaway from Table 5.1 is that out of 46 projects, girls attempted only 9.

Many of the projects taken on by girls in the makerspace were accomplished in conjunction with art classes, which suggests that a connection to the fine arts might have been the conduit for encouraging female participation at the school, rather than the STEM connection which held promise for the high school principal, Stephen, and is written about in maker literature. The inclusion of arts as a draw for girls to the school makerspace supports the educational community's embrace of arts as an integral aspect of STEAM programming.

Male Student	Female Student
Laser Cut Hand	Mural "Droids"
Talking Photo Frame	Mural "Logo"
Skateboard Deck 1	3d Printed Head Sculpture
Skateboard Deck 2	Painting Arcade Cabinet
Engraving of Tree Frog	Pin Art
Chladni Plate	Laser Cut Rose Earrings
Rubens Tube 1	Laser Engraved Metal Bracelets
Rubens Tube 2	Engraved Quote Sign
Cigar box Guitar	Arduino Robot Kit
Ferris Wheel	
Raspberry Pi Computer	
Rebuilt Computer 1	
Rebuilt Computer 2	
Rebuilt Computer 3	
Rebuilt Computer 4	
Raspberry Pi Car Sensor	
"Modded" Speaker	
Rail Gun	
Shelf for Sneaker Display	
Stunt/Racing Drone 1	
Stunt/Racing Drone 2	
Stunt/Racing Drone 3	
Stunt/Racing Drone 4	
Stunt/Racing Drone 5	
"Modded" Nerf Blaster 1	
"Modded" Nerf Blaster 2	
"Modded" Nerf Blaster 3	
"Modded" Nerf Blaster 4	
"Modded" Nerf Blaster 5	
Sword for Renaissance Festival	
College Mascot Wall Plaque	
Rebuilt R/C Helicopter	
Rebuilt R/C Truck	
Rebuilt R/C Boat	
3D-printed Coliseum	
Guitar 1	
Guitar 2	

Table 5.1. List of "Extended Projects" broken down by gender where one can see that there were far more projects taken on by boys than girls in the LAB

It is noteworthy that "the Ultimate Nerd Club", the student club which spawned/encouraged the interest in modifying Nerf Blasters had a fair number of female club members (more about "the Ultimate Nerd Club", Nerf Blasters, and Nerf Blaster games will be described in Chapter 7). Although girls participated in the Nerf Blaster games after school, none of the girls in the club participated in the activity of modifying Nerf Blasters.

During the first year, only 8 out of 38 student assistants were girls. During the second year, only 11 out of 57 student assistants were girls. Girls who were managers frequently confided in me that they were tasked more often with cleaning the space, and that their male counterparts would treat them differently. I had several conversations with two female managers, Karen and Izzy, about their frustration with the other managers (all boys) not cleaning up. [FN; 11/20/2015, 2/23/2016, 10/11/2017] I brought these conversations to a couple manager meetings and there would be a temporary acknowledgement from the other managers that they should not just leave the cleaning to Karen and Izzy. [Artifact - managers meeting notes; 3/2/2016, 10/12/2016] However, Karen and Izzy would report that the behavior was largely unchanged.

Anecdotally, there were a few boys that commented on issues of gender during the two years of the research study, but careful searches of my field notes revealed that I did not make note of these conversations. From my recollections, the conversations were supportive. I did not know what direction my research was going to take when it came to analyzing the gendered forms of participation, which is one reason why I might not have taken more notes on the conversations I had with boys in the makerspace. A more glaring reason is that due to my positionality as a male in the makerspace, I may have subconsciously assumed that the behavior of the boys, the de facto dominant gender in the space, represented the norm in terms of behavior. The dominant behavior of boys in the LAB, and Karen's resistance against it, is actually at the heart of tension that was illustrated by the narrative of the "Women In Tech" campaign.

Using an activity system model for analysis, it can be seen that the tension around gender in the LAB is a tension over the *community* that makes up the activity. The disparity in the numbers of girls to boys in the LAB is an indicator of how the community mediates the rest of the activity system elements. Due to the male-centric community of the LAB, girls were reticent to engage in the LAB and this affected their experience in the LAB. Further, girls expressed that their experience was different than boys in terms of caretaking and cleaning up in the LAB, and thus the tension around gender is a tension over the *division of labor* within the LAB.

Karen's resistance to the male dominance of the LAB highlights the tension that underlies girls' participation in STEM disciplines. This resistance epitomizes the underlying contradictory notion that girls are encouraged to participate more in STEM spaces, but the dominant behavior of the boys in these spaces is unwelcoming to girls (Wang & Degol, 2017). The fact that resistance emerged against the tension is good, because it sets a precedent and serves as an example for future actions. In this way, it represents a promise for the LAB because this resistance clearly illuminates an internal contradiction, and exposing internal contradictions is characteristic of using activity theory to develop expansive learning systems (Engeström, 1999b). This tenet is addressed by Engeström (1999a): "the internal contradictions of the given activity system in a given phase of its evolution can be more or less adequately identified, and any model for the future that does not address and eliminate those contradictions will eventually turn out to be nonexpansive" (pp. 34–35).

Karen's actions throughout the presented narrative are reflective of the failures, disruptions, and unexpected innovations that are necessary for an activity system to evolve (Engeström, 1999a). When Karen turned her attention to changing the name of the automated messenger bot from Phil-bot to Jamie-bot, and then again when she worked on customizing the Jamie-bot to provide feminist memes, these actions could be seen as disruptions to her goal of getting more girls involved in the LAB. But rather than being disruptions, her actions were directed at making the LAB a more inclusive space. In this way, her actions serve as examples for addressing the underlying internal contradiction of STEM spaces dominated by boys by addressing the aspects of culture that detract from its inclusiveness.

Throughout the period of the study, and even to this day, there are consistently more boys participating in the makerspace than girls, which shows that the tension is not resolved. This would make sense given that the tension aligns with the larger systemic gender tension in STEM education. Much has been written about the troubling, historical pattern in STEM practices and disciplines whereby girls are underrepresented in STEM fields (Wang & Degol, 2017), with Cheryan et al. (2009) describing the reasons for the gender gap in Computer Science programs included the culture of these male-dominant programs. The tension that manifested in the LAB is related further to the gender issues within the maker movement in which primarily white males are perceived as the target audience (Chachra, 2015; Tanczer, 2016) and the proclivities of girls are not considered part of the dominant form of participation in makerspaces.

Chapter 6: Group Politics and Conflicts Over Space

The makerspace was not immune to common schooling patterns regarding group politics and conflicts over space usage (Ball, 2012; Blase, 1991). There were many disputes over the use of space during my research study, as one would expect. In this chapter, I will analyze the evolving spatial arrangement of the LAB, then highlight one particular tension that occurred over the usage of space. This tension is marked by a conflicting situation after which my intervention as the director of the LAB likely resulted in influencing further tensions.

6.1. The Evolving Spatial Arrangement of the Makerspace

In order to provide context for the analysis of the tensions that developed over time due to conflicts over space, it is necessary to describe the evolving spatial arrangement of the makerspace. Embedded in this history are signs of the underlying tensions that one would expect due to the natural dynamics of human space usage and the politics of group identity, as related to schooling practices (Dickar, 2008)

To ground the discussion of the changing layout of the LAB, we must first consider the original layout of the space. As mentioned in a previous chapter, the LAB physical space originally consisted of half of the school's old stage, 15-foot tall glass walls enclosing the space. Figure 6.1 is a photograph of the LAB before adding equipment and tools where one can see the original layout of the worktables storage shelves, sitting area and TVs

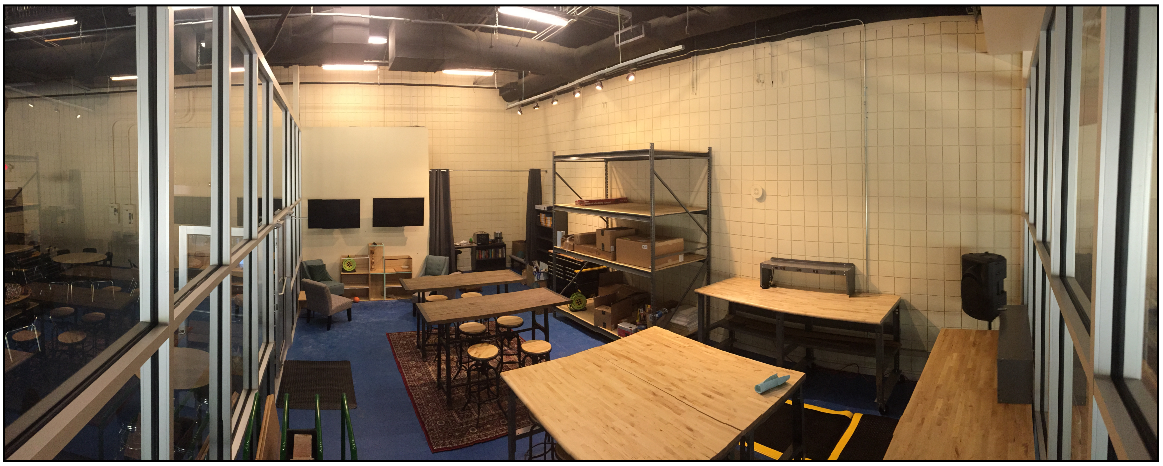
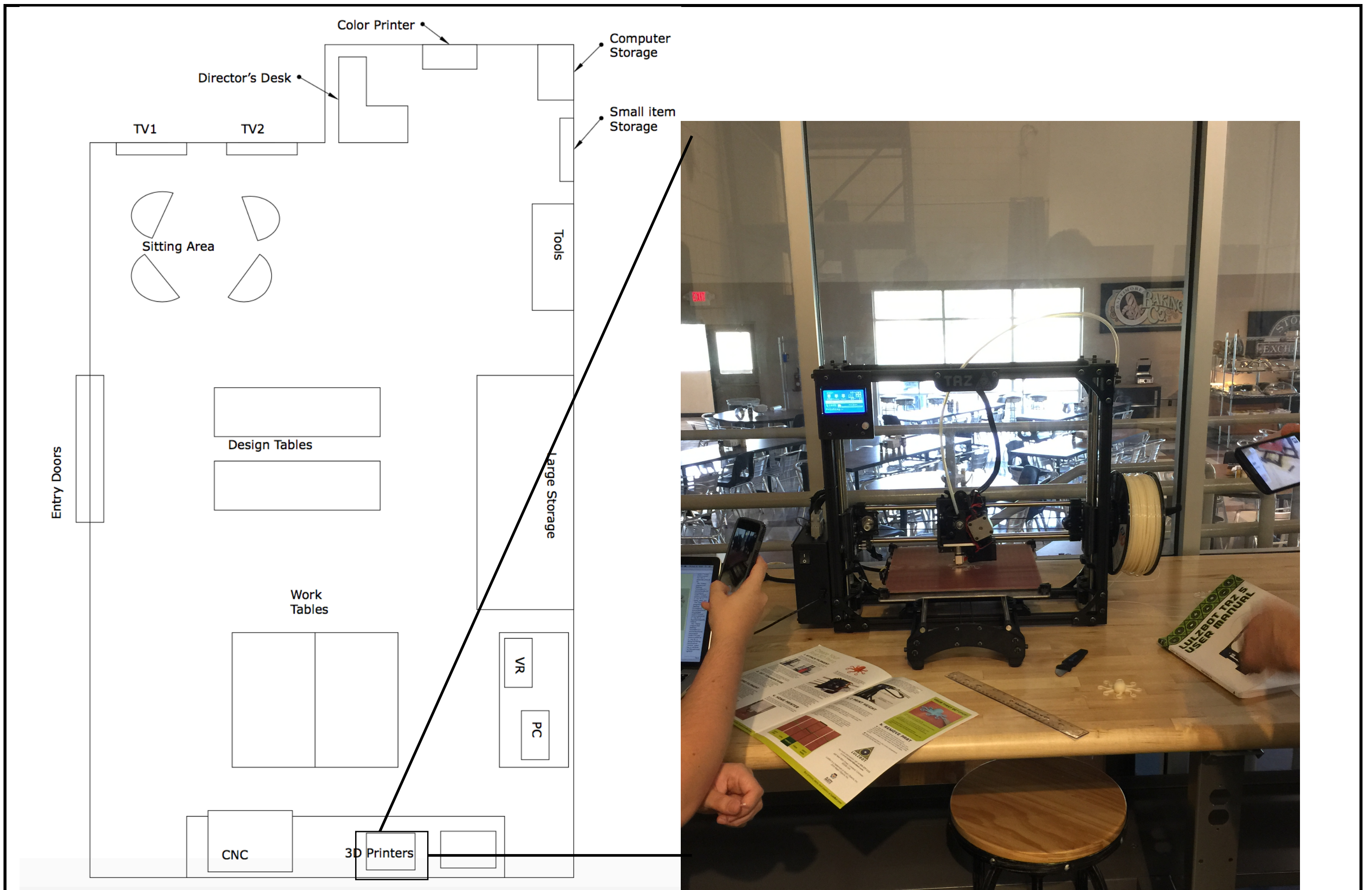


Figure 6.1. Photograph of the LAB without equipment taken 8/14/2015

Large worktables and two large *design tables* took up a lot of square footage, but I wanted to ensure there was plenty of workspace. The original donors to the makerspace requested the sitting area so that students could have a place to brainstorm ideas for inventions. [FN; 6/11/2015] The sitting area was closest to the two TVs, and a popular pastime was watching the TVs, but the students usually opted to sit on stools at the design tables to watch TV.

Hoping to provide as much usable worktable area as possible, I placed most equipment and materials in storage except for the CNC machine and 3-d printers. Given the association with makerspaces that 3-d printers and CNC machines hold within literature (P. Blikstein, 2013; Kurti et al., 2014a, 2014b), as well as their eye-catching method of production, I placed the 3-d printer and CNC machine closest to the glass walls so that students would see them in action when walking by the LAB. I was inspired to do this after visiting MIT's Media Lab years ago and being impressed that their lab is set up so that visitors can see users of the lab, and equipment, in action. Figure 6.2 shows a diagram of the layout of the makerspace next to a picture of one of the 3-d printers showing how the 3-d printer and CNC machines were positioned by the glass wall.



Glass wall facing out on the cafeteria　　LulzBot 3D printer next to the glass wall

Figure 6.2. Photo of a 3-D printer alongside its location in the LAB

Once the makerspace was open and frequented by students, I knew that their work habits and patterns, as well as the incorporation of future equipment, would necessitate rearranging the layout. Figure 6.3 represents the changing layout of the makerspace over the first year with changes/additions to the spatial arrangement of the LAB highlighted by dashed boxes.

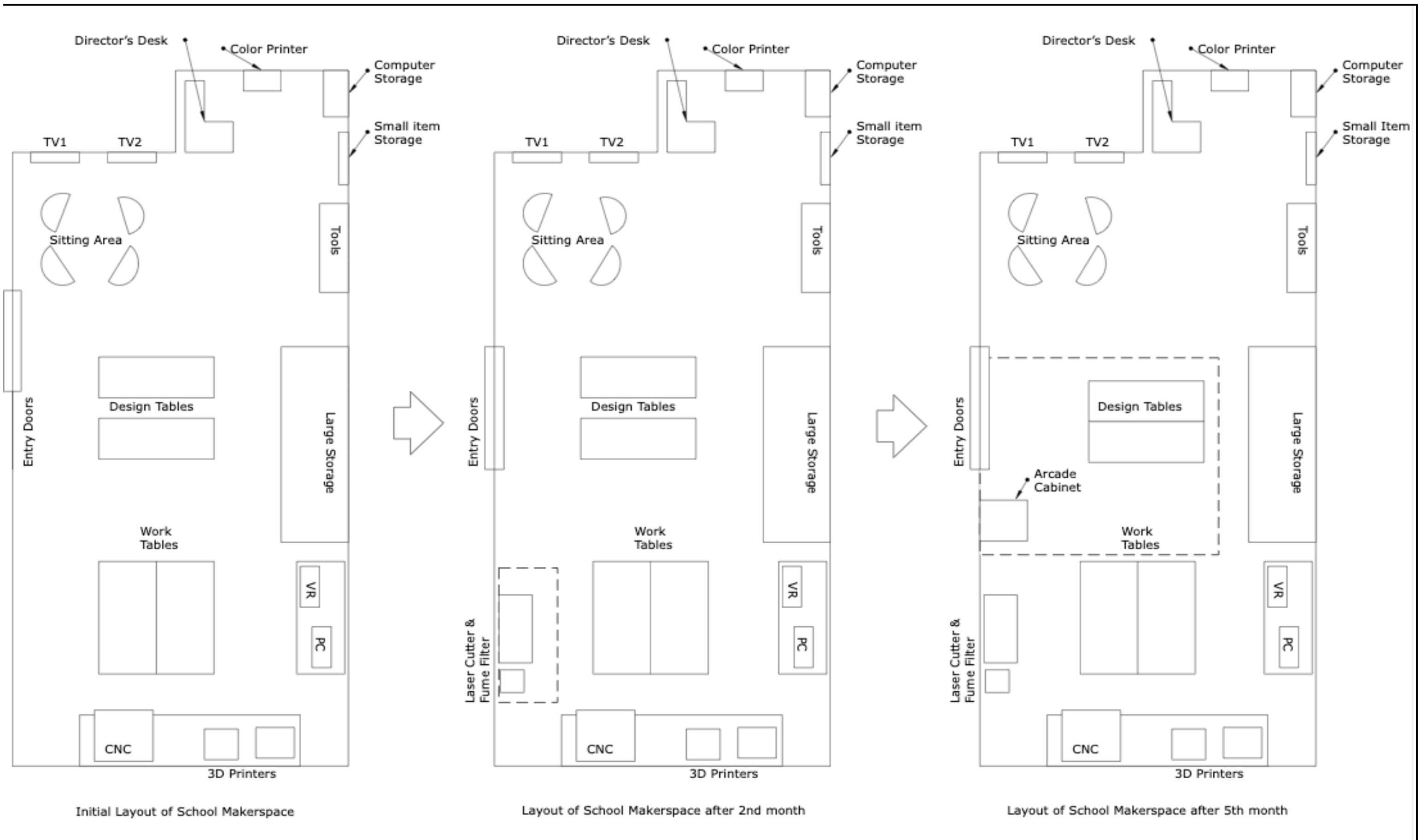


Figure 6.3. Diagram of the LAB's spatial changes during 2015-2016 school year

I will describe in some detail the changes in the spatial arrangement during this first year to demonstrate how the space evolved due to student requests and to the addition of equipment.

The first shift in spatial arrangement came after the addition of a laser engraver/cutter and a fume filter device that allowed for the laser cutter to be used inside.

The middle diagram in Figure 3 represents the spatial arrangement after the laser cutter was delivered.

The second shift in spatial arrangement occurred due to student requests to combine the two big “design” tables into one larger table to make better use of the space. The request actually came from student managers during the first manager meeting after the holiday break, on January 6, 2016. [Artifact – managers meeting notes; 1/6/2016]. During the meeting, one of the managers requested that we push the two design tables together. There was not adequate room between the tables and students would rarely sit between them, and we had added an arcade cabinet for a student project that made the space near the doors feel cramped. In addition, students opted to sit at the design tables to watch the TVs near the sitting area, and moving the tables together allowed more students to sit around the two tables.

The third shift in the spatial arrangement of the makerspace was the most substantial. During the summer of 2016, we expanded the LAB to include the entire stage, thus doubling the space’s area. Figure 6.4 is a diagram of the LAB after incorporating the rest of the stage. With the extra space, we moved the design tables, sitting area, and TVs to the open side of the stage, creating much more seating. The LAB was bifurcated into what we referred to as a “design side” and a “lab side.” [FN; 8/11/2016]

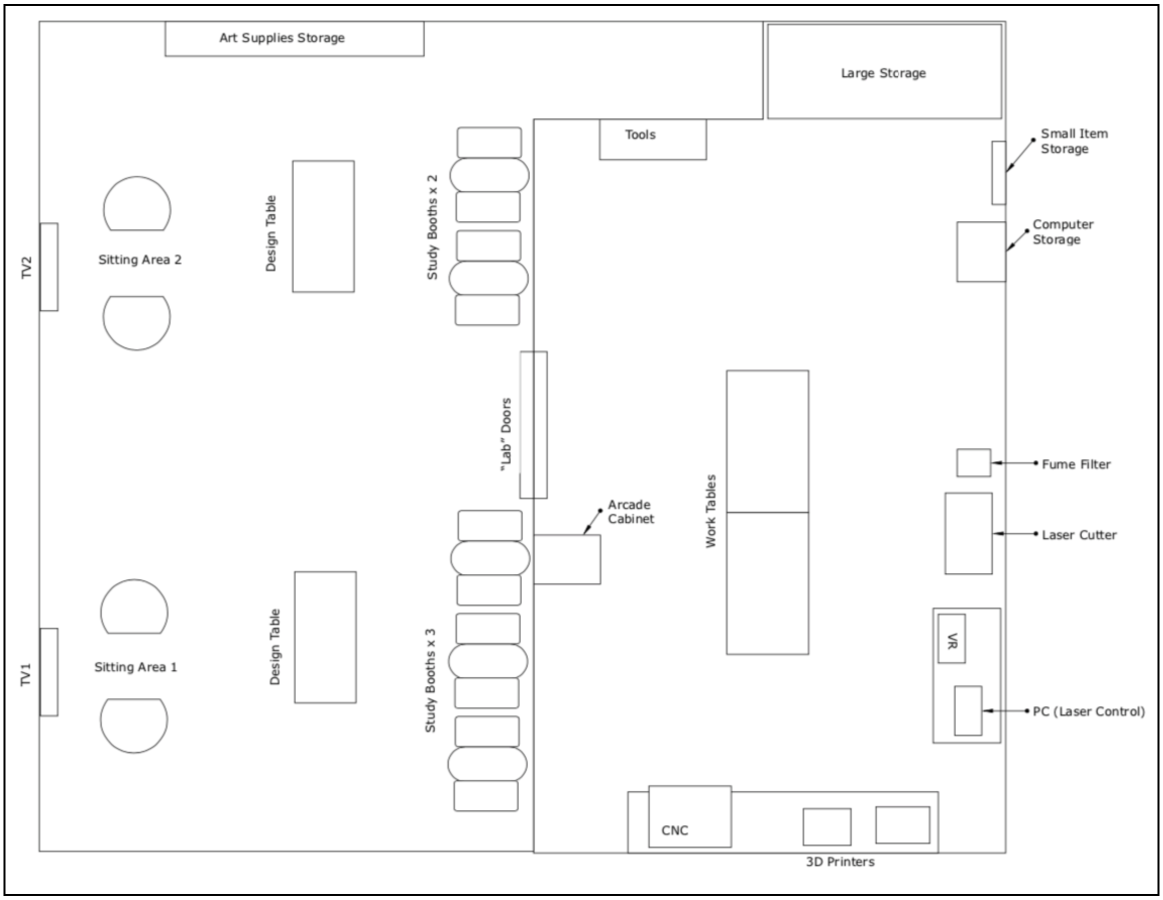


Figure 6.4. Diagram of the spatial arrangement of the makerspace after summer 2016

During a manager meeting in January 2016, a manager named Izzy formally proposed expanding onto the stage, which had been a popular suggestion from students, teachers, and the donors during the first semester that the LAB was opened. I told Izzy that it would require approval from the principal since student would sometimes eat lunch on the other half of the stage. [FN; 1/6/2016] Unknown to me, Izzy followed up with Stephen in person sometime during January 2016 and asked if we could expand on the stage allowing the condition that students still be allowed to eat lunch on the stage.

Stephen mentioned this conversation with Izzy to me in February 2016. He relayed how he enjoyed talking with Izzy about the LAB and how involved she was with it, and that he would allow us to expand onto the stage, but he wanted me to wait until the summer to do any moving or building. At this meeting, he also asked me to keep track of the number and grade level of students who ate lunch on the stage for the remainder of the year. [FN; 2/15/2016]

During the summer of 2016, I gradually expanded and rearranged the makerspace to include the entire the stage. I did most of the work alone, though a handful of students helped me move large equipment in early June 2016. The extra space allowed me to move the “design” tables and sitting areas to the open stage, while keeping all of the equipment and tool storage locked inside the glass walls. The extra space seemed like a good thing, except there was perennial work because students that ate on the stage would frequently leave dirty dishes and food waste on the tables. Cleaning up the mess left behind by students was a large source of frustration among student assistants and mangers. In fact, the issue of cleaning up after breakfast and lunch came up during at least six different managers meetings during the 2016-2017 school year. All of the managers were upset that they had to clean up the food waste and found that it was hard to convince student assistants to clean up [FN; 5/19/2017]. Throughout the 2016-2017 school year, we tried a number of things to combat the mess left behind by students, including making formal announcements to the student body about cleaning up after themselves. However, nothing seemed to work, and the daily mess left on the tables in the LAB by students leaving food waste, used plates, cups, bowls and utensils was a source of personal frustration for me, as well as for all of the student managers. [FN; 5/19/2017] The LAB had become a multi-functional space, which was good, but the multiple uses seemed to clash.

The fourth shift in spatial arrangement occurred after a student manager suggested that we make distinct "zones" for different types of work in the makerspace. During the September 23, 2016 managers meeting, Izzy pointed out that we basically had zones where activities were organized, and if we moved the CNC machine next to the laser cutter, we would have areas for cutting, printing, studying/socializing, designing, and arts & crafts. The suggestion was so simple yet elegant, and within days of that meeting I found an unused table and moved the CNC machine to the wall with the laser cutter and reorganized the wires and cables necessary to run the equipment.

The fifth shift in spatial arrangement occurred shortly after changing the layout to emphasize zones. In November 2016, I designated a table for the students to work on drones, called the "Drone Zone." Figure 6.5 is a diagram of the layout of the makerspace after creating the "Drone Zone." In the following section, I will describe in detail the accumulation of the tension that resulted from creating the Drone Zone.

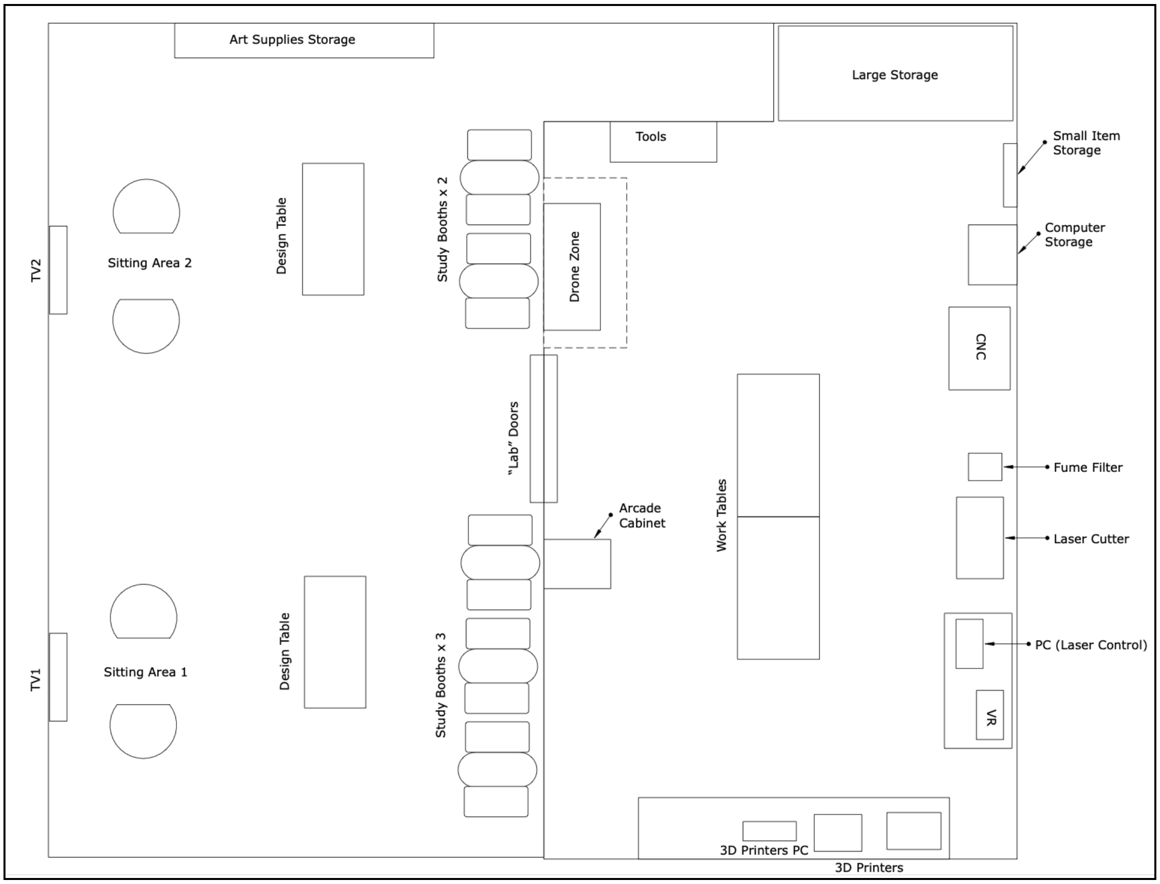


Figure 6.5. The makerspace layout after establishing the Drone Zone.

6.2. Group Politics and the "Drone Zone"

In order to better understand the escalation of the tension that resulted in creating the Drone Zone, I will describe (1) how two students, Daniel and Ryan, met in the LAB, and how their shared interest in drones developed over time, and (2) how two groups of students formed as a result of the drone activity in the LAB, which ultimately led to an incident that catalyzed the creation of the Drone Zone.

6.2.1. A shared interest in drones

The story of the Drone Zone begins with two students, Daniel and Ryan. When the makerspace opened during the 2015-2016 school year, Daniel and Ryan were in 9th and 10th grades, respectively. I interviewed and observed them both during the winter of 2016-2017 as they worked on self-initiated projects in the LAB. Beginning with his second day of high school Daniel was an early and regular visitor to the LAB, spending nearly all of his time there. To illustrate how much Daniel enjoyed being in the LAB, when I asked him how he felt the first time he visited the makerspace, he replied "It was kind of like that moment in Jurassic Park where they see the dinosaur for the first time. Music and all, yeah." When I asked Daniel how he developed an interest in drones, he described his history with remote control, or RC, vehicles, beginning when he was 10 or 11 with an RC car that had broken. In the process of researching how to fix his broken RC car, he happened upon a YouTube channel called "Flight Test" which Daniel said focused on "RC aviation."

Ryan and Daniel shared the same free period during the 2015-2016 school year and met in the LAB. Unlike Daniel, Ryan confessed that he didn't have any interest in drones until he and Daniel began hanging out in the LAB, and in particular one time when Daniel was working on his quad racer in the LAB: "I hadn't had that interest before I met "Daniel" because he came to school with this thing and I was like what is that? I was like

I want to do that, too." Although Daniel's interest in drones stemmed from his past experience with RC cars, according to both of them, Ryan's interest in drones didn't start until he first saw Daniel working on his drone in the LAB during the 2015-2016 school year. After that initial exposure to drones, Ryan was hooked, and he very quickly bought a drone of his own. As Daniel tells it: "he [Ryan] came in there at some point and I think he saw me working on it [his drone] and I think he'd seen some stuff online about quad racing and stuff and he was like, hey, that's pretty cool, I'm going to do some of it, and then he goes and buys like a ready-to-fly racing quad, and that lasted for about like the rest of the year almost."

For Ryan and Daniel, a lot of the time they spent on their drone hobby in the LAB from Fall 2015 to Winter 2016 was devoted to diagnosing and fixing problems with Daniel's drone ("quad"). When asked about becoming friends with Ryan in the LAB, Daniel said "I think he came in and was like – I think because at the time that he first started coming in I was in like that three month long period of me trying to diagnose like the millions of problems I had with my first quad and me just constantly blowing things up and making them go poof and making things catch on fire."

Throughout the first year of the LAB, the 2015-2016 school year, Ryan and Daniel would work on their drones any period they were in the LAB, preserving a few minutes at the end of each period to test out their work by going to the football field to fly their drones. In March 2016, Daniel bought a First Person Viewer, or FPV, setup for his drone, and Ryan quickly followed suit with an FPV setup for his drone. Throughout this period of activity, during the 2015-2016 school year, three other male students – Cade, Kent, and Robert – frequently joined Ryan and Daniel during lunch and before/after school to tinker with, and fly, the growing number of drones in the makerspace [FN; 5/12/2016]

6.2.2. Groups forming on either side of "drones"

Over the summer of 2016, Ryan and Daniel reportedly met up frequently to fly their drones. As the director of the LAB, I was excited when Ryan and Daniel returned for the 2016-2017 school year with an even greater interest in drones because I felt that drones represented a quintessential example of an interest-driven activity for students to pursue in a school makerspace. Although they did not share the same free period during the 2016-2017 school year, they spent almost every morning before school and almost every afternoon after school working on their drones in the LAB and taking breaks to fly them outside.

At the beginning of the 2016-2017 school year, six students (all male) regularly spent their time working on drones in the LAB. They comprised the largest group of students who regularly used the 3D printer, laser cutter, soldering tools, and computer repair tools. Due to this, there was a noticeable influx of drones, drone parts, and tools left out on the tables in the LAB. The mess left behind by the students working on drones catalyzed a group of four student managers (Jon, Izzy, Karen, Mack) who formed in opposition to the drone-builders, and who were less pleased that working on drones was so popular an activity in the LAB. At the time, I recall feeling that the four managers were overly concerned with the mess left behind by the drone-builders given how many other messes were left behind by the many other LAB visitors, including the ongoing mess that resulted from students leaving dirty plates and cups on the stage side of the LAB.

During two fall manager meetings, on September 23, 2016 and November 2, 2016, the four managers brought up the issue of the drone-builders not cleaning up after themselves. In the notes from the first meeting in September, I quoted Jon, saying, "Drone parts everywhere! – 'Jon'" [Artifacts – Managers Meeting Notes; 9/23/2016] During the second managers meeting, in November, I wrote: "Drones – Clean up (Daniel)" because at the meeting when the concern was voiced, I assigned Daniel to stay on top of cleaning up the mess related to drone activity. [Artifact – Managers Meeting Notes; 11/2/2016] In the days that followed, I was remiss in ensuring that Daniel clean up the mess left behind by the drone-building activity.

About three weeks later, after the Thanksgiving holiday break, one of the four managers (Jon) was upset that Daniel had left out his drone and some tools the day before, so Jon hung Daniel's drone from the ceiling using a rope. I was informed of the altercation much later in the day, after Daniel had already retrieved the drone. After I heard about the altercation between Daniel and Jon, I decided to designate a table in the LAB as a safe place for the drone builders to leave out their drones, drone parts, and specialty tools. I called the table the "Drone Zone" because we had just recently (two months prior) reorganized the makerspace to emphasize zones. Figure 6.6 is a picture of the Drone Zone during the 2017-2018 school year, where one can see that the space is essentially a table to store parts and tools.

Figure 6.6. A picture of the Drone Zone

When I interviewed Daniel in January 2017, about 2 months after the incident, I asked him if he could describe any incidents in the LAB that were due to the tension around the building of drones, to which he responded "you probably remember "ye olde drone hoist" – that was a good one. That was when I left my stuff out on the table – and I thought it was really funny too, when [Jon] he found my box of stuff, and this was back when we had the rope right there, and he "whoop" lifted the box." I asked Daniel if there were other instances in which people hid his drones or drone parts when he left them out, and he said "yeah."

I created the Drone Zone partly because I was a bit worried that Jon hanging Daniel's drone from the ceiling might escalate into a physical altercation. The incident was a signal for me to intervene and de-escalate the tension. I was hopeful that creating the Drone Zone would appease all involved parties and allow space for the drone builders' activity without upsetting the others were they to leave the table a mess. The four managers were unhappy with my decision to create the Drone Zone, but none more than Jon. Anecdotally, I recall talking with Jon on a number of occasions throughout the rest of the 2016-2017 school year in which he expressed his disapproval with my handling of the situation, wishing I had been more punitive with Daniel and the drone builders. Although he admitted that the mess created by the drone builders was at least contained by the new zone, he felt that the drone builders escaped punishment and were rewarded for not cleaning up.

6.3. Analysis of the Tensions and Promises

The story of the Drone Zone typifies the tensions and promises that can manifest due to the naturally occurring internal contradictions related to competing for dedicated space in the makerspace. I will now analyze the various activities and actions that took place in the reorganization of the LAB "with a keen eye on their inherent contradictions, many disturbances and dilemmas in everyday flows of work begin to make sense" (Engeström, 2008, p. 258).

To situate this chapter, I described the shifts in the spatial arrangement of the LAB to show that prior to expanding onto the stage after the first year of the LAB, the small changes in the physical space did not exacerbate the naturally occurring internal contradictions around space. Thus, an analytical interpretation of the tensions and promises related to the creation of the Drone Zone begins with examining the evidence of conflicting messages, situations, or demands within the LAB activity system. The altercation between Jon and Daniel in which Jon hid Daniel's drone certainly qualifies as a conflicting situation. Because of this conflict, I discovered the tension in a contemporaneous fashion, unlike other tensions that became evident much later during analysis.

Analytically speaking I was fortunate to have a physical conflict to signal the tension. In order to provide an activity theory analysis of the various activities related to the creation of the Drone Zone, it is necessary to analyze the inherent contradictions within the LAB system. Engeström (1999) suggests that evidence of inherent contradictions can be seen in examples of *double binds* that participants experienced. One such double bind that emerges in the Drone Zone narrative is the conflicting message that students were receiving about the importance of cleaning up the LAB. I must admit that, as the director of the LAB, I overlooked the conflicting message that I was sending to the LAB managers, assistants, and student visitors in regards to cleaning up the space. I realize that I was lax about having the drone builders clean up after themselves, and the message I sent to the LAB managers and other users of the space (that cleaning the lab was a priority) conflicted with the message I was sending to the drone builders.

Another example of the *double bind* that Engeström believes signals the inherent contradiction of the activity system is the conflicting demands placed on the student managers and assistants by tasking them with cleaning up after student visitors who ate on the stage side of the LAB. As I described in this chapter, cleaning up the mess left behind by students was frustrating to me, the student managers and assistants, and anyone else who was a regular visitor to the LAB. It was frustrating to clean up after students who were using the LAB solely as a place to eat, and it was additionally bothersome that we all thought the students who left behind messes were inconsiderate, yet we had to clean up after them.

The demand placed on the managers and assistants that they clean up messes related to students eating in the LAB conflicted with the demand that they clean up messes made by students using the LAB for activities more related to its purpose. It seemed that if one expended energy cleaning up the food mess, they were less likely to clean up the mess left behind by student activity more closely related to the LAB's purpose, and vice versa. This conflicting demand placed on the LAB managers and students exacerbated the tensions around cleaning up, including the tension that was related to the drone builders not cleaning up.

In relation to the activity model put forward by Engeström (1999), this analysis highlights systemic tension around the rules, division of labor, and community elements of the activity system. For example, the tension that was marked by the creation of the Drone Zone can be seen as a tension over the distribution of labor, one of the key elements in the activity system model. This is reflected in the issues that developed around who was to clean, either cleaning the makerspace's work spaces, or cleaning up the food mess left behind by students.

Due to the conflicting messages and demands that I have described, the buildup of the Drone Zone tension happened over the course of several months during the fall of 2016. Increasingly, physical space was co-opted by the students who worked on drones because they were not cleaning up regularly. Thus, the resulting tension due to the competition for physical space, and was exacerbated by the conflicting messages I was sending. These tensions were extended when I made the Drone Zone, although its creation did quell some of the frustrations caused by Daniel and Ryan spreading out their drone parts and tools.

During Daniel's interview in January 2017, I asked him if he thought the tension around the building of drones had abated after creating the Drone Zone, and he responded "I feel like the tension has flipped from the people who don't do it being annoyed at the people who do, from now to the people who do are annoyed with the people who don't, because they will just see it as another table, and cut wood on it and get sawdust on everything and that gets annoying, or just leave stuff there that has no relation to what should be on the table." Like Daniel, I believe that new tensions formed due to my actions, and I also acknowledge that creating the Drone Zone did not bring an end to the tension around the competition for space.

My response to the conflict between Daniel and Jon was intended to quell a rising tension, but my actions privileged a group of students by giving them dedicated space within making grounds. Considering that the Drone Zone was used primarily by white males, there is a chance that my actions could be perceived as further privileging members of that dominant group. In other words, I have further exacerbated the tensions that manifested in the LAB around gender (see Chapter 5). As I wrote in that chapter, the tensions around gender are due to the inherent conflicting message sent to girls that welcomes them to a space that is unwelcoming due to its associated male-centric culture. My actions in establishing the Drone Zone carry a weight in this regard, because rather than confronting the dominant behavior in the LAB, I encouraged it.

This analysis does not suggest that the activity of drones in the LAB was the source of tension in the LAB. In fact, the drone activity in the LAB represents a great promise for school makerspaces. When one examines the activity around drones in the LAB, it is an obvious example of student-generated interest that was allowed to flourish. This suggests the potential for students to use makerspaces for developing their own deeply personal pursuits, even while at school. Additionally, the growth in size and material inventory that the LAB experienced suggests a promise that makerspaces have the potential to expand and include more students in making activities.

Chapter 7: The "Nerdy" Makerspace

In the following chapter, I will explore the ways in which the makerspace was considered a home to so-called 'nerds', and the tension resulting from this assignment as a 'nerdy' space. I will first discuss how the makerspace came to be associated with 'nerds' and then discuss the promises and tension that resulted as a consequence of this association. I use the term 'nerd' throughout this chapter; while it holds negative connotations, it has become less pejorative over the years, and "as an in-group term, it can convey affection or acceptance" (Kendall, 2000, p. 262). I am using this term not because I personally believe that the students who frequented the LAB are nerds, but because participants described themselves and others who frequented the space as nerds, or described the space as nerdy.

7.1. The Makerspace as a Nerdy Space

Throughout my analysis, I was interested in identifying to which groups the many different makerspace participants belonged, or were perceived to belong. The impetus for this focus stems from my choice to use Legitimate Peripheral Participation for my theoretical framework, with particular attention to the crucial roles that developing identities and forms of membership play in understanding participation (Lave & Wenger, 1991). The school makerspace served multiple purposes, and as such, analytically distinct categories like identity, agency, and expertise are intertwined (National Research

Council, 2009). However, throughout my data I discovered the assignment of the "nerd" identity in association with regular participants of the LAB in the following ways: (1) the saga of "the Ultimate Nerd Club", which used the LAB as its club meeting spot, and (2) the association of regular users of the makerspace as "nerds" in interviews with two study participants.

7.1.1. "The Ultimate Nerd Club"

As director of the LAB, I was in charge of approving who could use the space and for what purposes. Two weeks after the LAB opened, in mid-September 2015, a student assistant named Jerry requested to use the LAB to host a student club that he was leading. The club was called "the Ultimate Nerd Club" and Jerry described the club activities to me as "typical" nerd activities – playing Dungeons & Dragons, playing board games, discussing fantasy books and movies, and anything else that a "nerd" would want to do [FN, 9/9/2015]. Many regular visitors to the LAB shared elements of what would be considered "nerd" culture, so in retrospect this club seemed like a natural social formation for LAB regulars.

Jerry made weekly announcements to the entire school community over the course of two years, advertising what activities were planned for "the Ultimate Nerd Club". These announcements took place after the daily chapel ceremony, during the only time when students could make announcements to the entire student body. Jerry's announcements followed the same pattern, starting out by saying in a monotonous, quiet tone, "Nerds: "the Ultimate Nerd Club" …" followed by a brief description of what they were going to do for their club meeting that week, and ending by identifying the LAB as the meeting place. [FN, 2/9/2016] After a few months, Jerry's announcements generated a few hoots and hollers from students and he would smile at the attention garnered by his announcements.

Over the first year, "the Ultimate Nerd Club" mainly played Dungeons and Dragons (D&D) and a humorous card game called "Cards Against Humanity" during their once-a-week meetings. Attendance at the weekly club meetings during the first year was never more than a dozen students, with almost half as many girls participating in the club activities as boys. During these meetings, the students would sit around the design tables in the makerspace and it was always a congenial, humorous atmosphere.

Starting in September 2016 (during the second year of "the Ultimate Nerd Club"), the club added an activity: Nerf Blaster fights. Nerf Blasters are colorful toy guns that fire foam darts, discs, or balls. There is a variety of types of Nerf blasters, ranging from single-shot blasters that shoot a single foam dart and fit in the palm of one's hand, to large (> 3 feet) blasters that can fire foam darts automatically using a small battery and a turbine hidden in the barrel, requiring the user to hold the blaster with two hands, much like a rifle. For "the Ultimate Nerd Club", students used all sizes and types of Nerf Blasters, but only the ones that fired the foam darts. Nerf Blaster fights are essentially contests in which individuals or teams attempt to shoot their opponents with darts while avoiding being hit themselves.

The Nerf Blaster fights were held on Friday afternoons, outside of the normal club meeting times, which alternated between Tuesday and Wednesday afternoons depending on the time of year (due to a large number of club members working on the Musical production in the fall). Many more students than the usual number of club members would attend these Friday afternoon Ultimate Nerd Club Nerf "wars." As many as 20-25 students might attend, typically ~75% boys. All combatants would meet at the LAB as soon as the last class was dismissed at 3:45pm, and begin by reviewing the rules for the different types of Nerf Blaster "games" that would take place "on the green," a large rectangular lawn that sits in the center of campus. The students would then go outside to the green and begin their games. Friday afternoon Nerf Blaster games would typically last 30-45 minutes from the discussion of the rules to the end of the contest, when students would return their Nerf Blasters to 2 shelves of plastic bins in the LAB.

During regular club meetings, those club members not interested in D&D or board games would work on modifying their Nerf Blasters so that they would fire darts more rapidly or shoot darts farther. Some modifications made by the students include swapping out the small batteries for larger batteries in the automatically-firing Nerf Blasters, or removing anything inside the firing mechanisms of the blasters that might limit their firing speed. It should be noted that although girls represented about half of the membership of "the Ultimate Nerd Club" and participants in Nerf Blaster fights, only boys engaged in "modding" Nerf Blasters.

The additions of Nerf Blaster games and blaster "modding" resulted in an increased number of students claiming membership to "the Ultimate Nerd Club", though the attendance to regular club activities like D&D, board games, and video games remained about the same as the previous year.

There were only two other clubs that used the LAB as their meeting place – VIVA arts council, and a small "Entrepreneurs Club." I mention these two clubs as a way to contextualize the size and visibility of "the Ultimate Nerd Club", but it should be noted that these other clubs demonstrate the potential of the LAB to attract a variety of students. VIVA arts council meetings consisted of 4-5 students (all girls), and at their semi-regular (almost "seasonal") meetings they would focus on planning different events and contests throughout the school year to highlight the arts. Their use of the LAB did not include the use of any equipment. The Entrepreneurs Club consisted of just 3 students (all boys), one of who was the son of the original donors to the LAB. Their meetings were sporadic and informal, and although their intent was to use the LAB equipment to build prototypes for a business, they never actually landed on a business idea (at least to my knowledge), and thus spent their meetings brainstorming and socializing. Both of these clubs rarely made announcements about club meetings, and in fact rarely held club meetings. Conversely, "the Ultimate Nerd Club" made regular weekly announcements about meeting at the LAB, and also met multiple times throughout each week. As an analyst, I believe the association of "the Ultimate Nerd Club" with the LAB, and the fact those students self-identified as nerds by attending the Ultimate Nerd Club, contributed to a perception that the LAB was a haven for so-called nerds.

7.1.2. Assignments of the "Nerd" identity in Interviews

Throughout my time as director of the LAB, I frequently heard students refer to themselves as "a nerd." I did not document these moments at the time because I did not realize their significance. I combed through my field notes and pored over artifacts trying to find record of these moments. To continue to analyze the tension that manifested as a result of the LAB's association with nerd culture, I turn to two excerpts from the interviews I conducted with 10 students and 2 teachers in the winter of the 2016-2017 school year.

During the first interviews with each participant, I asked who they thought comprised the community of the makerspace. For the most part, participants would use the broad category of "students", or they would list names of students that they personally knew were regulars in the makerspace. Two participants, Johnny and Mr. W, described the students who comprised the community of the LAB as "nerds" and described the LAB as "nerdy."

Consider this excerpt from my December 2016 interview (during the second year of the makerspace) with Johnny, an 11^{th} grader who worked on building the video arcade in the LAB. In response to my question about how he understood the makerspace fitting into the larger school community, Johnny lamented that there were not as many students visiting the makerspace as he anticipated, and he suggested that it was due to teachers not using the space, and that if teachers used it more then students would use it more. I followed up by asking him why he thought students did not use the space more, and he introduced the idea that the makerspace was aligned with "nerdy" students.

> Johnny: It kind of depends because the kids that use it now are you know, that these are the kids that are passionate about staying in one and use it as a career, and of course, they're kids that have gone to it a little bit to check it out and then there's kids that have never – even thought about walking in and I think it's more of a – I don't know, I feel like it's more of kids thinking it's like a nerdy thing or

– ‘cause there’s that group of kids that think its just like weird to like go in there and which is unfortunate – and yeah, and I think that has to do with it. I think a lot of it is, some people might not understand what they could use it for unless they actually were curious enough to go in and check it out and a lot of people aren’t like brave, but like –

Josh: Yeah. Right. Everybody has their own schedule of stuff.

Johnny: Yeah, and –

Josh: Teachers have to teach them a million things –

Johnny: Yeah and kids are all like I have this, this, this, why would I do that? And yeah, I guess, I mean, I’m sure there’s a ton of factors, I just –notice that a lot of kids either just don’t want anything to do with it, ‘because they think it’s nerdy – or they just don’t understand it enough.
[Interview with Johnny; 2/6/2017]

Johnny first described the users of the space as consisting of different groups of students – those that are passionate about the space, those that are interested in the makerspace because they see it as a place to prepare for a future career, and those that want to “check it out”. These groups of students suggest the potential that makerspaces offer by providing a space for students who are passionate about making and tinkering, or who see makerspaces as grounds for developing skills for future careers. But given that I had asked Johnny why he thought the makerspace was not used by as many students as he would have liked, he suggested that the students who had never visited the space considered spending time in the makerspace a “nerdy thing.” You can see in my responses to Johnny that I did not pick up the “nerdy” connotation instead suggesting that students have other commitments and the makerspace might not fit into their schedules. Johnny included my reasoning as one of the many factors why some students wouldn’t visit, but he returned to the notion that some members of the student body perceived visiting the makerspace as nerdy.

Mr. W, a Physics teacher, was a regular visitor to the makerspace and also believed that a certain type of student seemed to make up the regular visitors. His interview took place in January 2017, during the second year of the research study, and he worked with Johnny and three other students on building an arcade video game in the LAB. While describing his involvement with the arcade, Mr. W suggested that he saw the typical visitors of the makerspace as "nerds," saying "Like I think, you know, we would probably, you know, if we were just kind of lumping kids together in high school, right, we would say 'oh that's the nerds right there' hanging out during lunch and playing video games together." Mr. W viewed the regular visitors as nerds who played video games, and that is why he wanted to work on the arcade.

7.2. ANALYZING THE TENSIONS AND PROMISES

Throughout this chapter, I have shown that the LAB could have reasonably been associated in some way with nerds and nerd culture. The LAB served as the setting for a multi-year club, "the Ultimate Nerd Club", which celebrated nerd culture. Also, many of the regular visitors to the LAB embraced elements of what would be considered 'nerd' or 'geek' culture, including "being extraordinarily well-versed in the inner workings of computers, myopically being focused on them" (Varma, 2007, p. 360). These LAB regular visitors represented the typical nerd stereotype as "lacking social or sartorial skills, obsessed with trivia, and interested in fringe cultural activities" (Kendall, 2011, p. 521).

The LAB's association with nerd culture implies a tension in and of itself, as Kendall (2011) points out the inherent contradictions of the nerd identity that emanates from a powerful intelligence and aptitude of computers combined with a social ineptitude and desirability. The researcher suggests, "it is logical to expect that the inherent tension in those contradictions would resolve over time, as computers become more ubiquitous in society" (p. 505). The tension that Kendall wrote about is related to the systemic tension that was observed in the LAB, marked by Johnny's statements regarding students not visiting the LAB because of its nerdy undertones.

This tension would be based on the conflicting messages sent to the student body. I aspired for a message that all were welcome at the LAB, which conflicted with the message that only nerds are welcome. Johnny described how some students would never visit the LAB because they were afraid that would be brand them as a nerd. This is evidence that through some form of cultural transmission, students received a message that would put them in a double bind were they to choose to visit the LAB – stuck between choosing to visit the LAB and being considered a nerd. This double bind is corroboration of a troubling systemic tension. Students believing that visiting the makerspace would result in other students viewing them as nerds suggests that the LAB is similar to computer science programs, where much has been written about the associated nerd culture (Davis, Yuen, & Berland, 2014; Kendall, 1999, 2011).

Using an Activity System model, the LAB's association with nerd culture can be seen as a tension over the community element of the model. The tension is between the subject and the object mediated by the community. In this case, a visiting student who might have an objective of using the LAB would have their activity mediated by the perceived community of nerds in the LAB.

I do not know exactly when this tension originated, but I suspect that this process may have started soon after the establishment of the makerspace due to the early association of the LAB with "the Ultimate Nerd Club". Considering that Johnny and Mr. W described the type of students who frequented the LAB as nerds more than halfway through the second year of the LAB, I can surmise that the tension persisted for two years, and given that "the Ultimate Nerd Club" continues to meet in the LAB to this day, the tension likely remains. I have evidence neither for how pervasive was the belief that the LAB is a nerdy place, nor how pervasive was the belief that visiting the LAB would confer nerd status amongst peers. This information would certainly provide a clearer picture of the tension, but the fact that some students held these beliefs means that there is at least a picture.

Though it is troubling to consider the tension suggested by students avoiding the LAB for fear of being considered a nerd, the fact that self-identified nerds felt comfortable in the LAB suggests a promise of makerspaces for nerds to have a place to call home. As nerds are referred to as "antisocial" as a core attribute of their identity (Kendall, 2000, 2011; Varma, 2007), if the LAB provided so-called nerds with a social environment with connections to a community of like-minded students, this would imply an evolution of the typical identifiers of nerds. The number of girls involved in "the Ultimate Nerd Club" suggests a further promise, especially given how nerd culture is associated with males (Kendall, 2000; Varma, 2007). Ultimately, school makerspaces have the potential to be more than fabrication labs, and serve a crucial function within the school environment as uniquely social environments where students connect over shared interests.

A further promise suggested by this tension relates to how the activity of the Ultimate Nerd Club shifted into a maker-centered one with the addition of modifying Nerf blasters in the second year. This activity is more aligned with the use of the makerspace, and the fact that the club generated a maker-oriented activity that still fit with the club's purpose demonstrates a potential for makerspaces to infuse interest-driven activities with making.

Chapter 8: Conclusions, Implications, and Recommendations

In this dissertation, I sought to understand the unique tensions that manifest when a high school establishes a makerspace. With this goal in mind, in the preceding chapters I presented narratives that describe a few tensions that manifested during my two years of fieldwork in the LAB.

To conclude, I will focus on the implications of my research. I will begin the chapter by briefly reviewing the tensions and promises that I discussed in previous chapters. This will provide a background for discussing the educational implications that follow.

I will then proceed to consider educational issues, as they relate to the tensions and promises in the LAB, adding slightly to my analysis. I will split this discussion into two sections both directly related to education: implications for research and implications for practice.

Lastly, I will consider some limitations and needed improvements to my study, before concluding with some thoughts on the importance of researching learning in makerspaces and other informal learning environments.

8.1. Conclusions

In order to provide a background for the discussion of educational implications, a summary of the work I have done up to this point is necessary. For this research study, I sought to understand the tensions that manifest as a result of establishing a makerspace on a school campus. Over a 2-year ethnographically informed research study, I observed and documented activity and participation within a high school makerspace. As a full participant of the culture I was studying, I utilized traditional ethnographic methods, including writing up observations and reflections in my field notes, interviewing twelve LAB participants, and collecting artifacts. After collecting this data, I used an Activity Theory analytical approach in order to identify evidence of tensions, which included signs of conflict in the form of conflicting situations, messages, or demands. Finally, I relayed four narratives that allowed for a discussion of the evidence of the exposed tensions.

The four narratives allowed me to dissect the tensions within the LAB as they developed, as well as analyze their associated internal contradictions and promises for the makerspace. I next present summaries of the narratives and their associated tensions and promises.

8.1.1. Conflicting visions for the LAB

The first tension I described in this dissertation related to the competing visions for the makerspace. In this narrative, I described how the different visions that participants held for the LAB contributed to an overall tension. During the establishment of the LAB in summer 2015, I encountered competing visions for the space from both the donors and the high school principal. One donor envisioned the LAB as a place for invention and entrepreneurism, while the other donor imagined a place for students to interact with innovative technology. The high school principal believed that the makerspace was a STEM learning space. As the director of the LAB, I worked to establish a vision that was open for all kinds of pursuits, none solely related to STEM, entrepreneurism, or innovation.

These discordant visions resulted in conflicting messages sent to the school community as to the usefulness and value of the space, as evidenced by the different visions that students held for the LAB. The tension that resulted from the competing visions for the makerspace was further explored by discussing a biology class project that took place in the LAB during December 2015.

This project was marked with conflicting demands placed on me as the director, and on the LAB as a setting for the project. These demands ultimately led to undesirable courses of action. The project was also marked with conflicting messages about the utility of the LAB as a place where real learning happens versus a place where one can spend the week before a holiday in order to avoid introducing new classroom material.

The biology project discussed in Chapter 4 highlights the issues that can result from excluding some parts of the school community, including the faculty, in the formation of a unified vision for a makerspace. I contend that not including the faculty in the formation of the LAB's mission could have led to their not utilizing the space. If the makerspace could see more integration with classroom use and projects, it may enrich academic pursuits and perhaps increase the reach of the spaces and its population of users.

The promises associated with these tensions include: the potential for makerspaces to unify visions of learning and work activity within a school community, the generation of donations and grant monies, and the prospect of schools establishing informal learning spaces.

8.1.2. Gendered patterns of participation in the LAB

The tension I explored in Chapter 5 concerns the gendered patterns of participation in the LAB. I presented the evidence of discord around the inclusion of girls in the space during the formation of the LAB. This included comments made to me by the principal about ensuring that the makerspace did not become a "boys club," as well as comments from the original donors about welcoming girls. Additionally, within the first weeks of the makerspace's September 2015 opening, I addressed the school community during an assembly and implored more girls to participate in the LAB, suggesting that they could sign up to be student assistants.

I then explored the story of the "Women in Tech" club and campaign that were started by a student manager named Karen. With my sponsorship, Karen created the club in response to the male-dominated culture of the LAB. She described the makerspace as a "sausage fest" owing to the large number of boys who participated in the LAB. Karen made posters to encourage girls to visit the space, and held weekly meetings to discuss how girls could feel more comfortable when participating in the LAB. In addition, Karen lobbied successfully to change the name of an automated text "bot" in the LAB's SLACK messaging app from Phil-bot to Jamie-bot, and later customized the Jamie-bot to generate random Internet memes about feminism. Karen's actions represented a promise for makerspaces to be school settings where girls can address aspects of the culture, which reify dominant male behavior. Karen’s engagement in the LAB slowly trailed off as she joined a select choir at school.

After telling the story of the “Women in Tech” club, I presented a short description of another female student in the LAB whose resistance to the male-dominated culture of the space was less overt than Karen’s. Priya was described as a “monster” by one of her male classmates, and this designation struck me as important, given how girls in STEM have traditionally had to outperform their male counterparts in order to receive recognition. Priya attended Karen’s “Women in Tech” club meetings, which shows that she was aware of the same tension that Karen resisted. In contrast to Karen, Priya’s engagement with the LAB grew over time.

Finally, I explored the troubling patterns of gendered participation over the two years whereby there were consistently more boys in the LAB working on individual projects and serving as student assistants. My analysis of this tension identified the internal contradiction as underlying conflict that girls feel due to the male-dominated culture of the makerspace. This puts girls in a conflicting situation in which they must either ignore or resist the male-centric culture of the space.

The promises related to this tension include: the potential for makerspaces to increase female participation in STEM, the promise suggested by the administration, donors, and LAB director’s commitment to focusing on the STEM gender gap, and most notably the potentiality that is suggested by Karen’s resistance to the male-centric culture of the LAB.

8.1.3. Group politics and conflicts over space

In chapter 6, I explored the tensions that manifested in the LAB as a result of the naturally occurring-conflicts over space. To provide context for the chapter, I began by exploring the evolution of the spatial arrangement of the LAB over the two years of my research study. Most of the changes to the space's arrangement did not result in noticeable tensions, except for the expansion of the LAB during the summer of 2016 and the designation of a table in the space where students could work exclusively on drones. I explored the creation of this dedicated space, called the Drone Zone, which provided evidence of different tensions, all related to competition over space and group politics.

Throughout most of the 2-year research study, there was a group of students who spent much of their time in the LAB dedicated to customizing and fixing drones. After expanding the size of the LAB during the summer of 2016, these drone builders (all boys) spent even more time in the LAB working on their drones and as their participation increased, so did the daily mess that they would leave behind on the worktables. A group of four other students (2 boys and 2 girls) coalesced as a result of their mutual frustration with the drone builders' unwillingness to clean up after themselves.

The tension between the two groups was marked by conflicting messages as I emphasized to everyone except the drone builders the importance of cleaning up, and the tension culminated in an aggressive action by one of the students to hide a drone by hanging it from the ceiling. After this incident, I created the Drone Zone in an attempt to eliminate the tension. While this solved the problem locally, it created another problem because I empowered the group of drone builders by allowing them to appropriate physical space within making grounds.

After making the Drone Zone, the four students who had opposed the drone builders were unhappy with my action, suggesting another tension had manifested due to my privileging the drone builders. This tension is more problematic to me because I worry that by privileging the all-male drone builders, I could have exacerbated the tension explored in Chapter 5 related to the girls' experience in the LAB. Taken together, all of these tensions illustrate the continuous dilemmas of negotiating the practical function of the space while supporting all makerspace users in their deeply passionate pursuits.

The promises that are related to these tensions include: the potential for makerspaces to serve as settings where students can engage in meaningful pursuits of shared interests, and the increasing size and material infrastructure of the LAB suggests a promise for makerspaces to expand and potentially involve more students.

8.1.4. The nerdy makerspace

The last tension that I explored using an activity theory analytical approach concerned the association of the LAB with so-called nerds. As the tension was due to the LAB being perceived as a nerdy place, I presented supporting evidence in the description of a popular student club that met regularly in the LAB: "the Ultimate Nerd Club".

"The Ultimate Nerd Club" was a student club that celebrated nerd culture. Throughout the two years of my fieldwork this club met at the LAB at least once a week, with the president of the club making school-wide announcements about these meetings. During club meetings, boys and girls would play role-playing games like “Dungeons and Dragons,” board games, and video games. During the second year, club members engaged in modifying Nerf Blasters and had large Nerf battles on the school campus.

After describing “the Ultimate Nerd Club”, I discussed the viewpoints from participants in the LAB that referenced the LAB being considered nerdy, or that nerds were the typical users of the space. I presented interview data from a student named Johnny who suggested that many students thought exclusively nerds visited the LAB, and these students would not visit the LAB because it was considered a nerdy thing to do. A regular visiting teacher to the LAB, Mr. W, said during his interview that he thought the typical users of the LAB were nerds as well.

With this evidence of an association of the LAB with nerd culture, and nerds, I explored the tension suggested by Johnny’s statements that some students would never visit because it was considered nerdy to do so. The tension is marked by conflicting messages sent to the student body that the LAB was either a home to all students or a home only to nerds. This tension illustrates how the perceptions of a school space’s culture can affect the participatory rate of involvement for that space.

The promises related to the tension discussed in Chapter 7 include: the prospect suggested by the large number of girls who participated in “the Ultimate Nerd Club” when it comes to challenging typical nerd culture, the potential for makerspaces to provide a home for students on campus that otherwise have nowhere to socialize, and the promise that is suggested by the social nature of the nerd culture in the LAB which troubles the typical nerd identity.

8.2. IMPLICATIONS

My ultimate aim for performing the sort of expansive research that Engeström (1999) describes involves using the discovery of contradictions and tensions to evolve the activity system: "Expansive developmental research aims at making cycles of expansive transition collectively mastered journeys through zones of proximal development. In other words, it aims at furnishing people with tertiary and secondary instruments necessary for the master of qualitative transformations of their activity systems" (Engeström, 1999, p. 296). I interpret this to mean that the point of expansive research is to involve the participants in the activity system to confront the double binds, as well as address the elements and connections within the activity system that should evolve in order for future iterations of the activity system to be expansive.

The writing, and ultimately the publication, of this dissertation is thus necessary to enable the current and future communities of the LAB (and other school makerspaces and informal learning spaces) to identify and address any similar tensions within their activity systems. Furthermore, the framing of the implications of my research must relate to the tensions that I have identified as having manifested during my time as the director of the LAB. For each of the tensions, I will first discuss the implications for educational research, and then turn my attention to the implications for educational practice.

8.2.1. Implications – conflicting visions for the LAB

Initially, I will discuss the implications for future research that relate to the tension that manifested due to the conflicting visions for the school makerspace. I will describe the conflicting visions for the LAB that I identified earlier, and relate them to the three branches of Maker Education programs that the U.S. National Research Council delineated based on their review of educational literature on making and makerspaces in schools (Vossoughi & Bevan, 2014). Finally, I will discuss what recommendations are implied from this tension.

The original donor, Jake, envisioned a LAB that served as a hub for entrepreneurship, and this aligns with what the research community identifies as one of the three branches of Maker Education programs: Making as *entrepreneurship* (Vossoughi & Bevan, 2014). This vision suggests that makerspaces "are fundamentally organized to support the production of things – providing machines and other types of tools, such as 3-D printers, that may not otherwise be accessible" (Bevan, 2017, p. 79). Again, Jake hoped the LAB would allow budding entrepreneurs to make prototypes, and his donation was for the procurement of 3-D printers, 3-D scanners, and other tools for production, some of which he utilized himself. Jake's vision thus embodies Making as *entrepreneurship.*

The vision held by the high school principal Stephen (and others) was that the LAB would serve as a STEM learning space. This vision is analogous to the second branch of Maker Education programs identified by the U.S. National Research Council which emphasizes *STEM workforce skills* (Vossoughi & Bevan, 2014). Typically, programs that emphasize STEM workforce skills are found in secondary and post-secondary schools and involve design and fabrication projects in order to develop 21st-century skills such as problem-solving, critical thinking, and collaboration (Jenkins, 2009; Santo, 2011). STEM Maker programs may infuse engineering principles and instruction into Maker activities (Martin & Dixon, 2016). As Stephen envisioned the LAB doing, some STEM Maker programs are designed with a goal of expanding and diversifying the 'STEM pipeline' (Bevan, 2017).

My vision for the makerspace was one of openness and I resisted defining a programmatic emphasis or alignment. In this regard, my vision would be most closely related to the third branch of Maker Education programs: *educative* Making (Vossoughi & Bevan, 2014). Educative Making programs are typically found in primary and secondary schools and share "broader goals of developing students' interests, capacities, and productive learning identities" (Bevan, 2017, p. 80). Educative making depends on Maker pedagogies that Vossoughi et al argue infuse STEM concepts and practices in organic ways, and treat learning as a purposeful and social endeavor that cultivates play, imagination, and creativity (Vossoughi, Escudé, Kong, & Hooper, 2013). With this context in mind, it is discernible that my vision related most to educative Making.

With each branch of Maker Education correlating to different visions that stakeholders had for the LAB, exploring the natural tensions between the three branches might catalyze an understanding of the tension that emerged from those competing visions. Bevan (2017) describes the different branches of Maker Education as requiring different resources, instructional supports and pedagogies, and most crucially, different foci. The focus of entrepreneurial programs is on "the creation of products designed to address a market need" (p.83), while the focus of STEM Making programs is on 'pre-collegiate engineering skills and role models" (p. 83), and the focus of educative Making programs is "more on interest and identity development" (p. 83). There are clearly overlapping goals and processes for the three types of programs, but their different foci conflict in a fundamental way. An educative making program that is focused on interests and identity development would conflict with a STEM program or an entrepreneurism program if a student has no interest in those paths. Further, the different instructional supports necessary for entrepreneurship and STEM programs would likely result in conflict for this student, forced to learn topics in which they have no interest and do not consider core to their identity development.

Of the three branches of Maker Education, the curriculum of Making programs associated with STEM learning is most apparent in the biology class project, which emphasized project-based activities that involve innovative tools like 3-D printers (Bevan, 2017). However, STEM Maker programs are based on a vision for Maker Education, and the project-based activities should be designed with this vision in mind. The biology class project was not based on a shared vision for the LAB, or even a shared vision of the purpose of the project itself. It makes sense that there were conflicting messages and demands throughout the project given that it lacked a unified vision permeating it.

The tension fomented by conflicting visions for the school makerspace elicits several recommendations for future research. If a tension manifested in the LAB due to conflicting visions for the space, it is important to research the three branches of Maker Education and evaluate these visions for signs of implicit conflict and tensions. Hence, the first implication for educational research is further exploration into the varying types of Maker Education programs with special attention to distinct programmatic goals and supports. This research might reify what was implied from my research, i.e. that the varying visions for the Maker Education programs have inherent contradictions.

Another recommendation for research implied by my results would be further study into the educational realities of school makerspaces that are more akin to community-based and post-secondary makerspaces. Typically, K-12 school makerspaces are organized to "provide supervised and structured educative activities that may change from day to day or week to week" (Bevan, 2017, p. 80). The LAB was not organized in this manner, and I am left to wonder what effect the openness of the makerspace had on users' vision of the space. I would further suggest a comparative research study to contrast the different types of school makerspaces.

My recommendations for future educational practice center upon developing a shared vision for makerspaces. The LAB was approved and funded during a time when I was unable to solicit input from community members regarding the purpose of the makerspace. A primary recommendation for schools that are establishing makerspaces is to include diverse representatives of the school community to develop the mission and purpose of the space. This allows the school to determine its focus for Maker Education, and then develop the tools and instructional supports necessary for the makerspace programs to succeed. As I learned, it is difficult to establish a school makerspace that satisfies all three branches of Maker Education programs; thus, my recommendation is to focus on one, then work on educating the school community on the vision for that one branch.

Finally, a crucial recommendation for schools that want to establish (or have already established) a makerspace is to not underestimate the unique pedagogical approach that is needed for school makerspaces. Teachers and students must be educated on the pedagogies associated with Maker Education. These pedagogies demonstrably conflict with traditional school pedagogies, and in order for a school makerspace to thrive (i.e. be integrated into classroom use such that it enriches students' academic pursuits); teachers should receive training on the differing ways learning occurs in a school makerspace. An activity theory perspective could have teachers first identify the internal contradictions related to the central activity of participating in the makerspace, then develop new models for overcoming these contradictions.

8.2.2. Implications – the gendering of the LAB

I will now turn my attention to the implications for research and practice that relate to the tension that manifested in the LAB around the issue of gender. I will describe the internal conflict that girls experienced in the LAB and relate this to the experiences that girls find in STEM learning spaces, including those found in computer science programs at the post-secondary level. Finally, I will explore recommended research and practices related to this discussion.

Over the years, the number of boys who participated in the LAB far outnumbered the number of girls. Quantifiably, girls were underrepresented in the LAB. Karen, who believed it to be so male-centric that she developed the "Women In Tech" club and campaign to address the issue and to improve the space for girls, described the space as a "sausage fest." The culture of the LAB was not gender-inclusive, and I believe that the tension that manifested was due to the male-dominant culture of the space. In order to further understand how the culture in the LAB affected the participation of girls, I will explore the tension previously analyzed in comparison to the explanations of the STEM gender gap provided by Wang and Degol (2017) as part of their analysis of the last 30 years of research into this troubling phenomenon.

Researchers Wang and Degol (2017) reviewed 30 years of research on the STEM gender gap and summarized the following six explanations for the underrepresentation of women in STEM fields: (a) cognitive ability, (b) relative cognitive strengths, (c) occupational interests or preferences, (d) lifestyle values or work-family balance preferences, (e) field-specific ability beliefs, and (f) gender-related stereotypes and biases (2017). I do not have the evidence to warrant a discussion about cognitive ability, occupational interests, and field-specific ability beliefs, therefore I will limit my comparison of the tension in the LAB to the explanations concerning the sociocultural factors the researchers identified: *occupational interests or preferences*, *lifestyle values or work-family balance preferences*, and *gender-related stereotypes and biases*.

Wang and Degol (2017) observed that girls vary from boys in their interests in STEM occupations and that the gender differences in work preferences and occupational aspirations are established as early as middle school, with fewer girls aspiring to STEM careers than boys. The researchers suggest that due to women's greater preference for socially-oriented occupations, fewer girls opt for STEM careers, believing them to be "incongruous with communal goals" (p. 124). This provides an interesting connection to Karen's experience in the LAB, as Karen was a student manager in the LAB, and a leader of a schoolwork program. What can we make of Karen's interest in working in a LAB that many would consider a STEM learning space?

The next sociocultural explanation that Wang and Degol (2017) provide for the STEM gender gap is *lifestyle values or work-family balance preferences*. The authors describe a variety of studies that theorize that girls do not participate in STEM at the same rate as boys because girls believe that STEM fields are incompatible with having children. Viadero (2009) speculated that women do not choose STEM careers because, "they perceive them to be less compatible with the family lives they hope to shape for themselves" (p. 1). This explanation for the STEM gender gap is difficult to contrast with the gender tension in the LAB because I neglected to ask any of the girls for their estimation of their ability to juggle a future career with a hypothetical family. I have no evidence that the underrepresentation of girls in the LAB was due to an anticipation of future family lives.

The final sociocultural explanation for the STEM gender gap that I will explore in relation to the gender tension in the LAB is *gender-related stereotypes and biases,* which seem most connected to my analysis. Wang and Degol (2017) ground their discussion by reporting on a study by Ceci et al. that reviewed the literature for evidence of consistent or discernible favoritism of males across various STEM academic fields (Ceci, Williams, & Thompson, 2011). Ceci et al. (2011) could not find any remarkable patters of discrimination or bias against women and concluded that prejudice and discrimination towards girls in STEM is a historical phenomenon and not a current one. However, Wang and Degol (2017) note that the researchers did not distinguish between overt and covert forms of gender discrimination.

The covert forms of discrimination described by Wang and Degol (2017) included parents and teachers underestimating girls' math ability relative to boys, parents and teachers encouraging boys more than girls to pursue math and science, and encouraging the belief that boys' performance in math and science is more due to effort than is girls. They observe that the stereotype in the U.S. that girls are not as capable in STEM begins as early as six, while Cvencek et al. (2011) found that boys and girls in the first and second grade exhibit implicit and explicit gender-math stereotypes in which boys were more likely to associate math with their own gender than with girls.

Perhaps an effect of the covert forms of bias on which Wang and Degol (2017) report, researchers have shown that girls adjust their preference for STEM based on their social group, opting to retain their preference for STEM when other girls in their class also liked STEM (Raabe, Boda, & Stadtfeld, 2019). This social pipeline is not necessarily an explanation for the underlying issue of underrepresentation of girls in STEM, but it is offered as an explanation for the STEM gender gap's continuation.

Wang and Degol (2017) summarize how the implicit biases in STEM contribute to the gender gap, declaring: "although parents and teachers may not be consciously or intentionally perpetuating stereotypes, the gender experiences that girls have with math and science are likely sending the message that math and science are male dominant" (Wang & Degol, 2017, p. 128). The effect of male-dominant cultures in STEM learning spaces is evident in computer science programs where Cheryan, Plaut, Davies, and Steele (2009) have shown that the male-dominant culture dissuades women from participating, and additionally, that removing stereotypically masculine objects from Computer Science programs actually leads to more female interest and participation.

Karen's goals in creating the "Women In Tech" club were twofold: to increase the perception of girls' preference for technology, and to address the male-dominant culture of the lab. Both of Karen's reasons originate from biases that imply male-dominance in STEM. Karen was direct in her assessment of the culture of the LAB – it was "a sausage fest." Her choice of words not withstanding, we should give weight to Karen's assessment of the LAB's culture. Despite the commitment from the director of the school makerspace, the donors of the space, and the administration of the school to make the LAB a place that girls would visit just as much as boys, they simply didn't. In my analysis of why girls were less likely to use the LAB, I conclude that a probable reason is the LAB's dominant male culture. Wang and Degol (2017) provide a similar conclusion for why girls do not pursue STEM fields in the same numbers as boys: "gender stereotypes and implicit bias may dissuade many girls from even pursuing STEM fields in the first place, thereby effectively keeping male-dominated fields 'male-dominated'"

(p. 129). Makerspaces have the unfortunate potential for devolving into boys clubs, which correlates with white males representing the dominant culture in popular maker literature (Chachra, 2015).

Next, I turn to exploring recommendations for future research and practice based on this discussion. Ultimately, I propose further research into the culture of makerspaces. Because the male-dominant culture of the LAB contributed to the buildup of the gender tension in the LAB, I recommend further ethnographic studies that investigate the impact of dominant cultures within these spaces. There is already research into adolescents' perceptions of the gender and racial barriers to STEM that reports trends of microaggressions and microinsults within the broader sociocultural context of STEM classrooms (Grossman & Porche, 2014). Narrowing this research to focus on the perceptions of gender bias in makerspaces would likely add context to the conversation around STEM participation.

I would also recommend further studies into the programmatic makeup of K-12 school makerspaces with focus on understanding the kinds of activities being done in makerspaces, as well as the demographics of students served by these activities. As I discussed in Chapter 5, a girls' individual project in the LAB was most likely to be an art project, and this suggests that promoting art activities in school makerspaces will lead to more girls participating in these spaces. An interesting research question might be whether makerspaces that are aligned with STEAM programs, versus simply STEM programs, report higher rates of participation among girls.

In terms of educational practice, I must recommend that schools with makerspaces ensure that they are not perpetuating implicit gender bias or discrimination with the programs and activities offered in the space, and that they continually evaluate the space's culture for gender-inclusivity. Karen's alterations to the SLACK messaging bot (changing the name, customizing the bot to generate feminist memes) seemed insignificant in scale, but these little things contributed to creating a more gender-inclusive space in the LAB. Schools that have makerspaces should look critically at their unique cultures and develop metrics for ensuring gender inclusivity. Involving students in this process would allow them to identify problems based on internal contradictions and tensions and develop solutions to them.

8.2.3. Implications – group politics and the conflict over space

The tensions that defined the episode of the Drone Zone discussed in Chapter 6 were based on naturally occurring conflicts over limited space in a school-learning environment. These disputes laid the groundwork for the tension that manifested when I created the Drone Zone, effectively endorsing the activity of one group of students (drone builders) above others. Although I was responding to the rising tension between groups of students, I empowered one group of students above others, based on my belief that the interest in drones was beneficial to both students and the LAB. This is similar to the ethnographic study conducted by Leander (2002), who showed how social spaces played a role in silencing one student in an American History class while privileging others.

In order to situate the implications of the Drone Zone tension that arose from the spatial arrangement of the makerspace, I turn to Ma and Munter's (2014) research into the ways skateboarders "edited" space in skateboard parks. The researchers paired a sociocultural perspective with an ethnographic methodological approach to understand how skateboarders "edit" skateboard parks to provide learning and teaching opportunities. The researchers' findings "reveal how learning was accomplished in these two skateparks, settings with little formal, top-down organization for activity or for learning" (Ma & Munter, 2014, p. 256). Given the similar structure of the LAB, the findings of Ma and Munter would ground an extended ethnographic study into the ways LAB users edited the space. I did not explore the ways makerspace users edit their space for learning, but that was due to a lack of data connecting the editing of spaces to learning. I was able to explore the tensions that manifest in a learning space when users compete for space, and I believe the next step in researching the spatial arrangement of makerspaces is how makerspace users "edit" their spaces. The implied methodological approach for such research would be ethnographic in nature. It would be interesting to explore the short- and long-term spatial arrangements of makerspaces in order to better understand how students use these spaces for learning and teaching.

Another recommendation for future research would be to explore the ways makerspaces are used for interest-driven pursuits. Makerspaces have come to be used by educators as fabrication labs for robotics and engineering design competitions, e.g., it would be interesting to quantify the effects of empowering these clubs within making grounds. Perhaps this research could be grounded using the Lines of Practice theory offered by Azevedo (2013a, 2013b), in which persistent engagement in a practice stems from how interest in that practice is made meaningful in a person's life.

I have come to understand how creating the Drone Zone contributed to the development of further tensions in the LAB. My recommendation for educators in charge of makerspaces is to be judicious when arranging the space so as not to privilege a group of students within making grounds. Practitioners should heed the lessons I learned from dedicating space for making. Changes to the spatial arrangement should emulate the deliberate, purposeful way I approached changes to the arrangement of the LAB prior to the Drone Zone incident.

8.2.4. Implications – the nerdy makerspace

Lastly, I now turn to the final tension I described in Chapter 7 resulting from the LAB being associated with so-called nerds. In order to situate the implications, I recount both the available research that relates computer science programs with nerd culture, and research that concludes that the nerdy culture of computer science programs can be a barrier to participation, especially for women.

As I mentioned in Chapter 7, the association with a nerd identity does not define a tension, but the implication that non-nerd students avoided participation in the LAB because they thought it was nerdy does suggest a systemic tension. This is related to the systemic tension that manifests in computer science programs, which researchers have concluded largely typify nerd culture (Cheryan et al., 2009). This association has been shown to effect participation for nerds and non-nerds alike (Brown, 2002; Cheryan et al., 2009; “More women pick computer science if media nix outdated ‘nerd’ stereotype,” 2013). A possible reason for the limited female participation in Computer Science programs is that women viewed computer scientist traits as incompatible with the female gender role (Cheryan, Plaut, Handron, & Hudson, 2013).

In light of this research into the potentially damaging effects of computer science programs on participation, I must accept the suggestion that the makerspace’s associated nerd culture limited participation. I must take it all the more seriously given the research into the nerd culture of Computer Science programs association with elements of dominant male culture. Even though the LAB was not a computer science program, examining its culture for similarities to those programs provides an understanding of how the culture of the LAB might dissuade participation. This correlation was seen when Kendall (2000) used an online forum (BlueSky) to delineate the implications of the nerd identity’s relationship to hegemonic masculinity, concluding that the white nerd masculine identity was “congruent with related forms of masculinity found in computing and engineering fields” (p. 271).

The LAB’s population was male-heavy since its inception, and combined with the view held by some that it was a nerdy place; this suggests a troubling connection to the hegemonic masculine culture that Kendall (2000) describes as prevalent in BlueSky. A hegemonic masculine culture would be one that legitimizes male dominance in order to justify the subordination of women, which necessitates reflection on the culture of the LAB to understand how elements of hegemonic masculinity might have developed over time.

Most worrisome is the intersecting evidence that suggests that the culture of the LAB legitimized male dominance in order to justify the subordination of women, at least to some degree. Karen recognized and attempted to improve the components of the LAB's culture that she saw as masculine, but given the associated masculine culture embedded in places associated with the nerd identity, I worry that the nerdiness of the LAB was just more evidence of hegemonic masculinity.

My first recommendation for research is continued study into the culture of makerspaces, especially as related to elements of nerd culture. Researchers might build on my efforts combined with the earlier studies into computing and engineering fields referenced here. I would recommend further ethnographic studies in K-12 school makerspaces to determine how closely related these spaces are to post-secondary computer science programs. Therefore, my ultimate recommendation for research would be further investigation to determine elements of hegemonic masculinity in the culture of makerspaces.

It is noteworthy that my exploration of "the Ultimate Nerd Club" suggests that it was welcoming to girls, thus I would encourage further research into the nerd identity in informal secondary school environments. I found it interesting that girls were involved in "the Ultimate Nerd Club" but did not embrace the more technical aspects of the club, e.g. modifying Nerf Blasters. I would recommend further research into computing and engineering clubs and programs like Robotics programs in order to better understand the patterns of gender representation.

In terms of educational practice, I highly recommend that educators in charge of makerspaces and maker education programs attend to the gender-inclusivity of these spaces. I implore maker educators to address elements of dominant culture that limit participation. I am reminded of the research of Parsons (2005), who followed a white teacher as she actively addressed elements of white, dominant culture that affected the participation students of color. This teacher caringly pushed back against her white students when they subconsciously attempted to assert their dominance in her classroom. In the same vein, I believe that maker educators can caringly push back against the dominant cultures trying to mold their makerspaces.

8.3. LIMITATIONS OF THE STUDY

This ethnographically informed research study took place over the course of two years in a natural school setting. Throughout the research study, I served as director of the high school makerspace in question, and thus I was a fully invested participant in the culture described herein. Implicit in the preceding two sentences are limitations for my research study regarding data collection. First, collecting data over the course of two years produces a large amount of data, the analysis of which was arduous work. That I was the only one responsible for collection and analyzing this data could be considered a liability. Second, since I was a fully invested participant in the culture and there were countless activities and forms of participation in the LAB, there is no way I could have documented them all.

A further limitation of my study stems from my relative inexperience with ethnographic methods. I was provided excellent advice and support by my dissertation advisor, whose knowledge and experience with ethnographic methods is well known. However, my inexperience with the complex and difficult nature of ethnographic research is limiting.

The LAB is unique among school makerspaces in many ways: it was a drop-in makerspace available anytime before, during, and after school, and a corps of student managers and assistants helped run the space. Noting also that the LAB is a makerspace on the campus of an affluent private high school, a final limitation of my study becomes apparent: the setting's atypical nature among educational spaces. Because they are on school campuses, school makerspaces are more restrictive than community-based and post-secondary makerspaces in what users can do, and when users can access them (Bevan, 2017). As I mentioned throughout this dissertation, I developed the LAB to be reminiscent of makerspaces found off school campuses as possible. This was due to my research goal of understanding the participatory nature of makerspaces, but the reality that I have to confront is that most K-12 school makerspaces do not resemble their unaffiliated counterparts.

8.4. CONCLUDING REMARKS

Through this dissertation, I have attempted to identify the tensions and contradictions that manifest in a school-based makerspace. I want to specify that I am not interested in tensions in a punitive sense. Rather, I believe that in order to improve any activity system, one must attend to those elements that prohibit its continued evolution. I believe that tensions manifest within any activity system, and makerspaces are no different. The tensions I have identified in this dissertation do not imply that the LAB is not a legitimate learning space; instead, the tensions represent potentialities for the LAB, and highlight areas of concern.

I have been interested in alternative learning spaces most of my time in academia. As an educational reformer, I believe that we should be continually searching for new models of learning spaces because our current traditional school system is in need of serious reform. I hope to inspire future educators to push the boundaries of what they think defines their educational career. For many years, I cultivated relationships and established myself as an educator in the hopes that one day I might be given the opportunity to develop a new learning space that was unlike the classrooms in which I began my teaching career. I am proud to have established a makerspace on a school campus, and I encourage future teachers to pursue a similar path.

Before concluding this dissertation, I must thank the community of the LAB. During my time as director of the LAB, I developed bonds with students and teachers that will last throughout my lifetime. The LAB's regular visitors and I shared a connection that is hard to explicate, and my life has been forever changed by my time in the LAB.

Makerspaces still hold a promise to redefine our notions of learning environments, and the reformist in me wishes that there were more makerspaces (and other informal learning spaces like it) in K-12 school settings. However, I also worry about establishing makerspaces in schools without properly understanding the educational realities of doing so. The many different promises that the maker movement and makerspaces hold for educational reformists must be weighed against the different tensions that they represent. This dissertation has been a modest step in this direction. At the least, I hope that my efforts will encourage more research into the learning that takes place within a makerspace.

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