Bridging the In-and-Out of School Divide: Lessons for Supporting Learning in Educational Makerspaces

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Makerspaces and the practice known as "making" (creating physical and digital projects through often interdisciplinary, hands-on practices) have sparked interest in the world of educational policy, research, and practice as an opportunity for improving youths' motivation to engage with: science, technology, engineering, and mathematics (STEM), social-emotional learning, creativity, equitable learning, and more. The full extent of making's potential as an education practice is not yet known but continues to be explored both in and out of schools. Through three successive studies, I explore the learning taking place in both in-and-out of school environments and discuss the lessons learned in both settings for understanding and improving educational maker practice across contexts. The first study consists of a gap analysis of prior research literature related to educational making for youth across contexts to inform measurement of learning in schools and research. I identified the gaps between what learning has been measured in research, by what means, for which populations, and categorized learning outcomes based on practices the literature has indicated are critical to the making process. This sparked the need for a deep investigation into relatively unexplored practices that support learning to make and learning through making. The second study expanded upon learning outcomes identified in the gap analysis in an out-of-school setting, a makerspace based on a grant for STEM making in a transitional housing facility for young adults who have left foster care without the support of family, college,

and often employment. Through legitimate peripheral participation with a local maker community of practice, the makerspace supported the creative, entrepreneurial, and even therapeutic needs of the youths. The third study captures learning outcomes in a school makerspace. Students in a high school physics class worked as a team to compete locally in a drone-designing challenge and developed documentation practices to share ideas, learn from their mistakes, and get feedback. Taken together, these studies suggest that like youth, practices transform as they inhabit new contexts; a learning practice used in schools offers different affordances to the same practice out of schools. To measure and support learning in educational makerspaces or other learning contexts, one must understand both the educational practice and the larger organizational and cultural context that shapes it.

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Acknowledgements and Preface

Before I begin, I must first acknowledge those who have stood by me through this process. First, those who were there from the beginning: my parents, my siblings, my grandmother, and all the extended family who have cheered me on, prayed for me, and anchored me in stormy weather, and taught me to trust in the Lord, whatever may come. Second, I want to thank the many educators throughout my life who played a role in forming me and making me want to help make learning empowering and exciting for everyone, including: Dr. Sansone and the mentors in the C.L.A.S.S. program, the teachers from the many art and tech classes and clubs I attended growing up both in and out of school, peers and professors at the Rochester Institute of Technology, the professors at Loyola University Chicago who changed the way I saw the world, and finally the community I found in the professors and students at the School of Education and Learning Sciences and Policy program of the University of Pittsburgh. I would take up too many pages if I thanked by name every person at Pitt that lent me an ear when I wanted to talk through an idea or could not figure out what to do. Instead, I will thank my advisor, Dr. Kevin Crowley, who helped me reign-in and stay focused, my committee for their kind words, support, and invaluable feedback, and my cohort for always standing by me. I also want to thank the Forum for Youth Investment and my students in Educational Psychology for pushing the boundaries of my ideas and helping me remember that everything we do in research is only worthwhile if it reaches the teachers, educators, and other adults striving to support learning and development for youth everywhere. Finally, I want to thank Dutian Zheng and Dr. Tiffany Lumpkin for being sunshine on dark days and calming breeze amid turbulent chaos. I could not have done this without all your support. With that, I turn to my preface.

Education and learning have always been central in my life, simultaneously sources of tension and empowerment for my family and me, but it was a long time before I was able to disentangle the two in my mind. My k-12 education consisted primarily of low-resourced public schools where teachers and peers suffered a mutually contagious ennui towards the full rainbow of subject areas. I was not a fan of homework or classwork, but when I questioned the purpose of my daily suffering, my mother swiftly reminded me of the privilege I was taking for granted. Her mother came from Puerto Rico as a teenager to work as a housekeeper for distant relatives and send money to her family; once here, the family she cared for would not let her attend school or learn English. My grandmother fought for her education alongside my mother, studying together around the kitchen table with their family. My mother called education and the job opportunities that flow from it the "immigrant's dream"; she pursued her own dream of becoming a doctor, only to be underestimated by peers and professors as an "affirmative-action Hispanic" and eventually sacrificed her place in a medical program to care for her own family and work part-time as a nurse. She then did everything in her power to ensure that her own children would not be subject to prejudice, speaking little Spanish in the home, and oversaw every assignment we handed in to be sure that when it came time for us to graduate, we could go to any school we wanted and no one would question our place.

But how to be a good student was only one thing I learned from my mother. She had a bachelor's in microbiology and when I asked questions, she answered them. She *really* answered them. Certainly, she was at times too tired to say anything besides "because I said so," but she also explained so a curious child could understand how pathogens and microbes clung to the surfaces of fomites, life-saving information during a pandemic. She taught me how cooking and freezing temperatures differently impacted bacterial growth in perishable food. When her home-care patients were reluctant to follow protocols, she taught them, too. She piqued their curiosity and explained how medications worked in the human body, released chemicals at different rates, and how variables impacted the effectiveness of treatment plans over time. She taught them anatomy that they should have learned in school, and the practical value of cleaning practices. Teaching science to stubborn patients and children was a specialty of hers that left me wondering what she could teach schools about the gaps in their science curriculum and practices.

My father's relationship to education was different from my mother's. The son of a professor, his place in higher education was never questioned, and indeed guaranteed; from an early age, his father cultivated in him a philosophical way of being and knowing. Intrigued by knowledge and the European heritage of his family, my father studied French in college and became a high-school French teacher when he, like my mother, put further education on hold to care for their new family. He operated in the blurred space between learning as freedom and education as a mechanism of the seemingly capricious whims of policy and culture. Until his retirement, my father perpetually puzzled over ways to improve his practice, often testing them out on me, and even learned a second language when his school decided to phase out the French program. At home, he taught me the joy of engaging in rich, philosophical discussions about everything from economics to faith and inspired me to begin learning languages—including Spanish—on my own.

Long before they had money to spare on private schools, my parents cobbled together experiences and practices to cultivate each of us as learners, likewise devoting countless hours to molding us as accomplished students. They advocated for my siblings, who struggled when their school district took them from the relationships and communities they had cultivated to attend even lower-performing schools in the hopes of boosting test scores. When my youngest siblings were diagnosed with ADHD and Autism, my parents fought for accommodations in private schools under limited obligation to address the needs of students with learning disabilities.

For all of us, they did what they could with initially humble means to find opportunities to learn outside of school. That meant getting coupons and waiting for free days to take trips to museums to learn about impressionists, identifying planets in the night sky, and mineral formations. It meant enrolling us in elective summer school classes at local elementary schools so we could pursue interests and access resources that were unavailable at home and in our own schools. My parents pushed us to try community classes in sports and scouts to let us have the chance to build skills working on teams and develop physically as well as cognitively. When I fell in love with stories, my parents gave me hand-me-down books and art supplies and leftover notebooks from school supplies; I will never forget watching my father hunt-and-peck on an ancient typewriter while I dictated my first story.

They taught us to be curious, to research the answers to our questions, and to try without worrying about doing things *well*. Their tireless efforts shaped me to be the kind of learner who would be recognized as gifted and talented, and thus be given extraordinary opportunities in school, first in the C.L.A.S.S. program with Dr. Sansone, learning about Greek mythology and Papy's Minicomputer, later in advance-tracked classes and clubs, and finally in the form of scholarships and acceptance to higher education programs in film and animation, law, public policy, and the learning sciences, consecutively. But I am not the product of genius genes and sourceless potential. I am my parents' daughter, molded by their laughter, sweat, and tears.

This is a love letter to learning as much as to my parents. Out-of-school and at-home experiences with science, literature, foreign language, and art gave me a voracious appetite for learning and prepared me to endure the expectations and stress of nearly any academic program without wavering in the belief that I could do anything if I would only try and work hard. At the same time, I know that I only had those opportunities because my parents understood their value and the necessity of cultivating a mindset for learning, whether they had money to spend or not. Upwards of 50 million children in the United States are enrolled in public schools each year, but precious few have parents able and willing to focus so much of their time and resources on the formation of their children's love of learning, especially for students struggling with learning disabilities and the cultural disconnect of being remade in America's image, whatever that may mean. Over time, a nagging question grew in my mind; how could school be more like *learning*? That is to say; how could those practicing and designing environments in schools learn from the motivating, enriching experiences and relationships that can come from a supporting ecosystem of out-of-school and at-home experiences? I continue to ask this, not in effort to ask school to replace the need for out-of-school experiences, but rather to understand how to improve equity and learning for all youth with the acknowledgement that most children will attend brick-and-mortar schools, and the assertion that experiences they have there can either serve to bolster their trajectory as life-long, scientifically literate learners, or detract from it. Experiences that persist several hours a day for twelve or more years cannot be without effect, for better or worse.

I initially believed that changing education was a matter of changing law and policy, but when I studied both, I learned how detached the view of education policy was from *learning*. It had more to do with discipline, authority, and organization, all of which are important to school but not the foundation for equitable, motivating learning experiences. I learned, further, that policy change comes from salience, for which soundbites in the news are usually more compelling than empirical research, the natural consequence of a difference in barriers to consumption, interpretation, and affective response. I could not play a role in drafting legislation to the neglect of evidence, no matter how my personal experiences had convinced me of the value of out-of-school learning. My professors in the Learning Sciences and Policy program at the University of Pittsburgh have given me the tools to pursue questions whose answers can help us reshape the experience of youth and practitioners alike in education. Researching for a summer at policy action-tank the Forum for Youth Investment showed me that when research is both presented in a way that is salient, interpretable, and accessible across disciplines and shared in conversation facilitated between youth-serving organizations, research in education can shape policy and practice. Briefs like the 2019 report *From a Nation at Risk to a Nation at Hope* are changing the narrative from a stern culture of accountability and assessment to acknowledging the ever-growing body of research that shows how practices common in out-of-school settings show promise for transforming the social, emotional, and academic learning potential of schools for all children. Now is the time to ask questions like mine; What do we need to know about practices that are successful in OST settings to use them to promote equitable learning experiences in schools? The SEAD Commission (2019) stated in the report:

> The federal Every Student Succeeds Act passed in 2015 devolved a great deal of authority and power to states and communities—placing the future of education more directly in the hands of parents, teachers, and school leaders. This presents an obligation and an opportunity. Devolution creates an obligation on the part of adults to use their influence in creative, effective ways to serve every student. Local control is not a release from rigor and responsibility; it is the broader distribution of responsibility. This sense of obligation should extend to all of the adults who constitute a child's whole universe. Devolution also creates a tremendous opportunity to get beyond the rutted debates of the last generation and to seek solutions that are both hopeful and unifying. (p. 5)

The obligation and opportunity the SEAD Commission describe captures the responsibility of all those presently working to shape education policy and practice. On the one hand, research and policy in education within the United States have never been more focused on pursuing equity for the nation's growing student heterogeneity while simultaneously presenting opportunities for exploring the revolutionary power of informal practices in formal educational settings. On the other hand, the beauty and challenge of researchers as human instruments of discovery and, hopefully, truth lies in recognizing the bias of our own experiences. My parents', siblings', and personal joy and empowerment found in learning and barriers found in education inform where I see potential in the spaces and practices around me for guiding further research and practice. It is my obligation, opportunity, and privilege to be a contributing voice among myriad striving towards the same end, humble in the knowledge that I can only present what I have observed and analyzed in furtherance of education as a servant of equitable learning and development, and not an institution to its own ends.

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1.0 Overview

Learning begins at home and extends to a child's entire ecosystem; churches, schools, community programs, and so on (Barron, 2006; Bronfenbrenner & Morris, 2007). The quality, type, and depth of learning is dependent upon a number of factors that, primarily, come from a combination of the child, the setting, and the adults working with children to facilitate learning, such as socio-economic, historical, and cultural traits (Banks et al., 2007). For children that can access quality out-of-school-time (OST) programs, for example, OST learning opportunities include free choice, reflection, and collaboration and are often more motivating than involuntary learning experiences (Paris, 1997), sometimes even providing children with opportunities to practice skills and knowledge in real-world scenarios (Newell, 2005). Schools, on the other hand, are available to most children in the United States and offer stability, structure, and a foundation of knowledge, but factors like testing, funding differences, and accountability measures can diminish students' excitement and quality of learning (Herman & Golan, 1990). Together, in and out of school experiences can benefit a child's learning in terms of motivation and skill acquisition (Banks et al., 2007; Bonnette, Crowley, & Schunn, 2019), promoting life-long willingness towards education and self-empowerment (Day & Newburger, 2002; Liu, 2009).

But what if, instead, school were more like OST programs? The policy report *From a Nation at Risk to a Nation at Hope* celebrates efforts to incorporate OST practices into classrooms for their ability to improve social, emotional, and academic learning (SEAD Commission, 2019). In one example, the report describes the value of spaces for hands-on learning in every classroom within a school; as students used tools and materials to design projects, they developed "grit and persistence" and learned "they have to fail multiple times to get things right" (p. 48). The practice the report describes is called *making*, and the *makerspaces* it is often practiced in are an intriguing place to start when tackling the larger question of how OST practices can improve schools. This is because makerspaces can, seemingly, adapt to the needs and structures of multiple contexts, e.g. museums and community centers (Sheridan et al., 2014), schools (Tan, 2019), libraries (Slatter & Howard, 2013), higher education (Barrett et al., 2013), and even buses (Moorefield-Lang, 2015), and educators across these settings have used making for instructional purposes in multiple subject areas (Halverson & Sheridan, 2014). Consequently, the practice has caught the interest of education stakeholders globally (Irie et al., 2019).

As the *Nation at Hope* report recognizes, learning more about OST educational practices presents an opportunity for improving learning for children in schools. But, we cannot assume that practices that originated in OST contexts will remain the same in museums, libraries, schools, and community centers, benefiting children the same or even requiring the same teacher support. Thus, just as contexts shape youths' learning experiences, one must question how *practices* change from context to context, particularly one like making that can be mobile, adaptable, and has been used in a variety of school and OST settings for educational purposes. I begin my inquiry here, with the practice of making, and conduct a thorough investigation into what youth learning in OST and school makerspaces tells us about how contexts shapes practice.

1.1 The Maker Movement and Education

Making is a practice that some researchers and practitioners alike have been reluctant to define at the expense of excluding any disciplinary vein or cultural practice; others have drawn clear distinctions, establishing *technology* as the aspect of making that distinguishes it from other practices (Chu et al., 2015). At its broadest interpretation, making is a rebranding of the fundamentally human practice of creation, which has evolved with changes in culture and technology (Vossoughi & Bevan, 2014). MAKE: Magazine, the vehicle through which much of the current movement was branded and popularized, coined the term in 2005 according to their maker movement timeline. As represented in the magazine, the practice conjures images of people of all ages working with recently accessible technology like 3D printers and inexpensive Raspberry Pi computer processers (see https://makezine.com/). This privileges a view of making as a primarily STEM practice (science, technology, education, and mathematics) that reflects the cultural spaces of white, middleclass males (see Figure 1, below).

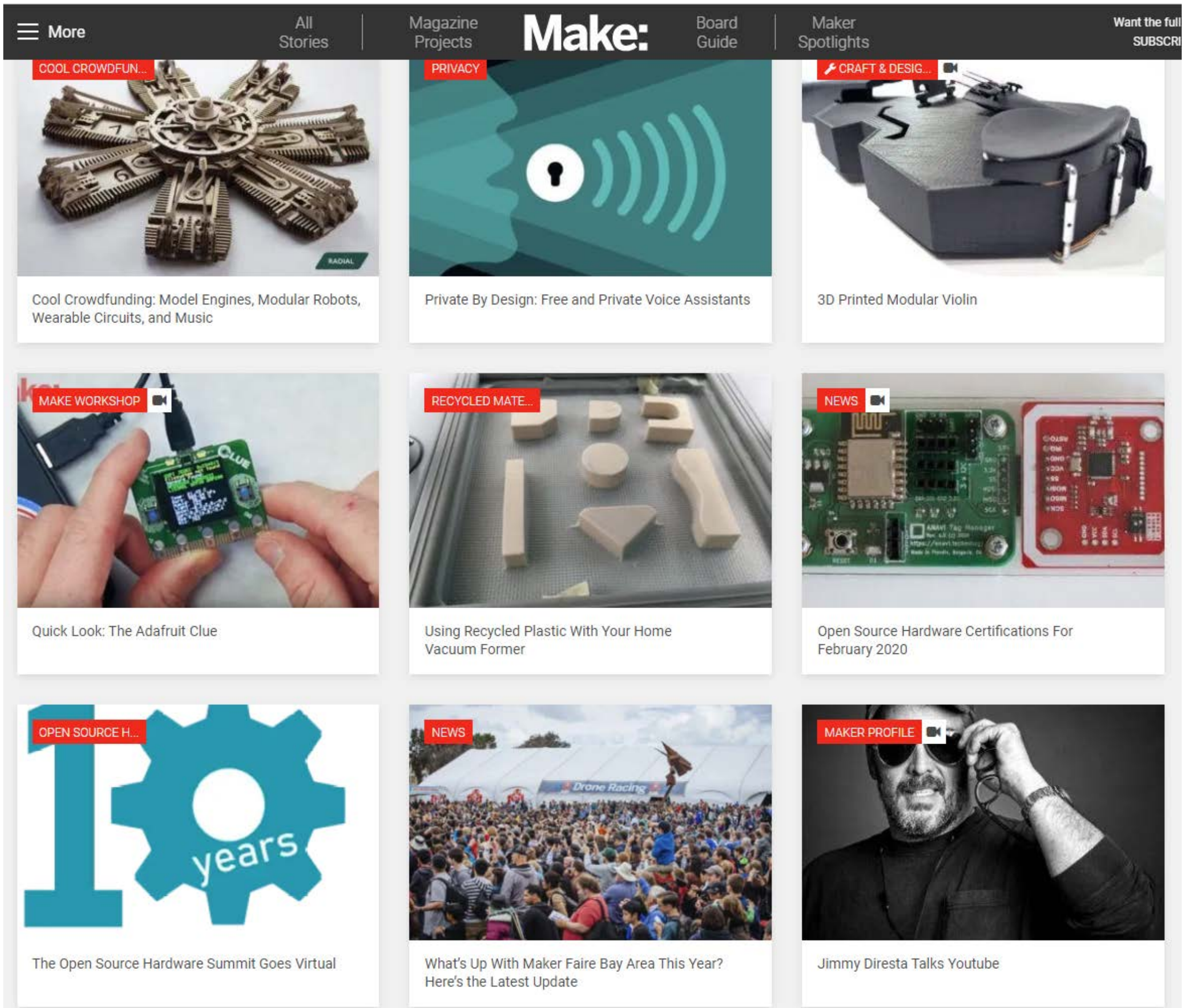

Figure 1 Screenshot of MAKE: Magazine posts demonstrates the website's often STEM-focused, masculine presentation.

Dougherty (2012), creator of MAKE: Magazine, described making as broadly as possible:

> When I talk about the maker movement, I make an effort to stay away from the word "inventor"—most people just don't identify themselves that way. "Maker," on the other hand, describes each one of us, no matter how we live our lives or what our goals might be. We all are makers: as cooks preparing food for our families, as gardeners, as knitters. (p. 1)

MAKE: Magazine seems to contradict the image, showing pictures of wires and 3D manufacturing on every page while separating craft practices into a sister magazine, CRAFT:

Magazine. Their questions-and-answers section characterizes making as follows: "The combination of ingenious Makers and innovative technologies such as the Arduino microcontroller, Raspberry Pi, and personal 3D printing are driving innovation in manufacturing, engineering, industrial design, hardware technology, and education." (https://help.make.co/hc/en-us/articles/204141849-Why-did-Maker-Faire-start-And-what-is-the-Maker-Movement-).

However, hobbyist and professional makers, researchers, and educators have also united arts, crafts, and varied cultural practices under the banner of *making* and worked to design equitable spaces for youth who do not identify with the cultural normativity presented in platforms like MAKE: Magazine (Vossoughi, Hooper, & Escudé, 2016; Martin, Dixon, & Betser, 2018). Projects in the aforementioned research have varied on multiple dimensions: low to high tech, e.g. advanced STEM projects in high schools (Tan, 2019); learner-derived or instructor-assigned, e.g. a task to design and assemble a light up flower (Sheffield et al., 2017); group or individual and long-term or short-term projects e.g. collaborative multi-disciplinary projects that cut across classes throughout a semester (Wallace et al., 2017); physical or digital products, e.g. animations produced on the online Scratch animation and game coding platform (Rusk, 2016); artistic or STEM-focused (Abrams, 2018; Sheridan et al., 2014); and cultural, crafting practices (e.g. Barajas-López & Bang, 2018). Makerspaces that reflect the practice presented in media like MAKE: Magazine tend to be skewed towards the white, middle-class males that started the movement, resulting in spaces that exclude girls and minorities and practices that may be cost-prohibitive for most schools. Choosing not to define making reinforces the power of the loudest voice to exclude disciplines and communities. Likewise, ambiguity makes it needlessly difficult to determine how maker research may generalize from one context to the next. I have endeavored, therefore, to present a definition that reflects the underlying theory and unique practices witnessed in much maker research, for the purpose of distinguishing making that shares traits leading to diverse learning outcomes from that which does not.

People learning by creating things that can be publicly displayed (Harel & Papert, 1991); this theory of constructionism builds on Piaget's constructivist theory of development, which states that people learn by doing. Constructionism underpins most educational maker research, and it is this definition, in concert with findings in research that associates making with learning, that I use to define educational making. Additionally, consider the following examples of projects observed in making research: a jacket African American girls designed to solve real, local problems important to them, which could call for help in the event of sexual assault or rape if the wearer stomped her foot (Greenberg & Calabrese Barton, 2017); and a keychain multiple children reproduced using professional-grade equipment after seeing one child's process for making keychains (Blikstein, 2013). In both cases, children are making something physical or digital. Both examples involve STEM practices, in the sense that both use technology to build their artifact; however, in the former case, youth approach the process of creation starting from a problem to solve with a unique solution to find. Additionally, the girls in Greenberg and Calabrese Barton's study combine electronics with fashion to find an interdisciplinary solution to their problem. This project exemplifies the power of maker education for student centered instruction, creativity, problem-based learning, equity, and motivation through autonomy and cultural relevance. If these are the kinds of outcomes we want to see exemplified in educational practice, the definition of making should reflect practices that result in these learning outcomes, rather than excluding non-STEM practices or including non-creative replication of others' designs. Thus, I distinguish hands-on learning practices that both reflect constructionism and present opportunities for creativity (e.g.

anti-rape jacket) from those that do not (e.g. keychain effect), regardless of whether the practices involved seem to be more focused in STEM, arts, or general creative self-expression.

As I define it, educational making is a practice in which youth learn by individually or collaboratively designing and producing digital or physical artifacts, especially when drawing on interdisciplinary practices or resources from a larger community of makers. In educational making, makers are not always responsible for the entire project process (Richard & Giri, 2017); this definition acknowledges that youth who engage in the various roles that comprise making may still benefit from the creative process (Cohen & Lotan, 2014). It is, additionally, important that the project involve *designing*, rather than replicating another's design or following a set of instructions to arrive at one set solution. When students engage in making, they can achieve conceptual growth and discover skillsets as an inherent consequence of working to reach an intended, perceivable goal, established either by students themselves or the teachers facilitating learning (Halverson & Sheridan, 2014). This is similar to student-centered instruction, where top-down lessons involve larger problems that students must find unique solutions to resolve (Brown 2008). This differs from direct instruction in schools, where measures of success often rest in students successfully replicating a modeled skill or proving the assimilation of a particular set of facts. Making is nothing so explicit and regimented. In addition to designing, youth must *produce* their designs to learn by making physical or digital artifacts, according to constructionist learning theory (Harel & Papert, 1991). Creating something that can be observed publicly combines acting to learn with an audience and a sense of permanence, which in turn allows for the possibility of feedback and public failure, a common part of real work and lessons that can provide support for learning or hindrance to motivation (Wigfield & Eccles, 2002). Finally, *interdisciplinarity* and *community* captures the unique maker practice of researching and combining skills and knowledge from across disciplinary distinctions typically drawn in a math or art class. Combining tools, materials, and disciplines is a common aspect of maker practice (Brahms & Crowley, 2016). Additionally, Make Magazine reports that makers often have interests that combine STEM, crafting, and design (https://make.co/maker-movement/). Although not necessarily present in all making, interdisciplinarity and connections to the community of practice of makers clearly distinguish making from other types of hands-on projects.

With this definition, one can see how the first child to create a keychain in Blikstein's example may have engaged in making, but the children that followed engaged in mere reproduction. This is not to say that their experience was without instructional merit. They learned how to use the same machine and learned one method for creating a keychain. But to enrich the field of research around maker learning, create more opportunities for generalizability in research, and distinguish making from other types of hands-on learning, we must understand what sets making apart as a practice. There is something new here, and to fully understand making's potential for education, we must begin to distinguish practices that embody the full learning potential of making from those that do not. The studies in Chapters 2-4 of this dissertation range from STEM making practices to artistic, self-expressive practices that meet the criteria for *making* established above.

1.1.1 Community in Maker Education

To understand how making evolved as an educational practice and the factors that contextualize and distinguish it from related but not equivalent instructional practices, e.g. student-centered instruction or problem-based learning, one must first understand the evolution and role of makerspaces and community in the maker movement. In the early 2000s, a cultural shift towards online social platforms and expansion of democratized technology, i.e. more affordable and accessible that previous iterations, gave those with spare time, tools, and education the power to innovate across disciplinary boundaries in their own homes and share their work; these “first” makers were primarily white, middle-class males with garages (Halverson & Sheridan, 2014; Blikstein, 2018). Their projects caught media attention and consequently shaped the practices and image many had of making (Schad & Jones, 2020).

As makers shared their ideas online and in media platforms like MAKE: Magazine and Maker Faires, a community grew online and cross-country, but few would-be makers had the material and intellectual resources to engage freely in the varied practices and tools of making until the advent of makerspaces and fablabs, spaces for making (Halverson & Sheridan, 2014; Vossoughi & Bevan, 2014; Schad & Jones, 2020). In makerspaces, members could share otherwise cost-prohibitive tools and learn from each other directly (Sheridan et al., 2014) in addition to sharing their work and learning from online sources (Brahms & Crowley, 2016). Such spaces turn the classroom paradigm on its head; children may be experts and adults novices. Local communities, in addition to the more widespread, online maker communities, became inherently part of maker practice through the evolution of makerspaces (Hira & Hynes, 2018). Some makerspaces are for-profit while others are free for the local community to use, built into community centers or museums (Sheridan et al., 2014). Some, especially in classrooms, are “pop-up” makerspaces that exist only for the duration of an activity, after which the tools and resources that made it a “makerspace” are transported elsewhere (Gierdowski & Reis, 2015). Makerspaces can be found in community settings as well as schools and universities, and are found throughout the United States, as well as worldwide (e.g. Taylor & Hurley, 2016; Han et al., 2017; Irie, Hsu, & Ching, 2019). Many makerspaces are subject to the kind of cultural normativity presented in sources like MAKE: Magazine (Vossoughi, Hooper, & Escudé, 2016), but recent years have seen a rise in spaces designed for women and underrepresented groups like African American or Latinx makers (e.g. https://prototypepgh.com/). Everything from the culture of the makerspace to the tools and guidelines provided for makers to use can present a skewed representation of *who* is allowed to participate and *what types* of participation are allowed in the space (Martin, Dixon, & Betser, 2018).

1.1.2 Research on Educational Making

Since 2012, researchers have attempted to qualify, assess, and improve experiences in educational makerspaces; to do this, researchers have begun studying learners, educators, environments, and activities in educational makerspaces and the relationships between them. Many studies, for example, have addressed learning outcomes for youth wherein making is the means to an end, especially motivation to engage in STEM (Bevan, 2017; Davis & Mason, 2017; Greenberg & Calabrese Barton, 2018). Vossoughi and Bevan (2014) observed that educational research in maker learning has gathered around three foci: STEM pipeline and workforce development, entrepreneurship and community creativity, and inquiry-based education. Today, although much interest in making for education still emphasizes STEM-related outcomes (Bevan, 2017), research and practice has expanded beyond the aforementioned categories to include educational outcomes like the social-emotional learning depicted in the vignette in the introduction (SEAD Commission, 2019; Gennari, Melonio, & Rizvi, 2017). Making has also been used to support instruction in history (Turner et al., 2017), general education across curricular boundaries within schools (Wallace et al., 2017), and racial identity development (Norris, 2014). Several researchers have made the argument that making has great potential as a practice to support equitable learning (e.g.

Calabrese Barton & Tan, 2018) but requires much work to create spaces supportive of diverse youth (Vossoughi, Hooper, & Escudé, 2016; Martin et al., 2018). Although it is unclear how extensively making may be useful in instructional practice, teachers' breadth of instructional uses for making thus far suggests that making is a versatile educational practice and a full range of learning outcomes should be studied more thoroughly.

Other studies have focused on understanding the skills and practices that are shared among makers, including developing a maker identity. Some define a maker broadly as anyone who engages in making as a maker (Halverson & Sheridan, 2014; Dougherty, 2013), Toombs et al. (2014) distinguished general from "established" maker identities; "Maker-ness manifests in degrees, which range from one who occasionally participates in DIY activities, to one who regularly creates their own processes and situations for DIY" (p. 2). A community of practice view of identity takes it a step further, suggesting that to be a maker one should engage with others in the community (e.g. through forums, at Maker Faires) and engage in the practices of the community (Lave and Wenger, 1991; Vossoughi & Bevan, 2014). Brahms and Crowley (2016) identified seven general shared practices among makers, including: exploring and questioning; tinkering, testing, and iterating; seeking out resources; hacking and repurposing; combining and complexifying; customizing; and sharing. Clapp et al. (2016) describe a disposition that supports the making process called *maker empowerment*, "a sensitivity to the designed dimension of objects and systems, along with the inclination and capacity to shape one's world through building, tinkering, re/designing, or hacking" (p. 98). In recent years, researchers have also begun to develop measurement tools for assessing learning and maker-relevant skills; e.g., Blikstein et al.'s (2017) Exploration and Fabrication Technologies Instrument (EFT). Together, these studies suggest the need for a deeper investigation into the skills that support making and methods for assessment and measurement.

Since Sheridan et al.'s (2014) groundbreaking study to compare three different types of makerspaces, still other studies have focused on the characterizing and analyzing the implications of the types of resources available in makerspaces. Litts' (2015) work to outline design considerations for makerspaces discussed the potential limitations of people as resources in makerspaces; facilitators are often rooted in their disciplinary expertise and may be hesitant to push youth to expand their skills and experiences beyond their own limitations. Likewise, Litts found that the appropriate quantity and visibility of available materials influences makers' willingness to engage with proffered materials. Hira and Hynes (2019) developed a framework of means, activities, and people to characterize resources in educational makerspaces. Researchers have only just begun to address how greater cultural and organizational factors influence maker learning, e.g. Tan (2019), who studied the unique tensions between instruction and creativity in a high school makerspace. Fundamental organizational and structural constraints and affordances of schools, for example, shape the types of activities, means, and people available within in-school makerspaces and in turn the implications for learning in therein, e.g. mandatory attendance, assessment, and long-term interaction with the same teacher (Darling-Hammond et al., 2019). This leaves a gap for understanding how educational making in schools may differ fundamentally from making in OST settings.

Most research in making is still exploratory in nature, but within it, researchers have begun to make recommendations for instructional practice, e.g. Wardrip and Brahms' (2016) model for integrating making into classrooms. Within research on educational outcomes achieved through making, there is more room to explore social and emotional learning outcomes and learning in non-STEM domains. Among maker learning outcomes, there is a limited understanding of the rich practices and skills that support educational practice through making and how those practices transform from one educational context to the next. Finally, research on makerspaces have dealt sparingly with the contextual differences framing educational experiences in school versus OST makerspaces. These gaps set the stage for the three studies that comprise this dissertation and my investigation into how context and the nature of making as a practice together shape youth learning.

1.2 Maker Learning in Three Studies

To understand how to support learning in educational making, to the extent that it is context-dependent or otherwise, one must first understand how learning is measured in educational makerspaces. Chapter 2.0, *Learning to Make or Making to Learn? Rethinking Assessment in K-12 Makerspaces*, provides a theoretical argument for focusing on maker learning outcomes in educational making contexts, as distinct from domain-specific goals like learning about physics, and identifies gaps in maker research of learning outcomes. The literature review identified maker learning outcomes that improve motivation to make, engagement with the community, and outcomes to facilitate the process of making. Although research has studied process-focused outcomes abundantly in schools, skills that support community engagement are infrequently the focus of study but have been observed in both OST and in-school maker learning and, fragmented, spanned several maker-learning frameworks. Similarly, these outcomes have been observed but not studied deeply to determine how youth learned the skills in a maker education context. Combined with research on related studio practices, this gap analysis highlighted the need for more research on community-related outcomes such as maker identity and the development of rigorous practices for learning and sharing process through making.

Legitimate Peripheral Participation in a Makerspace for Emancipated Emerging Adults, Chapter 3.0, deeply explored the trajectories of youth developing maker identities through engagement with a community of practice. This study followed the learning of youths in a unique OST setting, that of a transitional housing facility (THF) for young adults who had aged out of foster care and were left homeless; i.e., emancipated emerging adults. Through participation in a local museum's making community and making practices at THF more reflective of arts and crafts than MAKE: Magazine's brand of making, several residents came to see themselves as makers, find entrepreneurial and social-networking opportunities, and explored creative ways to meet their needs and interests.

My final article closely examined the development of documentation skills in an in-school makerspace, a practice with implications for all three categories of maker learning outcomes identified in the gap analysis studied in Chapter 2.0. In *From Compliance to Reliance in Makerspace Groupwork: Learning to Document and Documenting to Learn* (see Chapter 4.0), I followed the progress of a team of high school physics students as they participated in a Sea-Air-Land challenge to build a drone capable of completing a series of tasks. One of the main requirements of the project was that participating teams document their work, both to support their own learning and demonstrate their process to judges. In this study, I examined how students came to learn documentation practices as a core practice for supporting long-term group work in making.

These three studies allow me to investigate learning in educational makerspaces as situated both within maker culture and the educational contexts of schools and OST programs. Like much making research that has come before, the studies in Chapters 3.0 and 4.0 are qualitative, exploratory case studies set within educational makerspaces (Stake, 1995). The former presents collective cases of individual students while the latter examines a group of students working collaboratively as a team. Although limited generalizability is a frequent criticism of qualitative research, Stake argued that in education, case studies can serve the important and even preferred purpose of gathering practical information through inquiry, and that "such methods may be in conceptual harmony with the professional reader's experience, and thus be a natural basis for generalization" (as cited in Myers, 2000; p. 6). Both studies make use of rich, varied data sources to triangulate findings, e.g. field notes, artifacts, and transcribed interviews, but Chapter 4.0 makes extensive use of video data to capture the dynamics of an active group of students over the course of several months. This modification to my methodology likewise informs my recommendations for educational maker research in Chapter 5.0.

2.0 Learning to Make or Making to Learn? Rethinking Assessment in K-12 Makerspaces

Assessment is an important part of educational practice in schools; used properly, it can support equitable instruction in classrooms and accountability in schools. But when teachers bring informal, out-of-school practices into classrooms, deciding what outcomes to assess and how to assess them is not always straightforward. In this study, we examine research on learning outcomes and the tools that measured them in educational makerspaces (in and out of schools) to make recommendations about what learning outcomes teachers should assess and address the potential use of pre-existing measurement instruments to support educational maker assessment. We also address gaps in the research around assessment and learning outcomes in makerspaces to make recommendations for future research. We argue that assessments for educational making should prioritize assessment of maker learning outcomes to improve educational practice in makerspaces. We conclude with recommendations for the need for more research on assessment and learning outcomes in educational makerspaces for diverse makers.

Keywords: measurement, educational, instruction, making, assessment

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2.1 Introduction

Intentional teachers constantly seek ways to improve instructional practice in their classrooms (Epstein, 2007). Recent years have seen rising interest in student-centered, hands-on, and project-based methods of instruction, the success of which depends in part on assessment driven by students' needs and abilities (Panitz, 1999; Brown, 2008). When assessment is used formatively and reflectively, this supports teachers' abilities to gain a rich understanding of the many dimensions of heterogeneous growth in their students, as well as provide opportunities for feedback that students can use for reflection and learning (Sadler, 1989). Teachers can likewise use assessment to create classroom environments and lesson plans that benefit learners of heterogeneous abilities (Watts-Taffe et al., 2012). However, when assessment fails to measure diverse dimensions of growth or is used to sort students into classes by ability level (tracking) it can be a source of inequity, sharpening divides in instructional practice as standards lower for struggling students and teaching to the test increases (Darling-Hammond, 1994). Thus, it is necessary to create assessments that support equitable instruction throughout the schoolyear.

At its core, assessment is really about the learning outcomes teachers hope to achieve with their students and measuring whether those outcomes were successfully achieved (Wiggins, 2011). It is critical, therefore, to identify the wide range of student outcomes related to a given practice to inform instruction and assessment. This is more complex than it sounds when students are engaged in hands-on practices in which teachers themselves are not experts (e.g. Tan, 2019). This mismatch between teacher expertise and student outcomes is a typical challenge in educational *making*, which is the creative instructional practice at the focus of this literature review (Vossoughi & Bevan, 2014). Before we can identify outcomes teachers should assess, we must contextualize *making* as a practice in education and identify factors that distinguish school from OST settings, thus modifying the outcomes we would expect to see valued, measured, and even evidenced in one context versus the other.

2.1.1 Contextualizing Maker Learning in Education

To understand how to assess learning in a practice, one must first understand what the practice is and how it is used in instruction. Making is a recently-coined term for building something physical or digital; it emphasizes the form innovation and creativity has taken on in an age of social media and affordable technologies (Halverson & Sheridan, 2014). Initially a practice for hobbyists and professionals, making has made its way into instructional practice in classrooms worldwide (e.g. Tan, 2019; Irie et al., 2019) and attained praise in policy and research for its educational potential, e.g. social-emotional learning in classrooms (SEAD Commission, 2019) and science instruction (Bevan, 2017).

Making is unique as a hands-on practice because it is adaptable, interdisciplinary, and results in producing an artifact (Martinez & Stager, 2013). The theory of *constructionism* is the foundation for understanding making as a learning practice; Papert (1991) theorized that the construction of a public artifact affords specific potential for learning, based on Piaget's theory that action leads to cognitive development, i.e. *constructivism* (as cited in Martinez & Stager, 2013). Through constructionist practices, students build to learn, and in educational makerspaces, these learning outcomes have spanned a spectrum from domains like science (Bevan, 2017) to social-emotional learning (Norris, 2014; SEAD Commission, 2019). Making can transcend disciplines, drawing on STEM practices as readily as the arts (Peppler et al., 2017), and takes advantage of increasingly democratized technology, i.e. accessible versions of technology that were previously available only to professionals within siloed fields, such as 3D printers and

Raspberry Pi processors (Halverson & Sheridan, 2014). Finally, making has the potential to adapt to the needs of learners of all ages and disciplines (Sheridan et al., 2014; Peppler et al., 2017). It is for these reasons that educators across disciplines, as well as researchers and policy-makers, have grown interested in the educational potential of adaptable, interdisciplinary, hands-on making (Vossoughi & Bevan, 2014). Unlike direct instruction, where teachers know the material and the limited set of answers to which students should arrive in practice, making is limitless in the skills and knowledge students may have to use to complete a given project; this boundlessness can pose problems for both instruction and assessment, resulting in teachers' discomfort with assisting students to engage in projects that the teachers themselves would know how to complete (Litts, 2015). Other teachers have successfully used techniques to scaffold the making process without limiting students, using questions to push student thinking and find solutions (Tan, 2019). It is for these reasons that we define educational making as a practice in which youth learn by individually or collaboratively designing and producing digital or physical artifacts, especially when drawing on interdisciplinary practices or resources from a larger community of makers.

In addition to being a varied and diverse practice, making typically takes place in spaces called *makerspaces* that influence the practice of making through the means, activities, and people provided to students (Hira & Hynes, 2018; Sheridan et al., 2014). Some school makerspaces are popup-style; teachers or researchers temporarily make space in their school for making (Chu et al., 2015). Others reside in classroom corners or dedicated rooms within schools, such as makerspace corners in classrooms throughout a school (SEAD Commission, 2019; Tan, 2019). While some makerspaces offer youth the chance to use professional-quality tools like 3D printers (Vones et al., 2018), others rely on low-tech options like cardboard and wires (Sheridan et al., 2014; Hughes & Morrison, 2018). Although Hira and Hynes (2018) argued that the means, activities, and people available in educational makerspaces are critical to future research to understand students' learning outcomes, greater *means* does not necessarily indicate better learning outcomes; Blikstein (2013) found that when one child used expensive equipment to produce a keychain and showed others how to do the same, multiple children copied the process with little creativity or innovation. Clear, intentional learning goals are likewise not guarantees for success; Martin, Dixon, and Betser (2018) found that despite expectations youth would thrive if encouraged to work in groups, some young makers required autonomy over engagement styles to stay motivated and involved. Competence beliefs, i.e. expectations of success, likewise influence young makers' willingness to try difficult projects or waste materials (Han et al., 2017). These findings highlight the importance of assessment in every educational makerspace to shape productive instruction for all students; adequate means, exciting activities, and well-meaning practitioners are not a shortcut for supporting learning outcomes through making.

In addition to variations in learning outcomes based on resources and instructional practice, researchers debate whether and how making can afford opportunities for equity; most prominently, arguments focus on the fact that making came from middle-class, white, male practices of being creative with tools on hand (Vossoughi & Bevan, 2014) and that most making spaces reflect that culture to the exclusion of girls and underrepresented ethnic and racial groups (Vossoughi, Hooper, & Escude, 2016). Peppler et al. (2017) found that a majority of youth makers (45%) and educators using making practices in their classrooms (80%) are white. Researchers have attempted to make spaces that reflect the diversity of youth the spaces were meant to serve (e.g. Greenberg & Calabrese Barton, 2018; Sheffield et al., 2017), but most of these studies focus on motivational outcomes for youth and place less emphasis on measuring skill, process, or content-knowledge outcomes. In classrooms, youth from underrepresented communities tend to suffer most when assessments are not tailored to improve their learning and encourage growth (Darling-Hammond, 1994).

2.1.2 In or Out of School?

Although Hira and Hynes (2018) focused on the factors that influence educational makerspaces from within, one must also consider the greater organizational and cultural contexts influencing education in makerspaces (McLellan, 1996). In this review, we address maker research from schools and OST settings alike to identify assessable learning outcomes, but recognize that differences in school and OST contexts may limit the applicability of OST findings to classroom practice and assessment.

Schools have advantages and disadvantages when it comes to ensuring students learn when engaging in making; teachers can require students to engage in making, participate in assessments, and collaborate with peers, but have little control over the types of curriculum they must make sure students learn or the length of time they get to work with students each day (Darling-Hammond et al., 2019). Teachers do not face the same pressure to make sure projects are fun and minimally frustrating that drop-in OST programs reliant on voluntary attendance face; even demotivated students are legally required to continue attending classes in the United States. The structure and compulsory nature of schooling likewise means that teachers have opportunities to engage students in longer projects than museums or libraries can, resulting in different learning outcomes and more complex tasks. Likewise, assessment is a part of practice and culture in schools, and teachers may be more prepared and willing than their OST counterparts to engage in instruction-focused assessment; Peppler et al. (2017) found that 90% of educators using making in their classrooms already assessed student practice, while conversely only 68% of OST educators used some form of assessment.

On the other hand, teachers can experience pedagogical tensions when attempting to navigate the less formal waters of a makerspace (Campos, Soster, & Blikstein, 2019). OST programs have shown success in various forms of positive youth development and tend to lend themselves better to providing youth with motivating, low-stakes experiences and opportunities to build relationships (Balsano et al., 2009). Likewise, schools that are reluctant to engage in social-emotional learning may discourage teachers from spending time on practices that do not efficiently demonstrate academic outcomes; it is only in recent years that SEL has received greater priority in early education (SEAD Commission, 2019), but remains to be sufficiently embedded up to high school curriculum (Dunsenbury et al., 2015). The kinds of outcomes that are measured in OST settings may be present in both types of settings, but simply not prioritized in assessment, e.g. enjoying a lesson or desire to continue studying a particular topic. It is with these high-level contextual factors in mind that we turn to prior practice in the assessment of making, the practice at the focus of this study.

2.1.3 Assessment Practices in Maker Education

In educational practice, making is not usually considered an end in itself. Teachers typically engage youth in making as an instrument for some other learning goal (Vossoughi & Bevan, 2014), e.g. motivation to engage in STEM (Davis & Mason, 2017; Sheffield et al., 2017). However, these domain-specific learning outcomes do not reflect the full range of benefits young makers have obtained from making. Outside of schools, making has been found to support mental health outcomes such as well-being, inclusion, and other community needs (Taylor & Hurley, 2016).

Bonnette & Crowley (2018) likewise found that access to the maker community could also help vulnerable youth make friends, network, expand their skill repertoire, and enable them to engage in entrepreneurship. Sheridan et al. (2014) found that engagement in making allowed youth to act as teachers, explore interests, and learn to repair goods youth owned or wanted to use. Rusk (2016) found that engagement in Scratch, a coding platform, allowed youth to reap the intrinsic benefits of being able to make and share ideas youth had for games and animations. To assess learning in maker practice means to identify, then, not only outcomes desirable to the educators using the practice for instruction but outcomes found within the practice at large.

Despite the popularity and value of making for educational practice, though, recommendations for teachers' assessment of learning outcomes in educational makerspaces remain limited (Bergner et al., 2019). This is not to say that educators do not assess learning; Peppler et al. (2017) found that roughly 75% of a sample of in school (90%) and OST maker educators (68%) had some form of assessment in place, but it is unclear what outcomes they were measuring. As Peppler et al. (2017) put it:

> Across both types of sites, the use of assessment seemed much larger than anticipated, revealing the size of the demand for high-quality maker assessment. At the same time, it also demonstrates that practice is ahead of research; despite researchers not providing a firm answer on how makerspace learning can be measured, educators in and out of school are moving forward to meet the practical realities. (p. 11)

Peppler et al. (2017) found that school educators most frequently made use of self-assessment for grading, followed by portfolios that were frequently used as self-assessment tools, and when asked what questions teachers asked students for self-reflection, 33% of the sample reported using prompts and sentence starters:

> The prompts and sentence starters covered 18 aspects of making, among which learning, tools and materials used, project descriptions, challenges/failure, and proposed changes were the most frequent. Prompts included, "I had difficulty when...," "I solved my challenge by...," and "Did you use a new tool? Which one? How was it used to make your project?" (p. 13)

Recent efforts to develop other assessments or characterize the outcomes teachers should assess have been limited in different respects (Schad & Jones, 2020); e.g., Blikstein et al. (2017) developed an assessment with a heavy technological slant but limited in its capture of crafts practices. Pasavapolou, Giannakos, and Jaccheri (2016) reviewed maker literature and found similarly that many studies at the time emphasized STEM outcomes. Bergner et al. (2019), on the other hand, only identified outcomes that were already of interest to teachers or that they struggled to measure, in an extensive list of potential outcomes, such as: problem solving mentality, teamwork experience and skill acquisition, emotional resilience, design thinking, technical and fabrication skills, general claims about growth, flexibility and creativity, and communication skills. We build on these efforts to find learning outcomes that a) support educational making for youth and b) are characterized or measured in empirical research. Additionally, we seek to determine how these educational outcomes are measured and what implications these tools bear for assessment.

In this study, we first present a framework undergirding an argument for the prioritization of distinct categories of maker learning outcomes based on theory and prior research. Second, we examine empirical research on educational making to identify examples of learning outcomes and methods of measurement. Finally, we make recommendations about teacher assessment of maker learning and directions for future research.

2.2 Learning to Make or Making to Learn?

In our conceptual framework, we seek to prioritize the measurement of learning outcomes by their relationship to successful engagement in educational making. In K-12 schools, making is typically a means to a more distal educational end such as STEM engagement or 21st century skills (Vossoughi & Bevan, 2014), but maker skills and outcomes should not be considered irrelevant or tangential to the end-goal. Lundberg and Rasmussen (2018) argued that focusing on process over product is critical to learning and assessment in maker education, particularly when the activity is intended to support the development of youth skills like creativity or innovation. Additionally, when makers struggle to engage in the making process, it interferes with their ability to obtain the desired learning outcomes from engagement in making (Chu et al., 2015), as Hughes and Morrison (2018) observed:

> The choice of end product generated excitement about using the e-textiles and acted as an initial hook, but the difficulties that came with using e-textiles with this demographic of students arose when fine motor skills were required (accuracy and neatness in stitching and knot tying, specifically). While collaborative learning and the creation of personally meaningful artifacts were again important to make the learning process effective, unlike in the other iterations increased teacher intervention and support appeared necessary during difficult or frustrating points in the sewing process. We found that in order to help build the students' problem-solving and fine motor skills, we had to interject to facilitate the continuation of their creation process. Otherwise, widespread abandonment of projects was a real possibility (based on previously observed behaviour), and the learning that did end up taking place, we feel, would not have occurred. (p. 372)

This suggests that skills, competencies, and motivational outcomes such as identity development and interest related to making all mediate how effective making will be as an instructional practice (see Figure 2).

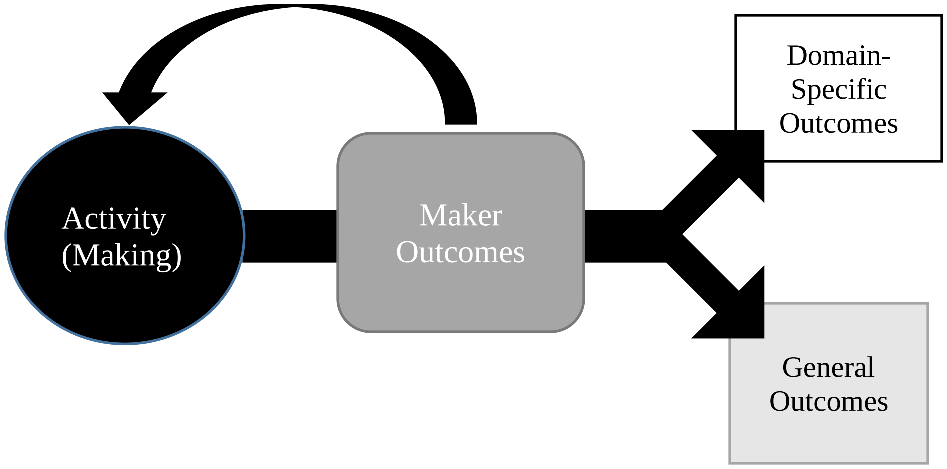

Figure 2 Maker outcomes mediate the relationship between making activities and general or domain-specific learning outcomes not related to the making process.

Therefore, to support maker learning in schools, assessment and measurement should account for maker learning outcomes first and attend to domain specific outcomes and general outcomes secondarily; Peppler et al. (2017) hypothesized that the opposite was true in suggesting that teachers relied on pre-existing curricular assessment regardless of instructional method. The purpose of this study, then is to characterize the range of maker learning outcomes that have already been identified and distinguish them from domain-specific outcomes (e.g. STEM motivation) and general learning outcomes. Likewise, we attempt to identify those outcomes that have been measured and those which have been identified but not studied to identify assessment tools and gaps in research.

Recent efforts to explore and characterize learning in making suggest that there are numerous dispositions and skills useful to all makers, e.g. *maker empowerment*, a disposition defined as “sensitivity to the designed dimension of objects and systems, along with the inclination and capacity to shape one’s world through building, tinkering, re/designing, or hacking” (Clapp et al., 2016; p. 98). Brahms and Crowley (2016) likewise characterized seven maker practices, including: exploring and questioning; tinkering, testing, and iterating; seeking out resources;

hacking and repurposing; combining and complexifying; customizing; and sharing. Agency*by*Design's framework for maker-centered learning encourages educators to use thinking routines in makerspaces that help students develop maker capacities such as looking closely and exploring complexity (http://agencybydesign.org.s219538.gridserver.com/edresources/). Simpson, Anderson, and Maltese (2019) emphasized that students and teachers alike needed the ability to identify and address failure in making. These are just a few examples of maker characteristics that youth could develop as learning outcomes to support making and, thereby, other learning outcomes.

Domain-specific learning outcomes are the frequent focus of maker learning; many studies in maker education focus on STEM outcomes, and Peppler et al. (2017) surveyed teachers and facilitators in schools and OST settings and found that making is also used to teach language arts, social studies or history, and performing arts. Likewise, teachers seeking to help students attain more general, non-maker social-emotional and 21st century skills have also used making for instruction. We do not argue that these are less important outcomes of maker education, but instead make the argument that teachers should assess all three categories of learning outcomes where appropriate, and determine for themselves whether domain-specific or general skill assessment is applicable to their instructional goals. Assessing maker outcomes first, on the other hand, ensures students' ability to safely and effectively engage in the instructional method, and helps to separate difficulties with *making* from difficulties with learning the *curriculum*. This may be the category teachers are least prepared to assess, however, as the outcomes directly related to making are least likely to have been incorporated into preexisting assessment methods.

In this study, we ask the following questions:

- How has educational maker research explored outcomes for K-12 aged youth?
- How has the measurement of maker learning outcomes differed between OST and school settings?

2.3 Methods

In this review of the literature, we identify and categorize the learning outcomes already researched in youth maker learning and draw on research from both in and out of school makerspaces for evidence of learning outcomes and the measurement instruments used to capture them.

2.3.1 Search Criteria and Procedure

We searched scholarly databases in September of 2018 looking for articles that specifically referred to the learning activity in question as "making" and where students or participants included youth between 4 and 18 years old as an approximation for a K-12 age range. Studies were included regardless of formal or informal context. Search terms were as follows: (makerspace OR makerspaces) AND making AND learn AND maker. Databases included Scopus, JSTOR, ERIC, ScienceDirect, Web of Science, and ProQuest. We excluded items that were not peer-reviewed, published articles or book chapters, giving us a sample of 195 articles and chapters. We added several other articles and chapters that were not available through the databases. Then, we eliminated literature reviews, essays, and conference papers. We then excluded articles that did not meet the following criteria:

- Making, as described in the article, met our threshold definition for educational making.
- Articles identified learning outcomes and traits that supported learning in K-12 aged youth.
- Articles were peer-reviewed journal articles, rather than conference papers, books, or essays.
- Articles were available in English.

The final sample included 29 articles; most of the articles excluded were excluded due to age range or failure to address maker skills or any learning outcomes (maker, domain, or general). We then read and analyzed the 29 articles for attributes such as the kinds of learning outcomes measured and the assessment instruments used. In several articles, assessment of learning outcomes was not the main objective, but rather a byproduct of implementation or design studies. These studies nevertheless contributed to our understanding of skills that benefit educational making and the means by which learning outcomes may be captured and assessed.

2.4 Findings on Maker Education Outcomes for Youth

Maker learning literature encompasses a broad variety of learning outcomes, subject areas, populations, and types of makerspaces, and measurement instruments. Table 1 displays a list of the articles and attributes of each study design, learning measurement, and outcome. Next, we briefly review our observations in relation to the depth and breadth of learning outcomes studied, the range of study designs used, the populations who participated, and the types of sites and domains studied. Note that this is not an exhaustive list of types of makerspace research or content learned within them, as our sample is restricted to articles that intentionally incorporate evidence of learning in K-12-aged makers (in or out of schools).

In this study, we theorized that maker outcomes were both most critical and least assessed in instructional practice within educational makerspaces. In part one of our findings, we give an overview of findings and patterns from the studies included in this analysis, including the proportion of studies that emphasized non-maker outcomes, contexts represented in each study, and research methods used. In part two, we focus on identifying subcategories and examples of maker learning outcomes, identify contextual differences underpinning where each outcome was measured. In part three, we discuss the applicability of research instruments for informing instructional assessment practices in schools.

Table 1 Coding for final article sample (UR = racial or ethnic groups underrepresented in STEM).

Citation	Outcome	Category	Context	Population	*n*	Instrument
Bass et al., 2016	STEM pipeline career readiness and interest	Domain	OST	Girls, Minorities, Low SES	146	Interview
Bers, Strawhacker, & Vizner, 2018	Positive technological development	Maker	School	Elementary	7 classes	Framework
Bevan et al., 2015	Tinkering learning dimensions	Maker	OST	Unspecified	50 groups	Framework
Blikstein et al., 2017	Digital literacy	Maker	School	Elementary, Middle, High	1065	Test, Survey
Brady et al., 2017	Attitude, interest, computational thinking	Domain	School	High: Girls, UR, Low SES	55	Test, Survey
Bull et al., 2017	Content knowledge, motivation	Domain General	School	Middle, Elementary; ELL	2 groups	Na
Calabrese Barton & Tan, 2018	STEM engagement	Domain	OST	UR	48	NA
Chou, 2018	Content knowledge, problem-solving	Domain General	School	Elementary, Middle	30	Test
Christensen et al., 2018	Design literacy, inquiry stance	Maker	School	Middle	246	Survey
Chu et al., 2015	Maker mindset; maker identity	Maker	School	Elementary	23	Survey, Interview
Chu et al., 2017	Fun, learning	General	School	Elementary	124	Survey
Davis, & Mason, 2017	Identity, interest, participation	Domain	OST	Middle: Girls, UR, Low SES	16	Interview
Dixon & Martin, 2017	Identity, interest, community practices, engagement	Maker	OST	Middle, High	11	Interview
Fields et al., 2018	Problem solving, programming, circuitry design	General	School	High: Low SES, UR	32	Interview

Flores, 2018	Science literacy	Domain	School	Middle	—	Survey, Interview
Greenberg & Calabrese Barton, 2017	Empowerment, Stem Engagement	Domain General	OST	High: Girls, UR, Low SES	2	NA
Holbert, 2016	Interest, Persistence, Motivation	Domain	School	Middle: Girls, UR, Low SES	9	Interview
Giannakos & Jaccheri, 2018	Motivation	Maker	OST	Middle, High	60	Interview, Survey
Hughes, & Morrison, 2018	Engagement: Choice, Collaboration, Purpose	Maker	School	Middle: Disabilities	50	Interview
Hughes, 2017	Digital Literacy, 21st Century Skills	Maker General	School	High: UR, Disabilities	7	Survey, Interview
Norris, 2014	Critical Literacies	Domain	School	High: Girls, UR	19	Interview
Perakh & Gee, 2018	Making Meaning	General	OST	Elementary, Middle	216	Interview
Reynolds, 2014	Social Constructivist Digital Literacy, Engagement	Maker Domain	School	Middle, High: Low SES	1063	Framework
Rusk, 2016	Motivation	Maker	OST	<18	119	Interview
Sheffield et al., 2017	Interest in STEM careers, Articulating science concepts	Domain	School	Elementary/ Middle: Female	2 grades	Interview, Survey
Sheridan et al., 2014	Engagement in Communities of Practice; students as teacher	Maker	OST	Mixed; includes UR, Low SES	3 spaces	Interview
Tofel-Grehl et al., 2017	Engagement, Interest	Domain	School	Middle	155	Test, Survey, Interview
Vones et al., 2018	Engagement	Maker	OST	Elementary: Boys	6	Observatio n
Wallace et al., 2017	Content Knowledge, Design Problem-Solving	Domain Maker	School	Middle: Low SES and IEP represented	60	Observatio n

2.4.1 Sample Overview

In this section, we describe the general characteristics of studies in our sample and characterize non-maker related learning outcomes found in educational maker research.

2.4.1.1 Sampling and Data Collection

Young makers in these studies participated in makerspaces in schools, museums, libraries, online forums, and community centers. Fifteen of the articles in our sample either focused on or contained a high proportion of underrepresented students, including those of non-white ethnicities, English language learners (e.g. Bull et al., 2017), students with disabilities (Hughes & Morrison, 2018), and females. Nearly every article that focused on girls or underrepresented students emphasized STEM curriculum (e.g. Greenberg & Calabrese Barton, 2017), despite the breadth of learning in making and domains that use makerspaces for educational purposes, and typically emphasized motivational outcomes over other learning-related outcomes; Norris (2014) provides a rare exception. Most other studies did not specify the demographic characteristics of the students beyond an age range (e.g. Chu et al., 2015; Flores, 2018); most studies looking at content knowledge and academic rigor referred to their subject populations in this manner.

Predominantly, studies took place in makerspaces in schools (18 articles), typically focusing on either making (6) or emphasizing STEM learning and practices (8). Other domains included interdisciplinary studies of history, science, writing, and a broad scope of curriculum expected for the grade level (Wallace et al., 2017). Most in-school (during or after school hours) makerspaces either “popped up” in classrooms or spare rooms for the duration of a study; few had a dedicated makerspace at the school. Community-center spaces varied from drop-in makerspaces that focus on making broadly (e.g. Sheridan et al., 2014) or STEM-focused tinkering and play (e.g.

Bevan et al., 2015) to short or long-run programs that youth signed up or were selected to attend (e.g. Davis & Martin, 2017). Online communities such as the Scratch community in Rusk (2016) are less readily identifiable as “makerspaces” but contain similar parts; youth are engaged in making with other makers who share product, process, and knowledge in a defined community.

2.4.1.2 Measurement Instruments

Twenty-two of the articles in our sample used interviews or observational data to capture the nature of maker learning in makerspaces (e.g. Sheridan et al., 2014). Eleven studies included surveys or tests (e.g. Tofel-Grehl et al., 2017). Two articles included frameworks for the observational analysis of learning in makerspaces (Bevan et al., 2015; Reynolds, 2014). Samples ranged from two cases closely followed in an ethnographic study to more than a thousand students in quantitative studies with surveys, frameworks, or test instruments (e.g. Reynolds 2014).

Interview data was the most commonly used instrument type in our sample. This was true across our three learning outcome categories, due partly to the presence of motivational outcomes in all three categories. In Sheridan et al. (2014), for example, makers talked about what was most important to them in their makerspace, described frustration with unsolicited peer feedback, and described what encouraged their attendance and continued participation. Hughes and Morrison (2018) asked whether students thought the program would help them in school, and about the relationship between work and projects in the program. At times the sensitivity of subject matter limited the ability to ask more direct questions; Davis and Mason (2017), studied STEM attitudes in relation to student characteristics, but to prevent stereotype threat focused their interview protocol on maker identity questions, making participation, family involvement and interest in their camp participation, and future career plans. Interview protocol was sometimes explicitly reported in the data, but in most cases could only be inferred from participant responses.

Surveys were used across our three learning outcome categories but were the most commonly used instrument in studies with maker learning outcomes. Surveys were frequently used for out-of-school programs. Survey data encompassed: youths' opinions, reflections, and motivations for participation in making; making, and interest in STEM making; and interest in STEM. Tofel-Grehl and colleagues' (2017) questionnaire gauged student perceptions of families' attitudes towards schooling and peer reactions to interest in STEM and school. Chu et al. (2017) surveyed students about their experiences after a week-long program. CT4G used a post-test survey that asked students to describe the class, how concepts could help them outside of the project, and other reflective questions (Brady et al., 2017).

Tests and frameworks were least frequently used in maker learning literature and typically focused on STEM domains, such as Tofel-Grehl and colleagues' (2017) test items drawn from the TIMSS and NAEP exams to measure knowledge of electricity and circuits, or Chou and colleagues' (2018) multiple-choice tests to assess students' problem solving and engineering skills. Frameworks were developed as models for analysis of behaviors of learning in makerspaces and intended as researcher or practitioner tools. Several frameworks directly supported maker learning outcomes, and we discuss them more extensively in the third section of our findings.

2.4.1.3 Learning Outcomes

The articles in our sample encompass a wide variety of learning outcomes for youth in makerspaces in testament to the growing interdisciplinary interest in the educative potential of makerspaces. 15 studies included maker learning outcomes, such as motivation for making (Giannakos & Jaccheri, 2018), digital literacies (Tofel-Grehl et al., 2017), which we discuss further in part two of our results. Non-maker outcomes ranged from domain specific (13 articles) to general learning outcomes that could be useful for students in any educational context (8 articles), e.g. problem solving (Chou, 2018). The majority of articles, 18 total, emphasized motivational outcomes, often in relation to STEM or making, and measured constructs like interest and engagement through observation or survey instruments (Rusk, 2016; Greenberg & Calabrese Barton, 2017), while others referred more broadly to motivation, perhaps to learn or engage in classroom activities, as an outcome of making (Bull et al., 2017).

General learning outcomes were the least common type of outcome studied in our sample. Examples included 21st century skills (Hughes, 2017), problem solving (Bull et al., 2017), general motivation to learn (Chu et al., 2017), and meaning-making (Perakh & Gee, 2018). Although most of the studies in our sample had a more specific domain focus (STEM) when measuring motivation or skills, numerous maker studies mention 21st century skills (e.g. Sheffield et al., 2017).

Domain-specific, non-maker outcomes were the most common in our sample. Of these, STEM motivational outcomes were the most frequently studied domain-specific outcomes (e.g. Calabrese Barton & Tan, 2018; Davis & Mason, 2017; Dixon & Martin, 2017). Articles focusing on a underrepresented (UR) population or girls typically emphasized motivation in STEM as the primary or sole learning outcome of interest, to the exclusion of content knowledge or skill development outcomes; Davis and Mason (2017), for example, followed the development of computer sciences identities, participation, and interest in Latina middle schoolers during a four-day STEM camp. Some studies measured additional learning or development that was more context-specific in nature, e.g. Brady et al. (2017) measured low SES and minority girls' interest and attitudes towards STEM in addition to computational thinking, while underrepresented adolescent girls in Greenberg and Calabrese Barton's (2017) study engaged in STEM and were empowered to tackle issues of sexual assault in their community.

Other STEM-specific learning outcomes included learning science content knowledge (e.g. Chou, 2018), developing science literacy (Flores, 2018), or engaging in inquiry-based learning to understand STEM-related concepts (e.g. Bevan et al., 2015). Some studies incorporated STEM but had additional foci; Wallace et al. (2017), for example, addressed content knowledge learning across multiple disciplines due to a school-wide effort to incorporate writing, history, science, math, and other curricula into a design challenge to teach children about food sustainability. A few articles explore outcomes entirely unrelated to STEM or making, e.g. Norris (2014) who studied Latinas in a three-week high school making program dedicated to developing critical literacies as a way of engaging with issues of race and identity.

2.4.2 Identifying Maker Learning Outcomes

Maker learning outcomes encompass those outcomes and skills that facilitate making; it is these outcomes that we suspect teachers least frequently assess in maker education, due to the fact that skills specific to making are rarely already part of explicit instructional goals in schools, e.g. learning about physics versus developing a maker identity. These outcomes are nevertheless important to successful making and enable youth to take advantage of learning in makerspaces. Fifteen of our twenty-nine studies explored or directly measured outcomes relating to the practice of making in and out of schools. We found three sub-categories of maker learning outcomes, as shown in Table 2, below: community, motivation, and process outcomes.

Table 2 Articles that identify maker learning outcomes for assessment in maker education

Citation	Outcome	Subcategory	Context	Measurement Instrument
Bers, Strawhacker, & Vizner, 2018	Positive technological development	Process; Community	School	Framework
Bevan et al., 2015	Tinkering learning dimensions	Process; Motivation; Community	OST	Framework
Blikstein et al., 2017	Digital literacy	Process	School	Test, Survey
Christensen et al., 2018	Design literacy, inquiry stance	Process	School	Survey
Chu et al., 2015	Maker mindset; maker identity	Motivation; Community	School	Survey, Interview
Dixon & Martin, 2017	Identity, interest, community practices, engagement	Motivation; Community	OST	Interview
Fields et al., 2018	Problem solving, programming, circuitry design	Process	School	Interview
Giannakos & Jaccheri, 2018	Motivation	Motivation	OST	Interview, Survey
Hughes, & Morrison, 2018	Engagement: Choice, Collaboration, Purpose	Motivation; Community	School	Interview
Hughes, 2017	Digital Literacy, 21st Century Skills	Process	School	Survey, Interview
Reynolds, 2014	Social Constructivist Digital Literacy, Engagement	Process; Community	School	Framework
Rusk, 2016	Motivation	Motivation	OST	Interview
Sheridan et al., 2014	Communities of Practice; students as teacher	Community	OST	Interview
Vones et al., 2018	Engagement	Motivation	OST	Unknown
Wallace et al., 2017	Content Knowledge, Design Problem-Solving	Process	School	Unknown

2.4.2.1 Community Outcomes

Community outcomes were the subject of seven of our fifteen studies and were found in both school and OST contexts. Maker community outcomes involve those skills, practices, and mindsets that encourage involvement within the maker community, such as identifying as a maker (Chu et al., 2015), sharing expertise with other makers (Sheridan et al., 2014), and practices that facilitate engaging with community resources, e.g. researching and socializing (Reynolds, 2014). Bevan et al.'s (2015) framework for tinkering and learning includes, among others, practices that reflect the kinds of learning and engagement typically found in makerspaces and are encouraged in the maker community such as "inspiring new ideas or approaches," "requesting or offering help in solving problems," and "physically connecting to others' works" (p. 105). Dixon and Martin (2017) interviewed youth engaging in public presentations to understand their trajectories of participation into the maker community. Due to the public, displayed nature of making and constructionism in general (Papert, 1991), presentation and communication skills relate directly to engagement with the maker community. These abilities allowed young makers to teach others in Sheridan et al. (2014) and, although community outcomes were not explicitly identified, explain designs to younger children in Holbert (2016). Bers, Strawhacker, and Vizner's (2018) framework of Positive Technological Development and Reynolds' (2014) Social Constructivist Digital Literacy frameworks incorporated elements of research and communication as a components of learning and development.

2.4.2.2 Motivation

Motivation was one of the most common forms of outcomes measured overall and was the focus of seven of the fifteen studies associated with maker learning outcomes; four of these took place in OST settings. This suggests that motivation to make, specifically, may be more valued as an outcome in OST than in-school contexts. Maker motivational outcomes can support long-term and short-term engagement with making. Several studies focused on engagement as a motivational outcome (Hughes & Morrison, 2017; Giannakos & Jaccheri, 2018; Dixon & Martin, 2017; Vones et al., 2018; Reynolds, 2014); of these, engagement was rarely the sole measure of motivation, but rather one of several focal points. Chu et al. (2015) developed a dispositional concept called *maker mindset*, which is distinct from other mindsets of the same name in that it is comprised of several motivation theories that promote persistence and engagement in making, such as self-efficacy. Other studies focused on interest in making or identifying reasons for engagement (Rusk, 2016; Dixon & Martin, 2017).

2.4.2.3 Process

Process-type outcomes were among the most frequently addressed maker learning outcomes in our sample, also found in seven of fifteen articles; all but one of the seven articles focused on in-school makerspaces. These process outcomes included fluency with tools and materials, skills that facilitate design, and knowing how to engage as a self-regulated learner in the process of making. Fluency with tools and materials is a basic competence that supports making and designing regardless of the task, given that hands-on learning in constructionism requires the ability to engage and continue engaging with the project or problem. This became a barrier for youth in Hughes and Morrison's (2018) study, as some students' disabilities prevented them from performing the basic tasks required to engage in the project. Several articles sought to measure youth makers' competence with tools and materials in making, such as Blikstein et al.'s (2017) Exploration and Fabrication Technologies Instrument (EFT), which measured proficiency on a basis of students' self-rated confidence and performance with fabrication tasks, e.g. programming robots or using 3D printers. Design skills included design literacy and having a productive inquiry stance (Christensen et al., 2018); Positive Technological Development, which incorporates positive youth development and technological development components (Bers, Strawhacker, & Vizner, 2018); and design problem solving (Wallace et al., 2017). Self-regulating maker skills were incorporated into several frameworks, including Bevan et al.'s (2015) Tinkering Dimensions Framework, which encompassed traits from each of the three maker learning outcome categories identified in this study.

2.4.3 Measurement of Maker Learning Outcomes

The majority of the sample of maker learning outcomes used observational data, artifacts, and interviews to measure youth outcomes, but eight of the fifteen studies included clear examples of tools and questions that could be adapted to measure maker growth, including surveys, frameworks, and tests. Four of the fifteen studies included surveys, which measured motivation in whole or part. Giannakos and Jaccheri (2018) used surveys grounded in motivational theory and included questions about youths' intention to participate in making, enjoyment, satisfaction, performance expectancy, and effort expectancy. Survey questions found in Appendix B of the article included: "I intend to participate in similar activities in the future" (intention to participate) and "I found the activity to be flexible" (effort expectancy) (p. 37). Christensen et al. (2018) used a Design Literacy (DeL) assessment tool developed in a previous study and tested in K-12 education (Christensen et al., 2016); the tool includes a survey and coding scheme for assessing students' design stance towards inquiry when confronted with societal challenges, dilemmas, ethical concerns, multiple stakeholders, and unfamiliar domains (wicked problems). Chu et al. (2015) used Likert scales in online surveys to ask about students' self-efficacy, interest, motivation to engage and their self-concept in STEM and language arts. Rusk (2016) used a single question prompt with an online maker community—“Why do you use Scratch?”—to explore motivations to make among young community members, which included learning, having fun, sharing, connecting, and creating. The only test included in the fifteen maker outcome studies measured process outcomes. Blikstein et al.’s (2017) EFT assessed students’ confidence with a set of digital and fabricating tools and asked students to identify parts of a blender and key fob to determine what parts were needed to make either device function, and self-rate their confidence in their answers. The three framework development studies included the most thorough combination of process, community, and motivation-related maker learning outcomes. Bevan et al. (2015) developed the Tinkering Learning Dimensions framework alongside practitioners and developed a toolkit for recognizing the behaviors associated with: engagement; initiative and intentionality; social scaffolding; and development of understanding. Bers et al. (2018) used a Positive Technological Engagement checklist, which included elements of positive youth development as well as positive technological development: content creation, creativity, choice of conduct, communication, collaboration, and community building. Reynolds (2014) used a social constructivist digital literacy framework that includes six contemporary learning practices: creating, managing, publishing, researching, surfing/playing, and socializing.

2.5 Discussion

Effective assessments are critical to improving teacher practice and equity in education, both through professional development and the ability to respond to individual student needs. Literature on educational making primarily focuses on one of three learning outcome categories: maker, general, and domain-specific. Of these, maker learning outcomes are critical to successful instruction (Chu et al., 2016; Hughes & Morrison, 2017) but unlikely to be captured in assessments developed prior to the introduction of making into instructional practice and least informed by research on best practices (Peppler et al., 2017). Maker learning outcomes included process, community, and motivational outcomes, each of which were present within our sample but unevenly represented across research in school and OST settings.

The school-based findings in our gap analysis primarily emphasized measurement of process skills. These findings are not surprising; although making may have introduced a unique opportunity for learning the skills in question to a classroom, these skills potentially overlap with other general learning outcomes such as the development of 21st century skills, e.g. creativity and problem solving. Likewise, this echoes findings in Peppler et al.'s (2017) survey in which process skills formed the basis for reflection self-assessment prompts used in schools, and Bergman et al.'s (2019) findings that maker educators recognize the need for and difficulty of assessing process-related outcomes. Nevertheless, teachers possess limited assessment tools beyond self-reflection (Peppler et al., 2017) for measuring the broad range of tools, materials, and process competencies makers can learn in a makerspace, a problem Blikstein et al. (2016) identified. The EFT instrument Blikstein et al. (2018) developed makes strides to address this problem but is limited: It relies on self-assessments for competence, e.g. scales of proficiency with a particular tool or task. It also presents a bias towards STEM-focused skills development. Finally, it includes questions that bias the knowledge of affluent children living in suburbs over that of their low-income, urban counterparts, e.g. what an electronic fob for a car or garage is and how it works. The test also does not test for process skills like design literacy (Christensen et al., 2018) or computational thinking (e.g. Chytas et al., 2019, not included in our sample). Rather, the combined value of tests like the EFT and comprehensive frameworks that address motivation and community outcomes may lend the most insight into test instruments that could inform overall levels of *maker competence* to assess well-rounded growth and student challenges in educational making.

Motivation outcomes related to making were most frequently studied in OST settings in our sample. Research has well established that educational making can be fun, engaging, and interesting for youth (e.g. Rusk, 2016). When assessing motivation, in-school maker studies emphasize students' engagement as students, not makers, or else motivation that supports STEM workforce development long-term with an emphasis on engaging girls and other youth of underrepresented groups in STEM fields (Greenberg & Calabrese Barton, 2017; Davis & Mason, 2017; Sheffield et al., 2017). However, motivation to engage in making should not be considered an afterthought in teachers' assessments, as the practice will be a more effective instructional tool if it triggers students' interest (Hidi & Renninger, 2006), piques curiosity (Loewenstein, 1994), or helps students concentrate on learning from an activity rather than on grades (Dweck, 2006). Students' motivation has been extensively studied in educational psychology, the learning sciences, and cognitive psychology (Wigfield & Eccles, 2002), suggesting that many studies and instruments outside of maker research may offer insight into the development of tools for maker motivation assessment in schools, so as to support the assessment of important motivation outcomes like maker mindset (Chu et al., 2015).

Community-related outcomes were identified within the articles in our study and studied in both schools and OST settings, but represented a limited list of skills that youth may need to effectively engage with collaborating peers or the social and intellectual resources of the maker community. For example, no instruments in the articles within our sample measured the young makers' abilities to present designs verbally or adequately document and curate artifact information into portfolios, but one can infer from studio practice that students may need to cultivate these skills to effectively communicate ideas through portfolios (Kuhn, 2001). Peppler et al. (2017) found that portfolios are used in 33% of maker education to facilitate self-reflection and pathways out of makerspaces, such as college applications or product pitches. Keune et al. (2017) argued that the ability to document and share one's process is critical for connecting youth to the maker community to get feedback and share expertise, all of which improve the making process. Of the maker learning measurements in our study, only frameworks included social, research, and communication skills that could support community outcomes (Bers et al., 2017; Reynolds, 2014; Bevan et al., 2015).

Notably, all three frameworks incorporated process, motivation, and community elements. Bevan et al.'s (2015) framework, for example, provides clear prompts that inform how instructors could assess maker learning in classrooms across all three maker learning outcome categories; e.g. "requesting or offering help in solving problems" is an indicator of *social scaffolding*, and is evidenced when learners in the role of novices or experts "request or offer ideas and approaches" and "offer tool(s) or materials in service of an idea" (pp. 104-105). However, this framework does not include valuable skills for engagement in the maker community such as researching (Reynolds, 2014), presentation skills for sharing artifacts and process online, or using other methods of engagement to interact with the maker community at large (Brahms & Crowley, 2015). In short, no single assessment within our analysis presents a comprehensive selection of outcomes sufficient for assessing students' progress as makers within a classroom. Instead, several assessments and tools such as the EFT test (Blikstein et al., 2018) and frameworks (e.g. Bevan et al., 2015) collectively present a more comprehensive view of maker learning outcomes than individual measures of process, motivation, or community outcomes alone.

With all the aforementioned maker learning outcomes, and especially skills or knowledge that facilitate process and community connection, there is a need for future research to answer the questions that will inform teacher objectives, assessment, and instruction in the classroom:

- What other kinds of skills, knowledge, and learning outcomes do youth achieve within the categories of process, motivation, and community learning outcomes?
- How do these outcomes develop in educational making, under what conditions and for whom?
- Do skills build on each other, suggesting that students should learn certain types of process skills before learning other process or even community skills, and vice versa; e.g., building blocks for learning presents a hierarchy of mindsets and skills that students must attain before moving on to higher-level attributes (Stafford-Brizard, 2016)?
- What teacher practices will best support maker learning outcomes; i.e., when youth's maker learning is assessed and teachers identify inconsistencies or low scores, what should their next steps be?

Ultimately, we recognize that teachers are already called to assess many general and domain-specific outcomes in their classrooms. Asking teachers to add maker learning outcomes to their assessment workload as well may seem impractical, if not impossible. However, to effectively use maker practices in instruction, teachers must know whether students are able to perform the tasks given (Hughes & Morrison, 2017) and whether the practice is effective for motivating students (Chu et al., 2015). Additionally, the same skills that promote community engagement to benefit from maker community resources and connections (e.g. Keune et al., 2017; Bonnette & Crowley, 2018) likely overlap with the kinds of skills teachers are expected to engender in students in 21st century learning outcomes, e.g. research and communication skills. Objectives inform assessment and in turn instruction; for educational making to be the powerful tool for learning many hope that it is, we must attend to the attributes that result in student successes, including social, emotional, and academic outcomes (SEAD Commission, 2019). Although recommendations for assessment in schools were the focus of this gap analysis, these findings may also support OST professionals seeking to improve educational practice in making.

At a larger scale, adequate means to assess learning in classrooms supports not only teacher pedagogy but also funding for innovative programs like makerspaces and research to improve practice and equity across systems. Like a camera, formative assessments can be used to zoom in and get a snapshot of details teachers and students might otherwise miss, or capture a full picture too complex to focus on at once in situ. When the “pictures” they take of student growth and learning throughout a unit or semester are understood to represent limited perspectives of a complex, evolving story, it can be a powerful supplement to reflection and overall measurement of learning. With data, researchers can look for patterns to understand how a makerspaces’ resources (Hira & Hynes, 2015) and the learning processes students engage in (Bowler & Champagne, 2016) mediate learning outcomes for students. This is especially critical for supporting equitable learning opportunities for underrepresented students because makerspaces were generally designed for middle-class white makers (Vossoughi, Hooper, & Escudé, 2016) and making research has overwhelmingly focused on motivational outcomes in STEM for these students (e.g. Sheffield et al., 2017), nearly to the exclusion of studying rigorous learning experiences, skill development, and maker learning outcomes. So long as we remember that assessments are a tool for capturing “snapshots” of growth, and that these snapshots provide a useful but limited perspective of learning, assessments can be used responsibly to support learning in educational makerspaces.

3.0 Legitimate Peripheral Participation in a Makerspace for Emancipated Emerging Adults

Following emancipation from foster care, youth often transition into adulthood without the support of family or school. For some emancipated emerging adults (EEAs), alternative support may come from informal educational programs like makerspaces—safe spaces to learn, explore identities, build relationships, and become entrepreneurs. This exploratory study uses Lave and Wenger's concept of legitimate peripheral participation as a lens to for analyzing the diverse relationships of three EEAs (ages 20, 22, and 25) to the maker community of practice, as they live in a transitional housing facility and engage with its on-site makerspace and its affiliated museum.

Keywords: emerging adulthood, legitimate peripheral participation, emancipated, makerspace, communities of practice

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3.1 Literature Review

3.1.1 Emerging Adults

Between the ages of 18 and 25, youths undergo a period of transition from adolescence to adulthood called "emerging adulthood" that is characterized by the following traits: optimism for the future, feeling between adolescence and adulthood, instability, identity exploration, and self-focus (Arnett, 2000). For many middle-class emerging adults, this transition occurs with the support of family and the resources available through postsecondary education, including clubs and classes to explore identity and career opportunities, as well as pseudo-parental supports such as dining services and campus health and safety (Arnett, 1994). Even with these supports, emerging adulthood can be a risky time for youth, as opportunities and pressures to engage in high-risk behaviors increase, like excess drinking, recreational drug use, and unprotected sexual activity (Chassin, Pitts & Prost, 2002; Pharo, Sim, Graham, Gross, & Hayne, 2011; Stone, Becker, Huber, & Catalano, 2012). Traditionally, youth began to see themselves as adults when they reached important markers of "successful emergence," including marriage, parenthood, and career progression (Arnett, 2000). As youth begin to self-identify as adults, they experience less depression, engage in fewer risky behaviors, and have a better sense of their overall identities, as well as the type of person they want as romantic partners (Barry & Nelson, 2005; Galambos, Barker, & Krahn, 2006).

3.1.2 Foster Youth

Emerging adults who are emancipated from foster care, i.e. age out, often lose government and foster-family supports long before the transition to adulthood has ended, between ages 18 and 21 (Avery & Freundlich, 2009). Like their counterparts, emancipated emerging adults (EEAs) demonstrate the five traits characteristic of emerging adulthood (Hokanson, 2014). Unlike their counterparts, however, a disproportionate number of EEAs come from marginalized groups; many are lesbian, gay, bisexual, transgender, or queer (LGBTQ) (Wilson, Cooper, Kastanis, & Nezhad, 2014), and nearly half of youth in foster care are either Latino/Hispanic or African American (https://www.childwelfare.gov/pubPDFs/foster.pdf). In addition to the high-risk behavior characteristic of other emerging adults, EEAs are vulnerable to other risks like homelessness, incarceration, and early parenthood (Fowler, Toro, & Miles, 2009; Jones, 2011). For such EEAs, the transition to adulthood may be cut short, limiting developmental opportunities (Berzin, Singer, & Hokanson, 2014). In addition, EEAs are often reluctant to seek assistance and support, as self-reliance and independence are important to their ability to view themselves as adults (Samuels & Pryce, 2008). Measures of adulthood become even more important for youth for whom traditional options may not apply, such as marriage and parenthood, particularly among LGBTQ youth (Torkelson, 2012). Traditional sources of support like family and college are limited for EEAs (Courtney et al., 2007). EEAs must seek jobs in an economy where college marks the threshold for entry (Carnevale, Smith, & Strohl, 2013), while facing higher pressure to pay for food and shelter and potentially support dependents (Pecora et al., 2006). Without the means to meet basic needs, EEAs' mental and physical health suffers (Fowler, Toro, & Miles, 2011). Despite high interest in attending college, Davis (2006) found that fostered youth rarely attend college during emerging adulthood. With prohibitive costs of attendance and lack of support during the college application process, many fostered youth struggle to get into college (Wolanin, 2005). For marginalized groups, negative school experiences may also discourage applying to or staying in college; Hefner and Eisenberg (2009) found emerging adults of minority race, ethnicity, or low-socioeconomic status in college often face social isolation and lower mental health. To that end, the maker movement offers promise as an alternative for youth barred from the developmental opportunities available through college experiences and training available through technical schools.

3.1.3 The Maker Movement

Making as an activity stems from the innately human practice of constructing physical and digital products through an iterative process (Halverson & Sheridan, 2014). The maker movement spread from home garages to diverse community makerspaces, hackerspaces, and fab labs as a community grew around the world to support practices for designing, testing, and sharing (Brahms & Crowley, 2016). Making crosses domains like science and engineering to include arts (Sheridan et al., 2014). In the United States, making in paid makerspaces and of the kind featured in popular MAKE magazine tends to represent a White, middle-class, male-dominated practice (Halverson & Sheridan, 2014), but through growing efforts, making is reaching broader audiences to support positive development and learning.

Making is an activity that supports learning and positive development. Those who engage in making learn through constructionism (Harel & Papert, 1991), building knowledge through the act of creating something digital or physical. Martin (2015) argued that the most critical aspects of the maker movement for supporting learning include increased opportunity for fluency with technology and tools; community infrastructure, including access to other makers and mentors through events, magazines, makerspaces, and meetups; the maker mind-set described by Dougherty (2013), comprised of playfulness in experimentation, asset and growth orientation, and failure positivity; and the collaborative sharing of process and products. Accordingly, studies have found that making can support youth interest in programming (Resnick et al., 2009) and help marginalized youths make connections between their identities and learning (Barton, Tan, & Greenberg, 2016).

Despite the broad range of ways in which makerspaces are anticipated to improve learning and positive development, the educational aims for which makerspaces are designed typically fall within one or more of three categories: science, technology, engineering, and mathematics (STEM) pipeline and workforce development; inquiry-based learning; and entrepreneurship and community creativity (Vossoughi & Bevan, 2014). It is this last aim, in particular, that holds promise for EEAs. The opportunity to work creatively in makerspaces can support wellbeing, mental health, and provide the means to make to meet one's individual or community needs, for example, building a lower cost alternative to something purchasable (Taylor, Hurley, & Connolly, 2016).

Participation in entrepreneurship, likewise, can support positive youth development through building competence and other 21st-century skills (Bowers et al., 2010; Obschonka, 2014; Schmitt-Rodermund, 2007) and, for disadvantaged youth, has been found to support empowerment in the form of increased autonomy and engagement and decreased risk avoidance (Jennings, 2014). Entrepreneurship is the process of devoting resources to creating something of value and assuming the accompanying risks, responsibilities, and financial rewards (Hisrich, & Peters, 1992). Examples of entrepreneurial makerspaces vary; in one case, a makerspace was available for a membership fee, full of expensive equipment, offered difficult classes, and hosted a high concentration of professionals, while in the other, the makerspace had less expensive equipment but was free for community use for learning, entrepreneurship, creativity, and repair (Sheridan et al., 2014). In such makerspaces, access to machinery and materials can lower the cost of prototyping and production, and diverse networks promote creativity and innovative thinking; thus, even activities that start out as hobbies may evolve into accidental entrepreneurship as individuals come to value the economic potential of their work (Van Holm, 2015).

3.2 Theoretical Framework

Lave and Wenger (1991) describe learning in terms of legitimate peripheral participation (LPP); learning is a social process where newcomers gain skills and knowledge by participating within a community of practitioners and eventually move toward full participation in the sociocultural practices of the community. Communities of practice are defined not by the physical boundaries of the community but by shared practices, knowledge, customs, relationships, roles, and identities. Communities of practice self-perpetuate by assisting newcomers in LPP, ultimately resulting in more members of the community who can inherit the tradition. In order to achieve LPP, a learner must engage in the following practices on an ongoing basis: (1) engage with the community of practice, (2) acquire skills and knowledge requisite of the practice, and (3) develop an identity as a fully participating member within the community of practice.

In this study, we use LPP as a lens for analyzing and interpreting learning in a makerspace for EEAs. Prior literature informs our understanding of LPP’s three constituent parts in reference to making and makerspaces. Although makerspaces can serve as entry points to different communities of practice, for example, the engineering community, as is often the goal in the case of STEM workforce development, we focus on LPP toward full participation in the broad maker community, as this is often associated with entrepreneurial making and community creativity (Sheridan et al., 2014; Vossoughi & Bevan, 2014).

3.2.1 Maker Community Engagement

Martin (2015) characterized maker community infrastructure to support engagement as consisting a network of museum and community events, makerspaces, magazines, and online platforms. With present technological advancements, access to a community of practice is not limited to in-person interactions but extends to social media, forums, sharing platforms like Pinterest, and media like Make magazine (see https://makezine.com). Makerspaces represent an opportunity to work side by side with other makers of varying levels of expertise and benefit from their diverse experiences and ways of viewing a problem (Sheridan et al., 2014). Attending fairs where makers sell items and share practices is another way that members of the maker community typically interact, but the maker community of practice extends across so many disciplines that makers might be found in shops, museums, schools, as hobbyists in their own garages, and more (Dougherty, 2012).

3.2.2 Maker skills and knowledge

A vast variety of skills, knowledge, and practices arise from and support the maker movement due to its nature as a multidisciplinary practice. Brahms and Crowley (2016) found that making typically involves seven general practices, including exploring and questioning; tinkering, testing, and iterating; seeking out resources; hacking and repurposing; combining and complexifying; customizing; and sharing. Dougherty (2013) also argued that makers must possess a maker mind-set, which he described as a can-do, problem solving, and resourceful attitude; this is compatible with Clapp et al.'s (2016) concept of maker empowerment, "a sensitivity to the designed dimension of objects and systems, along with the inclination and capacity to shape one's world through building, tinkering, re/designing, or hacking," (p. 98). These mindsets are both desirable learning outcomes of making and beneficial qualities in makers.

3.2.3 Maker community-member identity

Lave and Wenger conceived of identity as "long-term, living relations between persons and their place and participation in communities of practice" (p. 53). Therefore, although Dougherty, at the forefront of the maker movement, describes everyone as a maker due to the nature of making as an innately human practice, self-identification as part of a community requires more than passive qualification. In the maker community of practice, a relatively new community of practitioners, skills and roles alike are varied and flexible but involve relationships among hobbyists and professional makers, as well as teaching artists and facilitators, who employ a shared vocabulary and practices (Sheridan et al., 2014). In Davies (2018), makers identified as *hackers* or problem solvers both in and out of the makerspace and felt making was to be pursued for "pleasure, identity formation, and self-actualization" (p. 184). The identities marginalized youth brought to the maker community likewise shaped their maker identity development allowed them to reclaim spaces and practices in a way distinct from middle-class White male makerspaces, e.g. working on projects in familiar community hangout spaces with peers to solve local problems (Greenberg & Barton, 2017).

In this exploratory study, we use LPP as a means of understanding the relationship between EEAs and the maker community of practice. We present the cases of three EEAs whose ongoing engagement in a makerspace depicted different engagement with the maker community of practice.

3.3 Methods

We used Stake's (1995) instrumental collective case study method to frame our research, a methodology that uses interviews, observations, and documents to answer general research questions through the study of several related cases. The cases depict the diverse narratives of three emerging adults, Nadia, Clark, and Asa, as they engage with the maker community of practice through access to a makerspace within their place of residence and an affiliated museum with its own makerspace.

3.3.1 The Makerspace

Transitional housing facility (THF) was located in a mid-size, Northeastern United States city that provided up to 2 years of support for up to 24 selected EEAs at risk of homelessness. Many of its residents were African American, LGBTQ, Latino/Hispanic, or disabled. In 2015, THF partnered with a local children's museum to build a makerspace within THF's ground floor community room, free for EEA residents' use both during the THF program and after graduation. In their grant proposal, the museum stated that the makerspace would provide residents with "one-of-a-kind opportunities to discover their skills and future potential, explore their passions, and build confidence and coping tools through making with digital and physical materials" (quoted from grant proposal). To that end, the program would also provide youth with the opportunity to apply for a part-time, paid internship to learn to facilitate at the museum and eventually replace THF's facilitator, if practicable.

With funding from the grant, staff from the museum selected and purchased tools and materials for use in the makerspace, primarily including sewing equipment, various art supplies, woodworking and soldering tools, a few computers, and some notepads and pens for jotting ideas. Two to three times a week, the facilitator the museum had appointed to THF visited THF's budding makerspace to introduce residents to the new space and assist with the development of projects. A social worker typically moderates the space alongside the facilitator. The social worker was a self-proclaimed maker herself and described her role; thus, she ensured that the residents followed community rules, like referring to nonresident adults as "Mr." or "Ms." and kept the peace between residents, all while occasionally helping residents with projects. On several occasions, other staff joined residents in the makerspace, sometimes participating in making as well, but other times merely socializing with residents.

At the project's inception, the makerspace was nearly vacant most nights, but as the makerspace became more of a fixture in the residents' lives and norms were established, especially regular hours and the provision of food at making sessions, the makerspace saw more frequent attendance. Making sessions typically lasted 2 hours in the evening on three weekdays or two weekdays and a Saturday, depending on facilitator availability and residents' interest. At all other times, the community room was locked unless used for other purposes such as staff meetings. Residents occasionally trickled down from their housing any time before the makerspace closed to chat with other residents, listen to music, experiment with materials, and eat when snacks were available. Residents were required to sign an attendance sheet upon entry into the makerspace and visit at least once a month, but the rule was loosely enforced and did not require the residents to engage in making.

By 2016, around 3–10 residents were in the makerspace at any given time but often more if dinner were available or a special event were taking place. These special events included themed nights, like a make-your-own-presents Christmas party and a cake-decorating night. On these occasions, other facilitators from the children's museum or local artists visited THF makerspace to demonstrate new techniques and activities. Residents also had infrequent but nonetheless popular opportunities to visit the museum's makerspace, either for special events to sell things they had made during fairs or to attend 21+ nights. On such occasions, the museum typically provided a bus to support residents' travel.

3.3.2 Data Collection and Sampling

In late 2015, the first author spent several sessions familiarizing herself with the space and building relationships with staff and residents before selecting residents to interview and observe. Selection criteria included residents' voluntary participation in the study, their expressed intent to visit the makerspace frequently for the duration of the study, and evidence of some engagement in making during previous making sessions. Of the five EEAs initially selected, only four continued to be residents at THF for the duration of the study; of these, the researchers selected the narratives that presented contrasting cases and had the best data quality for a final selection of three case studies. Beginning in 2016, the first author interviewed the three focal residents approximately monthly, for a total of six interviews each. Interviews were semi-structured, conducted in the makerspace or other office space at THF, and included topics like how the EEAs defined themselves in relation to making, the extent of their engagement with the broader making community, what their interests in making were, what their career goals and other responsibilities consisted of, what their experience within the makerspace was like, and how resources within the space supported their process. Staff were asked about their roles, experience, expertise, and about the makerspace engagement of the residents being interviewed to supplement our understanding of the three residents' engagement with the makerspace.

In addition to conducting interviews, the first author acted as a participant-observer, primarily taking photos and field notes in the space but also working on projects alongside the staff and emerging adults; like the residents, she occasionally engaged in a teaching role if others became interested in the kinds of projects she worked on or helped out when a facilitator was not immediately available. The first author's role in relation to the emerging adults, although announced to staff and residents during the study, was ambiguous in the sense that while staff required the residents to address them with "Mr." or "Ms.," she did not, and additionally, she was closer in age to the residents than some staff, of mixed race/ethnicity (presenting as White, but identifying as Latina), and had interests in common with a number of the youth. This facilitated trust and conversation with the interviewees, some of whom eventually opened up about difficult topics, such as the treatment of transgendered youth or struggles with responsibility toward their families while still minors. After one interview, one resident in particular remarked that it was gratifying to talk to the first author and feel heard.

3.3.3 Coding and Analysis

Our analysis relied primarily on data from transcribed interviews conducted in a makerspace with three emerging adults, six each. Interviews collected with two other residents were not included in this study due to attrition and data quality. One facilitator interview, one social worker interview, filed notes on observations of the site, and photos of projects supplemented the analysis, all of which the first author collected during makerspace sessions at least once monthly during the first half of 2016. All names used are pseudonyms.

Following Stake (1995), we applied a direct interpretation to our data by events and narrative threads. Coding was an iterative process, using both codes derived from the themes that emerged from the data and a priori coding schemes. Emergent themes included residents' definitions and values concerning making and the unfolding narratives of their engagement and interactions with the practices and community of the maker movement. The most prevalent themes suggested LPP was an appropriate lens for analyzing learning and development during the emerging adults' participation in THF's makerspace, and we organized these themes within the three parts of our framework (Table 1).

Table 3 Codes for Themes

Framework Component	**Thematic Code**	**Description**	**Example**
Community			
	Engaging	Engaging with the community of practice, in a social, productive, or educational capacity.	Asa attended special events at the museum by invitation, enabling her to meet adults within the maker community.
Skills and Knowledge			
	Prior Experience	Prior experience with community or its practices.	Clark had previously taken studio-based classes for movie special effects (e.g., makeup, latex monster costumes).
	Participating	Participating to learn practices, skills, and knowledge of the practice.	Clark experiments with a spray that allows ink to transfer from one surface to another.
Identity			
	Defining	Defining the practice.	Nadia: Does baking count [as making]?
	Relating	Relating to the community of practice.	Asa: …let's say we going to [a maker fair] or something; I get to step outside of business, boring American 401k plans, and get to genuinely be myself…
	Valuing	Valuing the practice/community.	Asa: Let's say we going to [a maker fair] or something; I get to step outside of business, boring American 401k plans, and get to genuinely be myself…

3.4 Results

During the 6 months of the study, the three EEAs Nadia, Clark, and Asa evidenced LPP within the maker community of practice. Despite similar characteristics such as prior experience relating to making or crafting, being interested in but not presently attending postsecondary education, and living in transitional housing while working to become self-sufficient adults, their relationship to the maker community varied greatly, in turn shaping what benefits they reaped from their engagement.

3.4.1 Case 1: Nadia—22, Female, Latina/Hispanic

Nadia's narrative depicts how a strong interest in making and a positive mind-set for learning can support LPP in the maker community, particularly when supported by opportunities to grow, network, and be a part of the community. Her story also demonstrates, however, how EEAs have difficult and practical choices to make when faced with adult responsibilities and limited supports. A recent addition to THF after living in a women's shelter, Nadia's professional interests were not in making:

> Cooking has always been there in my life. It's something I've always done. I've worked in restaurants constantly, whereas bioengineering…I had a love for biology through high school, through middle school…. Genetics just interests me so much. I actually went to college for genetic engineering for a year, and I did pretty well. (Nadia, Int. 4)

As was the case with all residents, Nadia had goals to accomplish while at THF, with the support of a social worker; hers included getting a driver's license, paying off her debt from school before taking more genetic engineering classes, and taking the time to focus on her personal needs and well-being after a childhood spent caring for her family. Her plans to return to school fluctuated during the course of the study, moving from summer (Int. 1), to fall (Int. 3), and finally to spring of the following year (Int. 5), after she started a full-time job working in hospital kitchens.

3.4.1.1 Maker Community Engagement

From the start, Nadia's enthusiasm for making sparked deep engagement with the maker community, first through THF's makerspace and then the museum. In her first week at THF, she attended the maker session and promptly applied for the paid, part-time museum facilitator internship. "As soon as I saw the flyer I was like, 'I have to sign up!'" (Int. 3). Thereafter, Nadia attended making sessions at THF as often as possible, befriending other residents, and working on a variety of practical or experimental projects. The internship took her participation in the maker community from THF's makerspace to the museum, where she learned from museum facilitators with different areas of expertise:

> Since I'm an intern, I help everyone else with their own project. But everyone has such a vast variety of projects, and everyone is so talented. Honestly a lot of people don't need help. It's the newer tenants…who still see [the makerspace] as a shiny new area; they're the people who really need to be led through the process still. (Nadia, Int. 3)

As the study progressed, however, other opportunities that Nadia felt better addressed her goals and responsibilities competed for her time and, ultimately, won. After befriending a fellow resident in the makerspace, she learned of a higher paid, full-time, and entry-level work opportunity in the kitchens of a hospital. Nadia took the job, initially saying that she would juggle the internship, work, and school but shortly quit the museum internship and cutback on visits to the makerspace and museum. With this job, she believed she would be able to pay off her previous debt completely and become self-sufficient, allowing her to pursue restaurant management or return to school.

3.4.1.2 Maker Skills and Knowledge

Nadia's engagement in making practices and skills began long before the start of the study and expanded through her time spent making to meet personal needs and training to facilitate making for others.

> My grandmother…taught me how to cook, she taught me how to speak Spanish, she taught me how to crochet…. Unfortunately, we don't have a good relationship anymore, but…. She can't take away what I've learned from her. (Int. 1)

THF makerspace represented a renewed opportunity for her to pursue her interests in making-related domains: "I've always had an interest to make things, but I never had the opportunity to be able to make things. I never had the time. I never set aside the time for myself" (Int. 1). Throughout her time at THF, she relied on support from museum facilitators, THF staff, peers, other guest maker community "old-timers," and a can-do attitude to move her learning along.

> It's all something I've never tried before. So I try not to hold myself to any standard. I don't have any preconceived notion of how it's going to turn out…. [My silk-screened T-shirt] turned out really great. I also did marbling with this dinosaur pattern. So it's the first time [the facilitator] tried marbling, first time I tried marbling and screen printing, and it turned out marvelously. (Nadia, Int. 3)

She started with crochet, a familiar skill, working with the first author's help to construct a padded bed for her cat that ultimately proved too time consuming to be of immediate, practical use. She had a therapy cat coming to live with her and had just moved into THF housing but had limited resources and saw the makerspace as a means of fulfilling needs (see Figure 3):

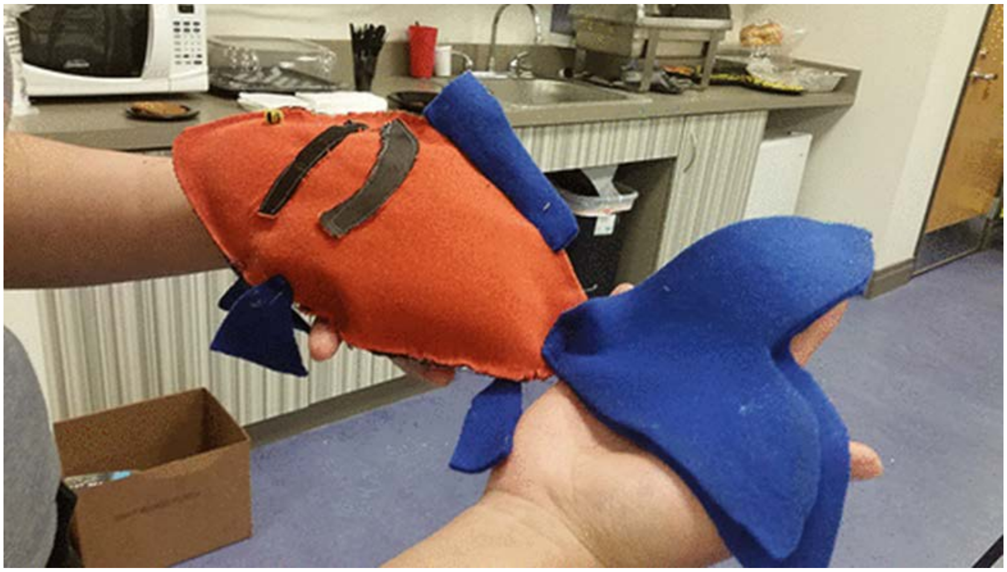

Figure 3 Nadia's catnip fish toy.

> I’d love to make a cat tower, a cat scratching post, some little kitty toys, honestly everything for my cat…. I’d love to learn how to make a blanket, I’d love to learn to make an apron here…. Whatever projects they have here. (Int. 1)

The crocheted bed proved complicated, and while she later finished it, in the meantime she constructed one with the facilitator’s help by sewing a pillow and assembling a wooden frame (see Figure 4).

Figure 4 The facilitator helps Nadia work on her cat bed.

The wooden bed was the first of many practical projects Nadia made over the course of several months. She also experimented with mini-projects on offer at THF makerspace and learned new skills through her internship. As an intern, her skills and knowledge broadened rapidly as she learned to use and facilitate others' use of materials and tools available at both the museum and THF. After she quit the internship, she continued to practice and experiment on rare days off from her job, but as a result considerably slowed her progress.

3.4.1.3 Maker Community-Member Identity

Nadia's view of the maker community reflected the belief that it was an innately human practice; throughout the study, she used inclusive language to suggest that she was a maker because all people are makers. "Making [is about creating] something by hand, to be able to create something of your own knowledge with raw material" (Int. 1). "I think almost everyone's a maker. We make things, I think, as a society, every day, whether it be a photo, whether it be food, whether it be a piece of clothing…" (Int. 3). She expressed uncertainty about the boundaries of making practices; however, when asked what she had made in the makerspace, she first excluded a cake she had baked from scratch and decorated on a cake-decorating guest maker night at THF makerspace, but then asked, "Does [baking] count?…. Then I'm always making food upstairs, always" (Int. 5). When asked who defines what making is, she said "[The facilitator], 'cause he just pulls all these ideas out of nowhere and creates the most wonderful items" (Int. 5). While she had the museum internship, she viewed herself as having a role within the maker community, locally, but despite referring to her responsibilities at THF and the museum, and believing that residents of THF would say she was a maker "because I would help them [with making]" (Int. 3), she never referred to a maker community beyond the sites.

Nadia's inclusive view of making as a practice did nothing to diminish her view of making as a valuable practice for her and for others. She believed making was helpful in meeting her goals and needs outside of making, including support for her well-being; "I think [the makerspace] really calms me down…. Which lets me be more successful in my life…. Just because with stress, I just feel…bogged down and so limited" (Int. 1). She also felt it was a means of learning important skills for her and others:

> It'll show me how to do different skills which I could learn in the future, and teach my kids in the future…. Especially in our generation, those skills are dying out, so I think it's really essential for us to learn right now, to keep those skills going. (Int. 1)

This belief which persisted to the end of the study: "I really think [making] effects our day-to-day life, because we all have to make things…. I think everyone uses a making skill every day of their lives" (Int. 5). To that end, Nadia was grateful for access to the makerspace: "I think [the makerspace is here] to help us learn and grow our talents, because honestly a lot of people here haven't gotten that chance, so this is almost like a second chance that we never had…" (Int. 4).

3.4.2 Case 2: Clark—25, Transgender Male, African American

Clark's story depicts the tension between having a fully formed but unsupported identity and trying to form a new identity as he made the involuntary shift from attending college to become a professional special effects makeup and costume artist to exploring how a makerspace could support his interests and needs and, potentially, help him find new goals. Already at THF for about a year prior to the start of the study, Clark worked as a security officer for a bank and as a mentor for lesbian, gay, bisexual, and transgender (LGBT) youth.

> I am trying to find a job that pays me to travel and talk to youth in foster care and LGBTQ…. Right now I just want to find a house that's forever, and maybe move to Philly, and sculpt. That's my personal goals as of right now. (Int. 1)

He had gone to art school for entertainment design and special effects makeup but dropped out when his funding depleted, prior to the start of the study. He dreamt of working in and on movies.

> Creatively, I really want to make a full-body [latex monster suit]…. I would love [to do the costumes and makeup for movies]…. And also to be a creature in one of those [movies]…. If I could ever do that, just once in my life, I'd be so happy…. I could die happy! (Clark, Int. 2)

Clark's plans to move to Philadelphia solidified as the study wore on: "Philly has a better trans community and everybody's more open" (Int. 3). Initially, he made plans to move there during the summer, but after being fired from his job near the end of the study, he had to postpone them. He still expressed optimism: "That's okay, things happen for a reason. I always believe that" (Int. 6). In the next year, he expected he would have to leave THF and the makerspace "because, you know, two years, so I'll probably be out of [the makerspace]" (Int. 6). Clark still planned to move to Philadelphia when he could, to start a business sculpting accessories for transgendered men.

3.4.2.1 Maker Community Engagement

Clark's on-again, off-again relationship with the maker community was a testament to his innate need for a creative outlet but frustration when comparing the makerspace to art school. His experience with making-related practices and communities started in his childhood; he sculpted on his own, shared his projects on social media, and eventually studied special effects costuming and makeup in college. Clark's involvement with the maker community (e.g., in spaces specifically referred to as "makerspaces" and where practices were referred to as "making") began with THF makerspace, which failed to meet his expectations:

> …. I go there, and I have all these ideas and I'm like, "I'm going to settle on just this one idea," and then we don't have the materials for it. And then I'm like, "Well, I'm going to do *this*," and they're like, "Well, we don't have [tools] for that either." So I just give up. (Int. 5)

Despite his frustration, he still came to the makerspace on nights he remembered it was available:

> [I come] every so often, because I keep forgetting that it's on a Wednesday…. It's my day off so I usually sleep all day, be a grandpa. And then I'm like, "Wow, so that was today…" (Int. 2)

Clark’s participation in the makerspace typically consisted of coming late, eating, and socializing briefly with other residents, but he was popular and well received, sometimes stopping by with his dog. On occasion, however, Clark did come early enough and stay to work on making things or show his work to others in the makerspace. Staff recognized Clark as a valuable and talented member of the THF makerspace community, sometimes inviting him to special events at the museum, including making items to sell at a maker fair. As long as the makerspace was available to him, Clark repeated a pattern of occasional social appearances and engagement in making projects. After Nadia resigned from the makerspace internship in April, Clark expressed interest in taking it but did not apply because he said he would not be able to earn enough income doing it. He continued making outside of the makerspace and sharing his sculptures through social media.

3.4.2.2 Maker skills and knowledge

Clark’s learning in the makerspace took place sporadically over tumultuous journeys that often ended when Clark abandoned his work partway. He had grown up loving to sculpt, inspired by mythical monsters and special effects in film, and had already taken college-level courses in pursuit of his well-defined interests. As a result, he frequently came to the makerspace with an idea in mind and no materials to support his plans: sculpting, in particular, required expensive materials that staff could order, but Clark said his request had been turned down:

> I’m a sculptor, and they don’t have anything that I need. What you need for sculpting is supplies that’s expensive…. If they’re going to spend a lot of the money on it, more than one person needs to want it. And I’m the only one that’s a sculptor. (Int. 4)

Clark’s exploration and interest was not restricted to sculpting; however, he said he was “always the person that liked to take things apart and figure out how it works and put it back together” (Int. 1) and had helped his foster mom put up a pool and build an attic. In the makerspace, he helped assemble shelves and tackled other practical projects to serve his individual needs, most notably silk-screening a series of hand-stenciled T-shirts in bulk so that he might sell them (Figure 5).

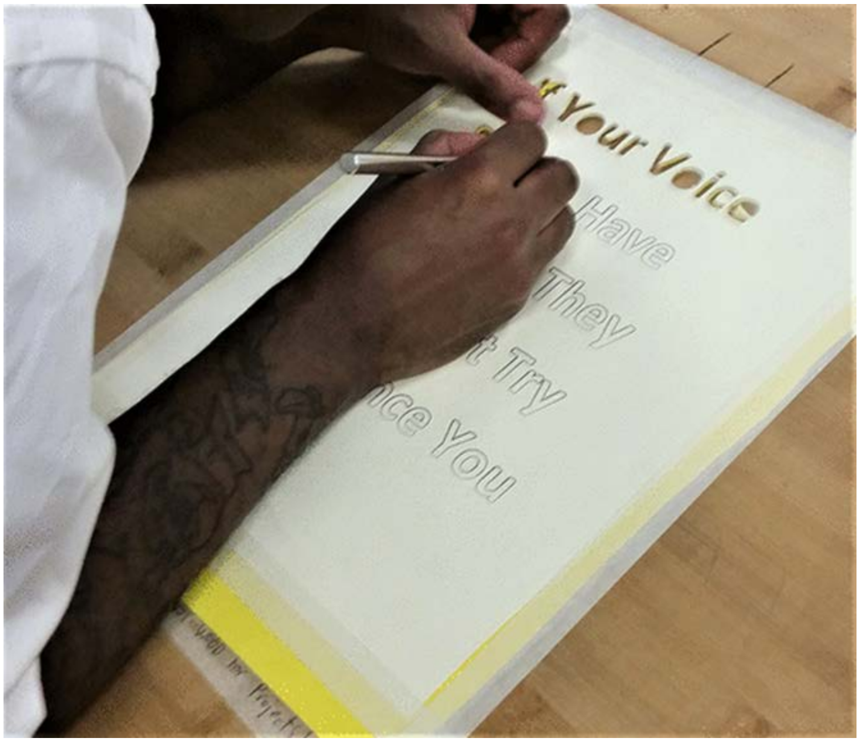

Figure 5 Clark cuts letters to make a silk-screening stencil.

> This [design] that I came up with…. I'm silk-screening it on shirts and putting a picture on the front, and then I'm going to be selling them at my organization that I work for. So that money will potentially be going back to the organization. (Clark, Int. 3)

The project took patience and diligence to design the stencils, painstakingly remove the inked areas, and silk screen T-shirts, something Clark had grown fond of at THF. It presented difficulties, however, and by the end, Clark had learned how to improve the process in the future:

> I have the two logos [done]…. My fingers started hurting and I gave up on [the others]. I'm going to still finish it…. I'm very mad though because there's another way of doing it that involves no cutting, you're just printing and then ironing it on. I'm so mad." (Int. 5)

The makerspace also provided Clark with the opportunity to use materials and tools he would not have thought to experiment with, such as an egg bot (see Figure 6) designed to draw on spherical surfaces and a spray that allowed him to transfer ink from a printout onto a surface like wood. “[Ink transfer is] really witchcraft! It’s amazing” (Int. 2).

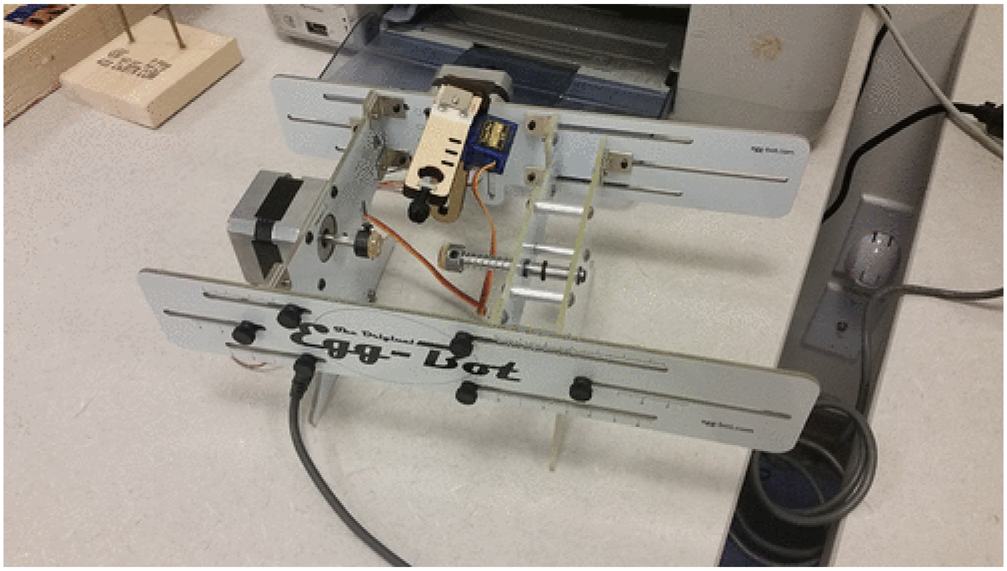

Figure 6 Clark uses the Egg-Bot to decorate a ping-pong ball.

Clark’s biggest hurdle to learning in the makerspace, however, was a tendency to start complex projects and stop before he could complete them:

> I’m just kind of a perfectionist with that stuff. I think I’m scared how it might come out. Because when I first started, everything was perfect, and then when I get on the sewing machine, it [messes up], and I’m like, “Welp! Time for something else.” (Int. 2)

At such times, staff attempted to encourage him to persist, with inconsistent results. In the case of the silk-screened T-shirts, Clark refused to give up despite challenges and sore fingers, insistent on meeting the practical goal he had in mind.

3.4.2.3 Maker community-member identity

Clark’s identity as an artist was entangled with his sense of being a maker, but he expressed no distinct attachment to the maker community of practice. Making was, to him, about making something and being creative. “Everybody’s creative in their own little way…. [In the makerspace] you can make jewelry or clothes—or [someone] made a chair…. Whatever you want to do” (Int.

4). He did not place clear boundaries between makers and non-makers or identify a community to which makers belonged; instead, he believed anyone qualified as a maker. "Well because if you think about it, like, everybody has made something, it doesn't matter what it is" (Int. 5). Clark's identity as a maker seemed to be a repackaging of his artist/sculptor identity rather than as a product of feeling that he was becoming part of a maker community of practice that included sculptors. When not prompted to talk specifically in terms of making, he described himself as a sculptor and was proud of his accomplishments as a sculptor:

> All of my sculptures I am very proud of, and I have an attachment with them, so when somebody's like, "Yeah, would you like to sell that? Pick a number." I'm like, "Oh, that would be amazing! But no." (Int. 1)

When questions were framed in terms of making, he said that being a sculptor made him a maker, he said, "Because you're making art" (Int. 2), and that, "Everybody who knows me personally and everybody who doesn't know me [would describe me as a maker], because I put a lot of stuff on my Instagram and Facebook and stuff like that" (Int. 5).

To Clark, the community and makerspace were important as a means of socializing, meeting individual needs, and having a creative outlet.

> I think [making is] important because it's a way for me to be creative…. This is reality, and I make stuff that's not a reality, so I make all these monsters and stuff and…it's just like, I'm going to make *this* and it's going to be *awesome*, and I'm going to need to make *this* with it so it can be awesome *with* it, but then I need to make *all of this*! (Int. 5)

For Clark, the makerspace's greatest asset was the "sense of community; instead of everybody all crammed in their room and going about their day-to-day lives, there's actually something we can all do in there" (Int. 3). He stated that he would lose access to the makerspace when he left THF's housing program, due to the fact that he intended to move to a different city. Resources available at the museum had caught Clark's imagination, however:

> I really want to build on a 3D printer…. If they had classes on how to work with that software on a 3D printer, you know how much stuff we could make? Let me tell you, I'd

> be on that thing every day. They're going to have to tell me, you know, that I'd have to start paying, because I'd be on it. I would. (Clark, Int. 6)

He hoped that in the future, guest makers might show him more about special effects makeup, how to make miniatures, and how to build ball-jointed dolls, a special kind of doll with joints that move more naturally than traditionally jointed dolls.

> [THF makerspace] is more open to…hearing what we want to do now. Before it was just like sewing and jewelry making, now it's sewing and jewelry making, crocheting, painting…. Next week I'm going to be making a house out of Popsicle sticks. (Int. 6)

Clark valued his practical projects, such as T-shirts to earn money for himself or his LGBT organization or a pallet bed for his dog, and enjoyed pride in his accomplishments: "I felt good, like I've achieved something that's going to make me money because I'm going to make a lot of [shirts] and then sell them" (Int. 5).

3.4.3 Case 3: Asa—20, Female, African American

Asa's narrative highlights a harmonious alignment between her interests, identities, goals, and opportunities through engagement with THF's makerspace. She was the most veteran in the makerspace, having been there since its inception almost a year prior to the start of the study. She was ambitious, had diverse interests, and was unafraid of hard work. At the start of the study, she worked at a security desk at a hospital and was not in school, but trying to get into school with the ultimate goal of going to an Ivy League school for sports medicine. She planned on becoming an orthopedic surgeon, as she was fascinated with the human body from an early age and loved sports.

> I had to wean myself off of doing a sport all day, every day, to become an adult…. I can't have a practice for three hours, I have homework and bills and stuff now…. [And] I'm actually a nerd. I don't admit it very often but it's true…. [So] I was like, "What profession is there that I can combine science and sports that's not overly analytical?" Because when you tend to analyze everything, it's overkill, and it's not as fun. And I really love interaction with people, understanding things, more than I do analyzing them…(Asa, Int. 4)

Asa also dreamed of becoming a professional performer:

> I would like to become the fat version of Beyoncé…. I feel we are just misrepresented. There's a lot of talent [in] the plus-size community, but we just get passed over because we're big and we don't conform to [society's standards]. (Int. 2)

She hoped being a successful performer would enable her to pay for medical school easier. She had been performing for 10 years in churches and showcases, and during the study, she increased her focus on recording music and taking hip-hop classes. She later got a second job working at a custard shop and planned on going to school in the fall. By the end of the study, her 2 years at THF were almost up and she was ready to move out. She planned on "getting an overnight job somewhere, hopefully, so that when I start school in August, I don't drive myself bat-crap crazy with trying to study and work and support myself at the same time" (Int. 6).

3.4.3.1 Maker Community Engagement

Asa's engagement with the maker community was one of steadily increasing and expanding involvement and connections. Known to be fond of arts and crafts practices among THF staff, Asa was one of the first residents that staff invited to the makerspace, participating frequently either socially or tackling projects of varying complexity.

> My makeshop journey began when [staff] approached me and said, "Hey we have this brand new idea, and it's called [a makerspace], and it's going to be here in the building a couple nights a week. I think it's something that you'd be interested in, because you are very interested in arts and crafts." So I was like, "Okay, that sounds so fun!" So, I decided to come…. I've actually been coming here since the program started. (Asa, Int. 2)

She quickly became a fixture in the makerspace, both as a maker and the center of attention, joking around with residents at a crowded table. Over time, staff recognized her, like Clark, as a valuable, talented, and responsible member of the makerspace. As a result, she was repeatedly invited to special events, like a museum showcase, sell her work at a fair, and talk about the importance of the makerspace to her in a video to be displayed at a museum gala. Through this experience, Asa was also able to network for her future plans in orthopedic surgery.

> I actually had a chance to sit down and talk with the executive director of the [museum], and she's like, "Yeah, so I heard you want to be a surgeon. I think that's cool. So, basically, my neighbor is the second head in charge through [a university's] medical school. She's a surgeon, and…. I want her to be your mentor." And I was like, "When are we doing this?! When is this happening? I'm so excited!" (Asa, Int. 6)

Asa had fewer opportunities than some residents to benefit from the museum resources, specifically because of her age and a conflict with her schedule, "If there's [an adults-only event], I'm at work. And then for a while when I wasn't at work, I wasn't 21" (Int. 6). Nevertheless, when guest makers were invited to THF's makerspace, Asa took advantage of the opportunity to learn something new:

> [Guest maker nights] make it just that much more fun, because sometimes I do have artistic block and they're like, "Oh but you can decorate a cake," and I'm like "Bro! I can decorate my cake and eat it, too." (Int. 6, see Figure 7)

Figure 7 Asa bakes and decorates a cake at Cake Night in the makerspace.

She continued to return to the makerspace even after successfully transitioning out of THF.

3.4.3.2 Maker Skills and Knowledge

Asa drew readily on the inspiration, support, and knowledge of others to learn in THF's makerspace.

> [Since the makerspace opened] it went from just a big boring community room to…. I think when we started there was probably me and maybe one or two other people that came consistently…. Now I would say probably sixty-five percent of the people, if they're not working…come, they enjoy it. It's like I can go in there, just look around, and get inspired by little dumb stuff. (Asa, Int. 4)

Like many other EEAs in the makerspace, she had come to THF with some experience with arts and crafts knowledge from family members and K–12 schooling but had found an interest in making from a young age:

> I started at a young age. My grandmother, she used to have an old-school sewing machine, so I used to try and operate it at the age of four and poke myself with the needle…. I've always been pretty hands-on…. And I took a lot of art classes in high school and outside of school. (Asa, Int. 1)

In the makerspace, Asa experimented gleefully on guest maker days, took advantage of the space's practical use for making items she needed, and at other times, just took inspiration from the materials available or others' projects. Her projects varied from painting on a canvas she had built and stretched herself, to cake decorating, to making a dress for a performance. One project took the majority of the study to complete, a round Batman-logo pillow (Figure 8), and through a series of trial and error and the support of staff proved a valuable learning experience for Asa.

Figure 8 Asa eats dinner and works on making a Batman-themed pillow using spare materials.

> It [was] my first time making a round pillow. Tracing [the logo], cutting it, and stitching it by hand was the easy part, but…it ended up [oval] because I don't know how to use a pattern…. I just sort of guesstimated. (Int. 3)

At times, she felt like giving up because the quality was not what she expected. "[The stuffing] didn't fit and it was really frustrating, and it was disheveled, and I was like, 'It looks like a fourth grader would have done this'" (Int. 3). She explained that staff supported her through her challenges: "From the beginning [the facilitator] was just like, 'You need to work on it.' And he was like, 'Do you need help tracing it? Let's trace it.' And he's just been very supportive" (Int. 3). In the end, she was proud of her accomplishments:

> I can be a bit of a perfectionist, so when I had originally planned it…. I wanted it to look like I went to a furniture store and I found this diamond-in-the-rough Batman pillow…. That's how I initially thought it was going to come out…. I'm very happy with the end result, because…it was definitely a challenge and I didn't give up on it, and…it's still pretty presentable. (Asa, Int. 5)

Asa was particularly proud of a painting of a mother and child she called "Roots." To her, it was evidence of growth as a maker and artist and opened up possibilities of turning her interest into a means of making money:

> The more I was looking at it, and I thought about it, I was like, “Yo, this is dope! I can’t believe I just did this!”…. You can feel what the artist is portraying and I feel like for me, artistically speaking, it was a big step…. To be able to take what was in my brain and actually throw it on a canvas and actually have it turn out how I wanted it to…. I was going sell it but I was like, “I can’t, it’s the first one!” (Asa, Int. 5)

3.4.3.3 Maker Community-Member Identity

Relationships and exposure to the maker community of practice were critical to Asa’s development of an identity as a member of the maker community of practice. In addition to the affirmation of being invited to speak at the museum gala through a video, staff encouraged Asa to consider selling things she made and viewed her as artistic. She was among the first residents to be told about the makerspace, as staff felt she would particularly enjoy it. Like Clark, Asa’s definition of making focused on arts and crafts, but she felt it was open to interpretation.

> At makeshop we make stuff. Arts, crafts, drawing painting…. You can make anything. It doesn’t even depend on what you’re making…. You don’t even have to know what you’re going to make to make something. (Int. 1)

She viewed herself as a maker: “I feel like my maker style reflects my personality, so it can be very rambunctious, it can be goofy and sporadic” (Int. 3).

Of the three EEAs, Asa was the only one to use language suggesting that that there was, in fact, a maker community somehow distinct from the outside world. Like Clark and Nadia, Asa believed that “everyone qualifies as a maker…. One person can be good at drawing or painting, another one can be good at sewing or coloring” (Int. 5). But she also acknowledged that “maker” was not a term in common use: “I feel like [people] wouldn’t necessarily use the term ‘maker’ because I feel like…the general public is not familiar with the term maker or what if vaguely describes what a maker is” (Int. 5). To her, being a part of the larger maker community was also integral both to learning more about making and to being herself.

> You're an adult, but then let's say we going to [a maker faire] or something; I get to step outside of business, boring American 401k plans, and get to genuinely be myself and be around people who appreciate things the way I do…. You can resonate with people better. (Int. 5)

She described making as a community activity rather than a solitary one, despite infrequently collaborating on projects: "Just to be able to be a part of a group of people that come together and have separate ideas…then all come together collectively…is amazing" (Int. 2).

Asa believed engagement in making was valuable and important to her well-being and growth. She chatted in the makerspace about selling things she made online or in a shop and contemplated taking business classes when she returned to school. She valued any opportunity for self-expression, something she mentioned repeatedly throughout the months of the study, and from her first interview defined making as an opportunity for self-expression. "Making [is] being hands-on and free and expressing yourself" (Int. 1). In addition to supporting her self-expression and progression as an artist, she valued making for the opportunity to hone dexterity: "…Being a doctor, [you're] working with your hands, and when you're a doctor the body's your craft…" (Int. 2). She described how making as a practice supported her ability to persist as well:

> I definitely learned patience because if you force things like [the batman pillow], you're going to get frustrated and you're not going to want to finish it. I've learned that it is okay that when things seem overwhelming…to take a step back and…just get it done when you can, not when other people feel like it should be done. (Asa, Int. 3)

Asa also identified the maker community and its infrastructure as critical to her growth as a maker.

> I want to go to [an adult making event] soon and be around adult makers, be like 'Oh so this is what the adult making world looks like'…. It just unlocks another level of making. (Int. 6)

The makerspace, in particular, provided her with valuable opportunities "[to] unlock your creativity, and to learn new things and try different things that you probably usually wouldn't be able to do or afford, because I know I can't afford a wood [burner] and that sort of stuff" (Int. 4).

After successfully transitioning out of THF in the summer, Asa continued to visit the makerspace to socialize with friends and work on projects.

3.5 Discussion

EEAs face barriers to access and continued participation in college (Courtney et al., 2007), but the three cases of LPP (Lave & Wenger, 1991) presented in this study illustrate how access to a makerspace could provide alternative support. Despite similarities in their artistic interests and limited awareness of making, each engaged differently with the maker community, obtained different skills, and formed different kinds of identities. Only Nadia participated in the proffered internship, learning much in a short time, and then resigned when the possibility of self-sufficiency conflicted with her creative interests. Clark engaged more in creative pursuits outside the museum and THF making community than within it, believing the makerspace frustrating and ill-suited to supporting his interests in sculpting, but ultimately broadened his experiences with making through the space and had practical opportunities to develop as an entrepreneur. Asa’s dreams expanded to include entrepreneurial aims after positive experiences with the maker community, while networking opportunities through the community bolstered her non-maker goals. Through a comparison of their narratives, implications emerge for those seeking to study and support the development of EEAs through makerspaces, community organizations, and entrepreneurial experiences.

3.5.1 Legitimate Peripheral Participation

3.5.1.1 Maker Community Engagement

Community engagement is a critical component of learning through LPP but connecting pathways between organizations can be a challenge for those seeking to support EEAs' engagement with a broader community of practice (Akiva, Kehoe, & Schunn, 2017). The design of this program supported the three EEAs' connections between the THF makerspace, museum, and other practitioners within the local maker community. Nadia, Clark, and Asa were all at a point in their life of directing their own learning pathways without support from parents and teachers. They received alternative forms of support in that social workers who knew their interests encouraged them to attend museum events. Familiarity with the breadth of the community of practice meant that some, like Asa, recognized the need and opportunity to identify and participate in makerspaces outside of THF in the future. Means of navigating the community while THF were similarly valuable; without resources provided through THF like a free museum shuttle or bus pass, the cost of transporting themselves to other events may have prohibited participation. Additionally, barriers like age restrictions and work scheduling conflicts at times prevented all three from participating.

3.5.1.2 Maker Skills and Knowledge

Perhaps because of the variability within the maker community itself, participation in the skills and knowledge of the maker community of practice can look and be paced different for everyone without invalidating individual growth and experiences (Sheridan et al., 2014). Through training to become a teaching artist and an eagerness to try everything, Nadia experienced the breadth of making available at both THF and the museum, the latter of which mainly consisted of short-term projects that could be done with children. Clark had a different attitude toward exploration and came in with a different level of expertise but still found new interests through moments of newness and surprise and explored entrepreneurship with his intricate silk-screened T-shirt designs. Asa's breadth of exploration sat between the two, but she completed projects of varying levels of difficulty and duration, enabling her to develop different skills and competencies. Despite this variety of participation, each took away what they needed from their experiences while still progressing toward a new level of expertise.

3.5.1.3 Maker Community-Member Identity

Engagement with the maker community of practice and learning the skills and knowledge of makers supports the development of a maker identity (Davies, 2018; Greenberg & Barton, 2017). The nature of participation and identities with which these EEAs entered the community, however, helped shape their unique maker identities. Through experiences at THF and the museum, the EEAs began to form understandings of the language and concepts around making, developed a sense of how they valued it and what it was for, and who existed "within" rather than "without" the maker community. Nadia, Clark, and Asa all talked about making as something "everyone" does, which is a core tenet of the maker community, as it is discussed in popular sources like Make Magazine. Nadia's exposure to making was primarily focused on teaching young children at the museum that anyone can be a maker. Clark's preexisting sculptor identity tied him more closely to the art community. Only Asa suggested that makers have a conscious, identifiable distinction from non-makers when she described wanting to go to making events where she could be with like-minded people and be more herself.

3.5.2 Other Key Findings

Although youth organizations often focus on developing interests and intrinsic motivation in children, supporting the learning of EEAs requires more attention to extrinsic motivators and the costs of their participation (see also Akiva, Cortina, & Smith, 2014; Wigfield 1994). In this study, the EEAs often had little free time to come to making sessions, might have to wait weeks for the materials they needed to arrive whether they could be ordered at all, and were less likely to complete projects without practical value. Fortunately, each also found opportunities for the makerspace to help them meet individual needs or goals, and all experimented with tools and materials they had never seen before, experiencing moments of triggered interest, the first phase in developing deeper interests in domains (Hidi & Renninger, 2006). Becoming self-sufficient is likewise of utmost importance to EEAs, and thus practicality and competing responsibilities are a constant factor in their ongoing engagement. For some, making presented an opportunity for addressing responsibilities and needs, such as Asa's plan to sell handmade items or Clark's plan to sell accessories for transgendered men. But for Nadia, there was not time or enough stability through the internship; therefore, despite strong intrinsic motivation, she was unable to maintain high levels of participation.

Learning research in makerspaces for youth often focuses on STEM educational makerspaces, emphasizing the importance of digital tools, competences, and technological interest (e.g., Bevan, 2017). But making is more than STEM; many makerspaces also value entrepreneurship, aesthetics, and creative work. Like youth in Sheridan and colleagues' (2014) comparison of three makerspaces, the EEAs in our study capitalized on opportunities to repair and make items that they needed or could support entrepreneurial aims. Asa, for example, indicated that opportunities for self-expression motivated her making, as they supported her needs and artistic development. Clark, though disappointed with the available materials, nevertheless returned to the makerspace frequently because it had the potential to address his needs to be creative and artistic.

3.5.3 Limitations and Future Directions

Our findings suggest that the impact and value of a maker program for vulnerable EEAs requires understanding of the needs and motivations of EEAs, and that, even with seemingly few resources, access to the maker community can have a meaningful impact for this population. Here, the community of practice included a museum, local makers, teaching artists, and the youth at THF makerspace, but it could have included a broader network online and through local maker businesses had the youth in this study been guided to take advantage of access to engage with more of the maker community. This study only captured a glimpse of EEAs' experiences in such an experience, raising questions like: What would have happened without social workers in the space? How would a program more closely targeted toward entrepreneurship or workforce development have benefitted them differently? What is the longitudinal impact of participation in a program like this for EEAs? What other developmental and psychological benefits are there for emerging adults with trauma or high levels of responsibility to participating in makerspaces? How do EEAs seek out maker community engagement on their own? Such questions were beyond the scope of this exploration but merit future study.

This study bears practical implications for organizations seeking to support EEAs as well. Staff may find that supporting EEAs' learning is to be challenging when participation is voluntary and drop-in, resources are limited, and staff expertise does not capture the diverse range of learners' interests, challenges not unlike those other youth program leaders face (Larson & Walker, 2010). These were all challenges in this study, but the EEAs each developed positively through their experiences regardless of the program constraints. Work schedules and expenses of transportation can also diminish EEAs' abilities to partake in a program, particularly if the housing they must leave from and return to is in a high-crime and poor infrastructure area. Programs can take means of access into consideration. Finally, organizations seeking to support EEAs' development should consider EEAs' perception of the practical value of engagement in offered activities. Ultimately, EEAs are burgeoning adults with more responsibilities and pressures and fewer supports than other emerging adults but who, in this case, dreamed big and could accomplish much through participation in a community of practice.

4.0 From Compliance to Reliance in Makerspace Groupwork: Learning to Document and Documenting to Learn

As teachers seek hands-on, project-based alternatives to traditional classroom learning to engage youth in STEM, the practices, challenges, and cultures of in-school and out-of-school time collide, raising questions about how to assess growth and support learning in nontraditional contexts. Documentation can play a vital role in making students' thinking and learning visible for teachers and make it possible for students to engage in long-term groupwork, but creating useful documentation requires more than knowing how to use Snapchat or Instagram. To better understand students' documentation practices, we studied a team of high school students tasked with designing a working drone over the course of several months. We explored how students came to view and value documentation practices, how their documentation practices evolved as a group during the project, and how in turn these practices shaped their making and learning process.

Keywords: makerspace; documentation; noticing; STEM; high school

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4.1 Literature Review

The United States Department of Education describes STEM education as an objective of both individual and national importance:

> In an ever-changing, increasingly complex world, it's more important than ever that our nation's youth are prepared to bring knowledge and skills to solve problems, make sense of information, and know how to gather and evaluate evidence to make decisions. These are the kinds of skills that students develop in science, technology, engineering and math—disciplines collectively known as STEM. If we want a nation where our future leaders, neighbors, and workers have the ability to understand and solve some of the complex challenges of today and tomorrow, and to meet the demands of the dynamic and evolving workforce, building students' skills, content knowledge, and fluency in STEM fields is essential. We must also make sure that, no matter where children live, they have access to quality learning environments. A child's zip code should not determine their STEM fluency.

Although STEM-related classes are a required part of school curriculum, the quality and depth varies across the nation, and the STEM workforce remains characterized by an overrepresentation of white and Asian males; it stands to reason that traditional classes are not enough to engage youth in life-long STEM learning and practice. Indeed, students' love of science has been shown to diminish over time with exposure only through traditional classroom experiences with science, while informal science can help bolster and retain students' fascination (Bonnette & Crowley, 2018). Blurring the lines between informal and formal STEM learning through non-traditional classroom experiences may be a key part of providing equitable access to engaging experiences for all students. The maker movement in STEM education promises to do just that.

4.1.1 The Maker Movement in STEM Education

In recent years, policymakers and educators have seen the rise of an educational movement to promote STEM or STEAM (which includes arts) learning through hands-on self-directed construction, the Maker Movement (Vossoughi & Bevan, 2014). *Making* can be described as the human practice of constructing physical or digital products from the resources one has available to them (Halverson & Sheridan, 2014); making can be the powerful foundation for a STEM learning experience (Bevan, 2018) and so much more. Through the process of creation, children and youth research, design, problem solve, interact with tools and materials, and challenging their preconceived theories about what might “work” to come to better understanding of concepts and materials; Harel & Papert (1991) called this kind of learning *constructionism,* building on Piaget’s theory of constructivism, which postulates that individual knowledge is constructed through experiences. Unlike instructionist teaching practices, students who make engage in hands-on projects that typically allow them to pursue their own direction of inquiry, if not their own interests (Kafai, 2006). This gives students a chance to apply concepts and engage in scientific reasoning first-hand. A recent report, *a Nation at Hope* (2019), likewise showcased the potential of making in schools for incorporating social and emotional learning into day-to-day practice. In addition to offering a different way to learn content, making also promises to improve equity in STEM education through access to motivating experiences in non-traditional contexts; multiple studies have found improved interest and confidence from STEM making for students who remain underrepresented in STEM fields in the United States, especially girls and youth from marginalized cultural and racial groups (e.g. Calabrese Barton, Tan, and Greenberg, 2018; Barajas-Lopez & Bang, 2018; Davis & Mason, 2017).

4.1.2 Educational Makerspaces

To introduce maker learning to K-12 settings, some schools have begun providing makerspaces to their students, dedicated spaces and tools for making activities (Stornaiuolo & Nichols, 2018; Baker & Alexander, 2018; Craddock, 2015; Fields et al., 2018). Makerspaces typically provide makers with a combination of physical and digital tools, e.g. 3-D printers and sewing machines, materials for making, and facilitators or teachers who can guide the making process, with wide variability from one space to the next (Sheridan et al., 2014). Hira and Hynes (2018) captured this variability in a framework called *people, means, and activities,* arguing that the ability to qualify differences from one makerspace to the next was critical to "realizing the educational potential of makerspaces."

Notably, Hira and Hynes' (2018) framework is limited in the respect that it does not account for differences in the context in which the makerspace is situated, particularly in schools. Bringing practices from out of school contexts into in-school spaces reshapes the potential of makerspaces for STEM learning. Fundamental organizational and structural differences of schools to OST contexts shape the types of activities, means, and people that would exist in in-school makerspaces and in turn, the implications for learning; e.g., teachers in schools face pressures to quantify and demonstrate growth in their students on proscribed dimensions, but may be unprepared to measure the additional dimensions of growth their students display in an ever-changing context (Salvia & Ysseldyke, 2001). School policies and culture can discourage and even prohibit students' engagement with controversial topics (Evans, Avery, & Pederson, 1999); it is conceivable that the girls in Greenberg and Calabrese Barton's (2017) study would not have been encouraged or even permitted to design a project that involved researching sexual assault in some public schools.

Conversely, the cultural context and resources of schools offers unique affordances for learning through making uncharacteristic of informal learning settings. Students' attendance is mandatory and engagement with the same teachers and students is long-term (Darling-Hammond et al., 2019), meaning that teachers may engage students in long-term projects they might not have voluntarily sought out but would ultimately learn from and enjoy, as was the case in our study. Teachers can also require students to work as a group, both developing students' collaborative skills, a valued 21st century skill, and enabling students to benefit from the learning that happens when students of different skill levels work together. Vygotsky argued that cooperative learning is a powerful cognitive development tool. Cohen and Lotan (2014) further emphasized the value of heterogeneous groupwork where students with diverse abilities can participate in the learning task, without the direct supervision of a teacher. Teachers may also provide guidelines and rubrics for the intentional development of skills that may seem out of place in a drop-in makerspace, but are useful and appropriate in an academic context. Students might not voluntarily practice documentation skills in non-academic settings, for example, unless prompted, encouraged, and even required. It is this last affordance we explore in-depth as a potential source of rigorous, motivating learning in STEM makerspaces.

4.1.3 Student Documentation in Maker Learning

Everyone has heard the classic teacher's comment, "Show your work." Teachers across subject and content areas often rely on students' clearly presented steps, arguments, and evidence to understand students' thinking and provide feedback. With hands-on learning, it can be more difficult to follow students' thinking. In studio-based classes, teachers often use students' documentation of their work, collected, curated, and explained through portfolios and presentations, to gauge growth and creativity (Kuhn, 2001). Through portfolios, teachers can engage in formative assessment to reflect on and support students' learning (Klenowski, 2002). This provides teachers with a basis of assessment at distinct checkpoints, but does not necessarily capture daily growth or highlight necessary points of intervention. Rinaldi (2006) posed pedagogical documentation as a means of "visible listening" whereby teachers could generate documentation themselves to reflect upon students' learning in-situ. In the case of a maker project where students are engaged in hands-on work as a group, students may generate documentation both to facilitate groupwork and aid assessment, as was the case here. In one study, makers used process-documentation in portfolios online, capturing a history of successes and failures (Keune et al., 2017).

Sharing one's work and ideas is a common maker practice that supports engagement in the maker community (Brahms & Crowley, 2016) and the ability to document one's thought process and share it in portfolios has had demonstrated utility for a variety of purposes, including allowing youth to take ownership of their portfolios, work towards final projects, compare solutions with others, and connect to authentic audiences (Keune et al., 2017). From a technological standpoint, documentation has also never been easier to capture, thanks to the growing availability of smartphones and tablets in schools (Parnell and Bartlett, 2012). McKay et al. (2015) observed that documenting in makerspaces can be tricky, however; students are often caught in the project "flow," too occupied to remember to snap a photo or jot down notes. Students who have a negative emotional response to failure (e.g. De Castella, Byrne, & Covington, 2013) may also be reluctant to capture moments they perceive as embarrassing or discouraging.

4.2 Noticing for Documentation

Rinaldi (2006) viewed pedagogical documentation as a way to make thinking visible; Dahlberg (2012) elaborated further that it is "a process for making pedagogical (or other) work visible and subject to dialogue, interpretation, contestation, and transformation" (p. 225). When documentation is to be interpreted by others to negotiate learning, it must also contain "sufficient detail to help others understand the behavior recorded" (Forman & Fyfe, 2012, p. 250). Documentation, then, is heavily shaped by what those who create it find noteworthy and their ability to record it in a useful, interpretable manner. Goodwin (1994) theorized that individuals sharing a profession develop *professional vision*, similar patterns for perceiving and responding to stimuli, e.g. the way a lawyer views evidence in a video versus the layman's perception or the shared jargon of a profession. It stands to reason that to create meaningful documentation to support a practice, e.g. making, possessing professional vision would allow one to see what is relevant and translate it for later discourse.

Building off Goodwin (1994) and Goleman (1985), Jacobs, Lamb, and Philipp (2010) called the skillset teachers possess for seeing and acting upon evidence of students' thinking in-the-moment as *noticing*. They developed a noticing framework comprising three skills, attending, interpreting, and responding. This framework has been adapted to show how students notice and act upon the information competing for their attention in mathematics (Lobato, Rhodehamel, & Hohensee 2012), as well as how students and teachers jointly notice failure in makerspaces (Maltese, Simpson, & Anderson, 2018). We likewise adapt their attend-interpret-respond framework here to examine students' developing documentation skills.

Table 4 Noticing framework as applied to two stages of documentation in making.

Noticing	Creating Documentation	Referring to Documentation
Attending	Identifying information relevant to making or learning	Referring to (the makers') documentation
Interpreting	Determining how to translate the information for the purpose of recording	Determining the meaning captured in the documentation
Responding	Recording, labeling, and organizing the information for later use	Acting in response to the meaning of the documentation, including modifications to making or learning

Unlike mathematical thinking or failure, understanding makers' evolving documentation practices requires a view of both the point at which makers create the documentation and refer to the documentation (see Table 4, above). As a result, our framework accounts for noticing at both points.

The definition of documentation and form it takes varies with the purpose for which it was created. Forman and Fyfe (2012), for example, distinguish between *design* and *documentation* because of the distinct metacognitive purpose documentation serves in negotiated learning. Metacognitive reflection supports learning through the process of one thinking about their own learning or knowledge (Flavell, 1979; Sawyer, 2014). Documentation, therefore, must be created to form the basis of discourse to support learning, typically between teachers and students (Forman & Fyfe, 2012). Alternatively, Schön (1983) described a process of negotiating with the design called reflection-in-action, in which the maker observes in-situ or virtually through interaction with a sketch or plan (e.g. documentation), develops a theory of how to change it to reach the desired outcome, and then changes the design to see whether the change results in the desired outcome (see-move-see). In both negotiated learning and reflection-on-action, documentation is created through attending to documentable evidence, but for this study, documentation was not explicitly created for the purpose of metacognitive reflection. Documentation created to remember how to position a part, for example, would be a *design* according to Forman and Fyfe, but would easily serve as a virtual platform for reflection-in-action to decide upon the modification of the designed object.

In this study, we explored how students in a high school makerspace came to define documentation and its purposes in the course of a long-term, group maker project and used noticing as a lens for analyzing learning with relation to documentation practices and making.

4.3 Methods

We used Stake's (1995) case study method to frame our research, a methodology that uses interviews, observations, and documents to answer general research questions through the study of a single case, here a team of five students working together in a class to design and build a drone capable of performing specific tasks at competition. As part of their grading requirements, they were expected to regularly create and use documentation to support their learning and the adults grading their progress, including judges from the competition and their physics teacher.

4.3.1.1 Data Collection

From January 2019 to April 2019, the 3rd period physics class at a small, innovative high school in suburban Pennsylvania participated in a military-sponsored robotics project called Sea-Air-Land (SAL). Between two and three days a week leading up to a local competition, the twenty-two 11th and 12th grade students in the physics class worked in one of three groups (sea, air, or land) to create a drone capable of completing several specific search-and-rescue tasks. The analysis in this study uses a subset of a larger dataset that was collected to assess learning and documentation practices in educational makerspaces, which included video data (approximately 90 hours) on three teams' semester-long project process, pre and post-test surveys with quantitative and qualitative questions, interviews of a core group of students, photos, rubrics, and teacher and staff interviews.

The dataset focuses on the video, notes, photos, tests, and interviews of a single team, the Air team, a group in which nearly all members engaged richly and dynamically with documentation practices over time, as well as returning parental consent forms to participate in the study. The first author acted as a mentor to the students, at the teacher's permission, and was primarily responsible for collecting data. Of the eight original members of the Air team in Mr. Mancina's[1] standard physics class (as opposed to AP), six students acquired parental consent to participate in the study. After several absences, expressing frustration the two or three times they were present, and feeling overwhelmed during SAL class periods, one of the team's members dropped the class altogether, leaving five students in the study.

4.3.2 First Author's Positionality Statement

As a researcher interested in improving opportunities and quality of learning for students whose needs traditional experiences and under-resourced programs have struggled to meet, the first author approached this study as an efficacy study. In other words, in such a well-resourced

[1] All names are pseudonyms.

school in a higher income area, any findings should be scrutinized to consider how replicable or generalizable those findings could be in less-resourced settings. The first author also had little personal experience with high-resourced K-12 schools and the students attending them and was frequently surprised by school policies, students' skills and resources, e.g. access and permission to use iPhones and laptops in class, and other factors. As a result, this study emphasizes the implications of access to skills, resources, and school policies that may not exist in other types of schools or educational settings.

In addition, the first author's prior experience in designing and producing film and animation offered professional vision for understanding the importance of visual interpretability and means of communication. This resulted in an emphasis on the teams' efforts to improve visual interpretability in their team documentation and communication practices, in both the analysis and in the first author's mentoring role throughout the process, e.g. encouraging students to sketch ideas they could not communicate in words. Researchers with backgrounds in engineering or technology may have found and interpreted other forms of communication and documentation.

4.3.3 Coding and Analysis

Coding was an iterative process that took place during and after the four months of data collection. Initial fieldnotes were subject to passes of descriptive and in vivo coding (quoting field notes or students directly in comments) in Microsoft Word (Saldaña, 2016), with findings summarized in analytic memos that the research team discussed at length in order to adjust the data collection process as necessary, e.g. focusing on one team rather than acting as a disruptive presence by repeatedly leaving and entering different classrooms to check on all three teams. By the completion of data collection, the research team determined that it was most appropriate to focus on the analysis of one team of students as a case study rather than comparing individual students at length in order to understand the role documentation had played in their collective learning and collaboration. After themes emerged from the coded data and the research team had discussed and determined that it was appropriate to apply the noticing framework in future coding, they enriched the fieldnotes by carefully reviewing approximately 30 hours of video data relating to the team of students at the focus of the case study and their documentation practices. This two-part process enabled them to capture rich details while focusing the analysis on a robust subsection of the data, as watching video offers a different perspective from notes initially captured in situ. This resulted in approximately 50,000 words of video notes, which were coded first with a combination of descriptive and in vivo codes to capture any additional emergent themes not obvious in the initial coding stages, then holistically coded data to determine which subsets related to similar, sequential documentation instances. Themes emerged suggesting that the team had different patterns of documentation behavior during the process, including complying, reacting, and relying. These “chunks” of data were then copied into a sequential, date-stamped matrix in Excel with the final codes added as columns. Descriptive codes were added to indicate whether a documentation instance involved complying, reacting, or relying behaviors and detailed the methods of capture or referral in addition to identifying instances of attending, interpreting, and responding. Summarized results were then compiled with dates in the tables displayed in the results section and triangulated against interviews, photos, and the Air team’s documentation to verify the validity of interpretations.

4.3.4 Sea Air Land Project Days

A typical day started with students coming to the physics room for announcements and attendance, an expansive science-lab classroom with long tables, counters with sinks, and small desks at the far end set up with soldering irons, wires, and objects for demonstrations and experiments. The teacher would stand at the front of the room by white boards and a smart screen to share any rubrics, tips, or announcements he might have to the class, take attendance as students trickled in around the bell, and finally announce to the groups which of three rooms he wanted them to work in. Students had access to tools and materials in both the school's new makerspace in the library and the teacher's back supply room, and groups rotated between their classroom, a conference room, and the makerspace. Mr. Mancina sometimes called up team leaders for a brief check-in, but otherwise returned to his desk to give groups a chance to settle in and work independently before he made the rounds. He checked on group progress, answered questions when necessary but encouraged independence and inquiry, and reminded students of guidelines and that they were expected to document their work. Three times during the project, an engineer came to the class to mentor groups; his role included demonstrating parts to teams, answering questions, and sharing his experience of the competition and regulations.

Although students were generally expected to stay and work in their appointed space, they were free to come back to the classroom to ask the teacher questions, get a tool demonstration, or borrow tools from the physics room or makerspace. Students had assigned themselves roles at the beginning of the semester, such as leader or documenter, that often proved flexible during the course of designing and building. Groups occasionally used other spaces in the school campus to work, such as gyms, hallways, and even outdoor tennis courts in order to flight-test drones. At the end of each roughly hour-long working session, students piled whatever parts they were working on into large cardboard boxes, emblazoned in sharpie with their team name, and then returned them to the supply room before moving on to their next class of the day, which for several students was lunch or study hall. Throughout the semester, students typically worked on their project only during their physics class, but in the days leading up to competition some students came to the classroom during lunches, study halls, and other free time to work alone or with other available teammates.

Students were tasked with deciding on their own how to divide work amongst themselves and when to pace different tasks, but were charged with the following responsibilities:

- Read, research, and understand the requirements of the SAL challenge
- Research possible parts and designs to use as a basis for the drone
- Create a budget, order parts, and create and execute a fundraising plan
- Schedule the completion of tasks
- Develop a written/visual plan for the drone
- Build the drone; test and iterate upon the prototype
- Prepare a pitch to explain their drone to the judges at competition
- Perform the search and rescue tasks at competition
- Document ideas, budget, and process throughout the four months of the project

4.3.5 Student Profiles

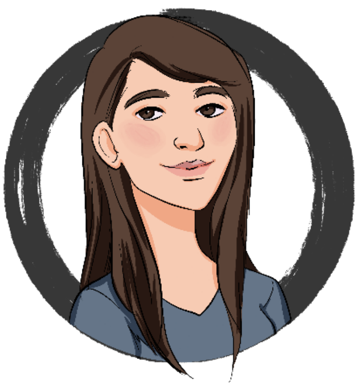
4.3.5.1 Samantha – Documenter

An athletic and friendly student interested in a future career of interior design and often motivated by grades, Samantha initially rarely documented anything and found other tasks to perform, such as focusing on fundraising efforts and supporting the building process. Samantha became close friends with Billie during the course of the project and often followed her lead; Billie regularly left on missions and took Samantha with her, distracting her from the role of documenter. As the project progressed, she focused more on her role as documenter and even reminded others to share information, take notes when working outside of class, and called for the team to pause and repeat tests as necessary to ensure the successful capture of relevant information. Her documentation style consisted primarily of bulleted lists of notes, uploading videos that she had labeled through narration, and uploading pictures of others' diagrams and lists.

4.3.5.2 Nick – Team Leader

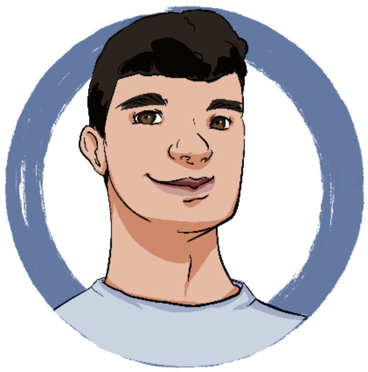
Football player and would-be future mechanical engineer and the only member of the group with previous experience with robotics and STEM making, Nick officially held the role of team leader. Unofficially, he described himself as the team's safety patrol, often distributing safety goggles to teammates, reminding them to stand at a safe distance, and reminding teammates to tie back long hair. He took on more of a supporting role than leadership role as the project progressed. His support included researching solutions, studying the project requirements, hunting down tools and parts needed for project completion, helping to build and adjust the drone's main body, and diagramming to problem solve.

4.3.5.3 Billie – Fundraising



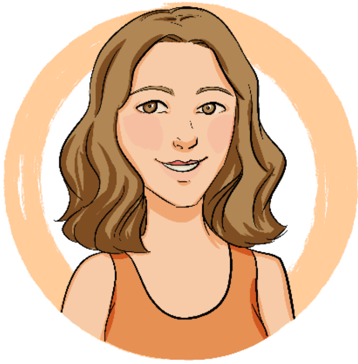
A talkative and energetic student interested in criminal psychology, Billie quickly transitioned from begrudging participation in the SAL project to exclaiming with excitement at the start of every project class. Her official role was primarily fundraising, but she quickly stepped into the unofficial role of builder and leader, and contributed extensively to brainstorming discussions. She fell in love with the drone, wanting to name it, decorate it, and find a way to keep it after competition. Her enthusiasm was infectious, and she often delegated tasks when others were not working, but she just as easily caught the group up in distracting conversations. Likewise, she often persuaded the team's documenter to join her unnecessarily on missions to talk to staff or fetch parts. Like other members of the team, she occasionally assisted documentation by video recording test flights and creating diagrams when necessary to support her thought process. Billie made the most effort to add labels to the teams' diagrams and drone, assignments, and documentation, even modeling diagramming and labeling for the team's documenter, Samantha.

4.3.5.4 Eliot – Programming, Fundraising, Co-Pilot



A football player like Nick with a dream of a career in sports radio broadcasting, Eliot initially kept to himself, clowning around or offering quiet but helpful suggestions that others could not hear. He viewed himself as a poor student and said he did not understand all the "numbers and things" in physics class. As the project progressed, however, he took on several components by himself and became the only member of the team that learned to solder. He soon became a vital component of the team's progress and an authority that the team turned to for advice, explanations, and ideas. He obtained and practiced a variety of new terminology over the course of the project, easily explaining how new parts could communicate with the drone's brain and openly reflecting on the quality and nature of material parts. He retained his sense of humor, however, often making jokes when tensions were high; at a point in competition when everyone was concerned whether the drone would fly, Eliot said that competition was going to be about "whose drone crashes softest." Eliot rarely assisted the team with documentation even when he worked alone and preferred to dictate to his phone rather than typing notes, but at a late stage of the project, when Samantha was absent and the team needed a stand-in, he wrote detailed information, including a reflection of their feelings at the time, and when he read it to the team they asked why he had not been the documenter all along.

4.3.5.5 London – Programmer



Somewhat quiet and often focused, London often moved the project forward when the others were distracted, discouraged, or confused. She researched, programmed, and modified the drone, as well as regularly diagramming changes to the drone and configurations. She made frequent attempts to explain her thinking and understanding, but often sounded uncertain of her explanations and the terms she was using. For London, the social aspect of the project was the most rewarding part, but she spent much time frustrated with the fact that a class she anticipated being easy ultimately involved a complex, difficult project, and she felt frustrated that her teacher had not offered more direct support during the process.

4.4 Students' Evolution in Documentation Practice

4.4.1 Overview

The SAL challenge spanned four months, with the expectation that student would create a thorough record of their process and progress to be presented to SAL judges near the beginning of their project and to their teacher at the end of the project (for full list of project and documentation activities by date, see Appendix A). Throughout that time, the teacher and researcher supported the team's process of learning to document with rubrics, modeling practices, and feedback. Initially, students' practices were typically confused and often frustrated attempts to comply with documentation requirements. These responsibilities were often foist upon one person with the official role of “documenter.” By the end, students had developed finely-tuned collaborative routines for the capture of specific information, with clear purposes, and recognized the value of iterating upon inefficient documentation and communication techniques. Tables 5-6 on the next pages summarize and map the evolution in documentation practice against the months of the project.

Table 5 Evolution of documentation practice in relation to adult scaffolding and project phases.

<table>
<tr><th></th><th>January</th><th colspan="2">February</th><th colspan="2">March</th><th>April</th></tr>
<tr><td>Design Phase</td><td colspan="2">Planning
Students ask questions and research to understand project requirements, designing drone, raise funds, and order parts.</td><td colspan="2">Building
Parts are in and students begin assembling drone following instructions; students celebrate milestone of "completing" drone.</td><td colspan="2">Testing and Iterating
Team tests and iterates upon drone design.</td></tr>
<tr><td>Scaffolding</td><td colspan="2">Rubrics and Assignments
After several sessions without clear documentation guidelines, teacher distributes rubrics and offers feedback. Teacher, SAL judges, and mentors, including the first author, give initial feedback or grading on documentation practices.</td><td colspan="3">Prompting and Modeling
Teacher and researcher encourage students to remember to document, occasionally presenting suggestions of how students could create documentation.</td><td>Feedback and Reflecting
Teacher and researcher advise on means to improve documentation practice.</td></tr>
<tr><td rowspan="2">Student Documentation Phases</td><td colspan="2">Complying
Students question and reflect on feedback and guidance while attempting to comply.</td><td colspan="3">Reacting
Students are uncertain about when and why to capture, frequently creating documentation as a response to crises and lamenting failure to capture. Students continue to create documentation without clear reasoning or purpose.</td><td></td></tr>
<tr><td colspan="3"></td><td colspan="3">Relying
Students begin to iterate upon their documentation processes and develop routines for capturing information. Students generally have developed a clear sense of the purpose for which information will be captured, either to support the process of iterating or for graded, formal documentation.</td></tr>
</table>

Table 6 Evolution of documentation practices, continued – capturing and referring to team documentation.

<table>
<tr><th></th><th colspan="2">January</th><th colspan="3">February</th><th colspan="3">March</th><th>April</th></tr>
<tr><td>Capturing</td><td></td><td colspan="3">· General photos
· Basic diagrams
· Any artifacts copied into required Google Docs "documentation" (links, order forms)
· Notes</td><td></td><td colspan="3">· Photos and videos of specific parts or accomplishments
· Limited use of labels for specifying information
· Failed video captures
· Disorganized notes and photos</td><td>· Making use of labels
· Keeping and modifying upon diagrams on whiteboards
· Labeled parts, narration, and slow-motion enable capturing specific information on video, photos</td></tr>
<tr><td>Referring</td><td colspan="3"></td><td>· Labels to divide labor on paperwork</td><td></td><td>· Inventory</td><td></td><td colspan="2">· Testing and iterating upon designs</td></tr>
</table>

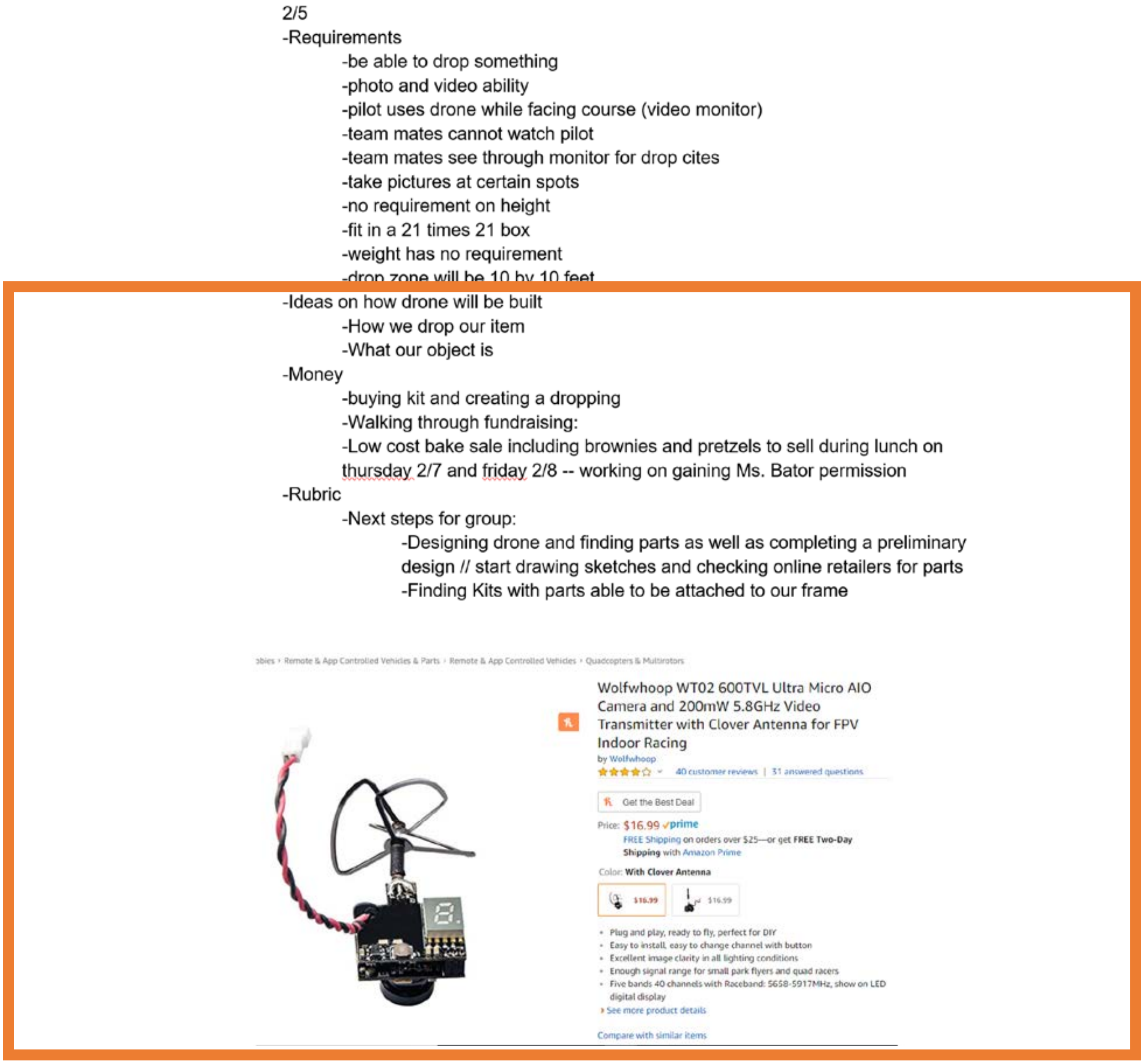
4.4.1.1 Compliance

From late January to mid-February, the Air team was in the initial planning stages of their project, and likewise in the initial stages of understanding “documentation” as a required aspect of their grade. Documentation in this stage largely followed recent prompts, such as graded documentation assignments or suggestions from adults that they take a photo. Students were often unsure of the value of documentation, when to create it, and missed opportunities to use it; Billie, for example, remarked, “I just wish instead of (non-consecutive days) we could do it on like, a Tuesday and a Wednesday *so we wouldn’t forget what we did*” (emphasis added). In this stage, students used practices they were likely familiar with from other groupwork and tasks:

- Divide work on written documents, such as color coding their PDR document
- Making written shopping lists
- Taking notes in Google Docs
- Taking indiscriminate photos

With expectations that the team fundraise, document their project, and research and order parts to build a quadcopter, the team spent a lot of time talking about bake sales until their teacher distributed the first documentation rubric on February 5th. “Early on self-reflection point. Not a major grade, not meant to harm you, but to give you future instruction.” The rubric stated that to get the maximum of ten points, students would have to show “the evolution of team ideas/build via ideas, analysis, pictures, video, sketches, models, resources *through entire process*.”

Up to now, the team had only been saving links for parts they might order and jotting down names of people they might ask to sponsor their team. London immediately told Mr. Mancina that the team didn’t have pictures or videos. “Would you have a lot at this stage of the game?” he replied. The team scrambled to assemble pictures of some kind. London volunteered to “draw it out.” Samantha and Billie worked together to describe their process in Google Docs, the formal platform for documentation in the class (example in Figure 9, see next page). Their initial documentation restated the requirements of the project, which they had been asked to do in class, but included almost no information about their design ideas, thought process on what parts to include, or other information that would be useful to advancing their design process.



2/5

-Requirements

- -be able to drop something
- -photo and video ability
- -pilot uses drone while facing course (video monitor)
- -team mates cannot watch pilot
- -team mates see through monitor for drop cites
- -take pictures at certain spots
- -no requirement on height
- -fit in a 21 times 21 box
- -weight has no requirement
- -drop zone will be 10 by 10 feet

-Ideas on how drone will be built

- -How we drop our item
- -What our object is

-Money

- -buying kit and creating a dropping
- -Walking through fundraising:
- -Low cost bake sale including brownies and pretzels to sell during lunch on thursday 2/7 and friday 2/8 -- working on gaining Ms. Bator permission

-Rubric

- -Next steps for group:
  - -Designing drone and finding parts as well as completing a preliminary design // start drawing sketches and checking online retailers for parts
  - -Finding Kits with parts able to be attached to our frame

Figure 9 The team's initial documentation in Google Docs, with box added to highlight information about the team's progress.

The following class session, the team received an email from their teacher saying that they had received only 7/10 on documentation. Amid frustration and outrage at the impact this would have on their physics grade and confusion that their work was insufficient (Billie, in particular, said, “We included a picture of the drone and still only got a seven out of ten on documentation?”), Samantha the documenter read Mr. Mancina’s feedback to the group; “Each time you meet you should have a good representation of your work documented by date. This includes pictures, videos, and links to your thinking process and ideas. What you have currently is limited but I am confident that after our discussions you have good understanding of the expectations.” Billie reflected to the team, “I don’t know, even if we got a bad grade I’m proud of us on our documentation, even though we didn’t have a lot of pictures, I think it’s pretty and detailed.” She also said they should ask for more feedback “Because I would like to not get a C next time...”

The Preliminary Design review formed the next major documentation checkpoint for the team. Over several class sessions, the Air team studied the Preliminary Design Review rubric and found a sample from a previous year’s land team of a PDR to follow like a template. The team was shocked and upset to see that the requirements for documentation were even more detailed than they had interpreted from their teacher’s rubric. Several members of the team expressed that they felt the PDR was hopeless and impossible, and reflected that they did not have a lot of the information and documentation necessary for all the parts of the very long writeup (one student estimated about 20 pages). “Our prices are supposed to be in a chart?” Billie exclaimed, examining the document. “We’ve ordered one thing!” Eliot asked the group if anyone knew they had to keep a daily log; they all say no, despite earlier feedback from their teacher about this requirement. They read through the rubric and sample several times over several sessions as a team before they understood the depth of what the PDR was asking for, for example a daily log of all activities throughout the entire course of the project.

Instead of relying solely upon the documenter to fill in the gaps, the team color coded sections they planned to work on to divide and conquer, quickly putting together whatever information they had scattered across Amazon shopping carts, Google Docs, browser tabs, and memory into the format the PDR requested. At the first author's suggestion, Billie and Samantha used a whiteboard in the room to draw their drone design. Samantha initially asked, "Should I be drawing all together what it is going to look like?" Billie took the lead, telling Samantha how to label the diagram and modeling the process for her. The initial attempt at diagramming included relatively little information; of the three systems the team was expected to design for, the students had only accounted for the body of the drone itself (Figure 10, below). Samantha took a picture of the diagram and uploaded it to the Google Docs folder, where it could be added to the PDR. The team submitted their documentation late, had a partial design at the time, and received only 12.5/20 points (see rubric, Figure 11).

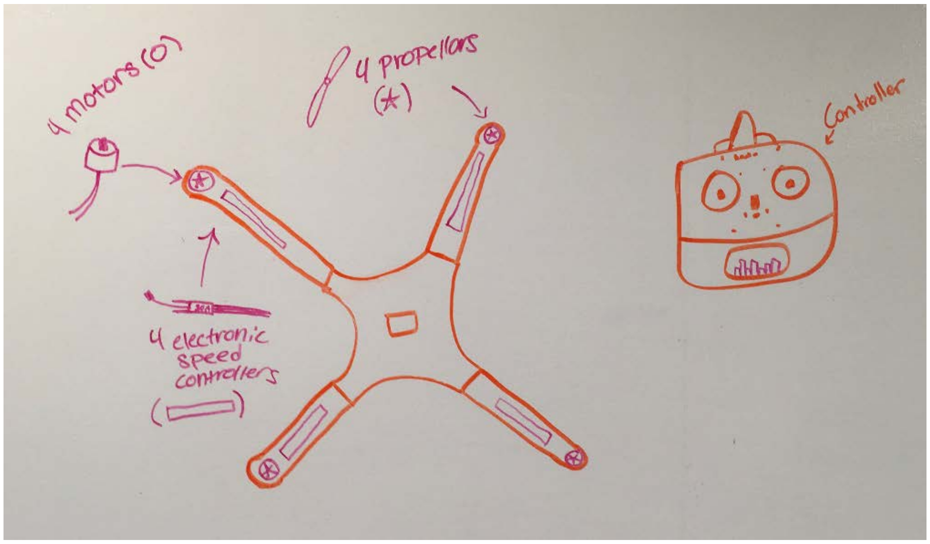


Figure 10 The Air team's first whiteboard diagram.

Region ______
School ______
Challenge Air
Team ______

Electro-Optics Center

PennState Applied Research Laboratory

SEA AIR & LAND CHALLENGE

12½/20

PDR RUBRIC

Item	Possible Score	Your Score	Comments
Submitted Properly	2	0	PDR (in pdf or word format) should be submitted on-time to seaairland@eoc.psu.edu or other designated engineering group late
Core Information	2	2	Proper cover page/format
Understanding of System Mission	2	2	Comprehensive understanding of system mission Time is important ✓
System Description	2	1½	Thorough system description included
Supporting Data	2	2	All supporting data (links/references/people/etc.) are presented
System Drawings	2	½	Very clear system drawings along with electrical schematics
Schedule	2	½.	Rational implementation schedule included place import. dates
Bill of Materials (B.O.M.)	2	1	All materials are accounted for
Costs	2	1	All costs are accounted for
Requirements Matrix	2	2	Tracing functionality to system
Total Points	20	12½	

Reviewer Comments:

- *Note that the challenge may be indoors with smaller boxes/bins than the 10'x10' outdoor tarps.*
- *Need more specifics on dropper design. What concept have you downselected from your research + brainstorming?*
- *Add these extra dropper/payload materials to your BOH/Costs, as well as the laptop to monitor the camera output. Is the camera new or used?*

Figure 11 Graded PDR rubric and feedback for the Air team.

Despite the frustration the team had endured, this was the last checkpoint prior to the final documentation grade enforcing the students' official documentation. Once the harrowing experience had passed, the team experienced a lull in their documentation practices, taking sparse notes here and there. The documenter, Samantha, was often distracted from her role; Billie, her friend, took her on missions around the school building that could have been accomplished with one student, and at times Samantha was absent or seemingly unaware that there was information to be captured. She only took ownership of her role, even reminding other students to record information, when the team as a whole came to see the value of documentation through a series of crises and emotional stimuli.

4.4.1.2 Reacting

As the team began to order parts and build their drone from mid-February to end of March, they entered a phase where problems and celebration pushed them to reflect on their informal documentation process; in other words, what they were recording regardless of whether their documentation grade specifically called on them to capture the information. These events prompted them to develop documentation independent of the documentation they expected to hand in at the end of the project for a final grade.

- Thinking their drone was stolen and developing a system to prevent theft
- Celebrating the first completed build of the drone's body and sharing images on Snapchat
- Testing the drone without making a list of modifications
- Lamenting failure to adequately record tests
- Lamenting failure to record schematics so as to be able to easily take apart and put back together the drone

Just before the building stage began, the Air team received notification that their parts had arrived, only to learn that the parts had been given to another team. This was the first major crisis to shift the team from documenting for a grade to documenting for their own sake. Upon reviewing their order forms and talking with staff, they eventually came to the conclusion that their kit had not arrived yet, but the scare had already done its work to motivate the team to document. Billie reflected, “After Friday, I’m a little paranoid about losing stuff” and came up with a comprehensive system to inventory all the parts they had. “I feel like we should be writing down what comes in each little bag. I know that sounds stupid, but...” The team supported her idea and she and Samantha set to work inventorying the parts and creating an organizational system. Later, when the drone was fully built, they took pictures and posed with it, and Billie reflected that it would be “hard for someone to argue” that the drone was not theirs anymore.

Celebration often prompted the team to take pictures or videos, but they did not automatically associate this with their official documentation responsibilities. When they finished cable management and had taken videos of the drone to share with friends, Billie remarked, “She was kind of a mess before...she wasn’t an organized queen but now she’s an organized queen.” Several times, they took pictures to celebrate their progress or share with group members; Billie and Eliot, in particular, took photos and videos to share on Snapchat of team members posing with the drone, only reflecting afterwards that the images should have been saved for their final documentation submission.

The team was still learning to anticipate what they might need to iterate upon the drone as well. During the building process, the team followed a silent, confusing video to assemble their drone. When the team fully assembled the drone to the point where it could theoretically fly, but then removed the propellers to safely perform a motor test indoors, the team experienced a moment of frustration when they realized they had not recorded propeller position at any point and would have to watch the confusing instructional video all over again. “Shoot,” London lamented, reflecting, “We didn’t intend to take the propellers off again.”

Sparking perhaps the most drastic change in the team’s view of the importance of documentation and their roles in relation to it, when the team flew their drone the first time, it suffered a catastrophic crash. At the time, only the team’s documenter, Samantha, was holding a phone at the ready to video record the test flight. The drone rapidly spun out of control, went off camera, crashed into a wall, and could no longer fly (see Figure 12, below). Not only was Samantha’s video insufficient to capture and diagnose the problem, but the team also lacked documentation to determine how to reassemble the broken drone. They scrambled to look through order forms, links, and even take pictures of the broken parts to collect a list of materials to reorder. When the first author asked what the pilot (not in the study) had been doing during the flight test, Nick vowed to video record the controller and drone together from then on.

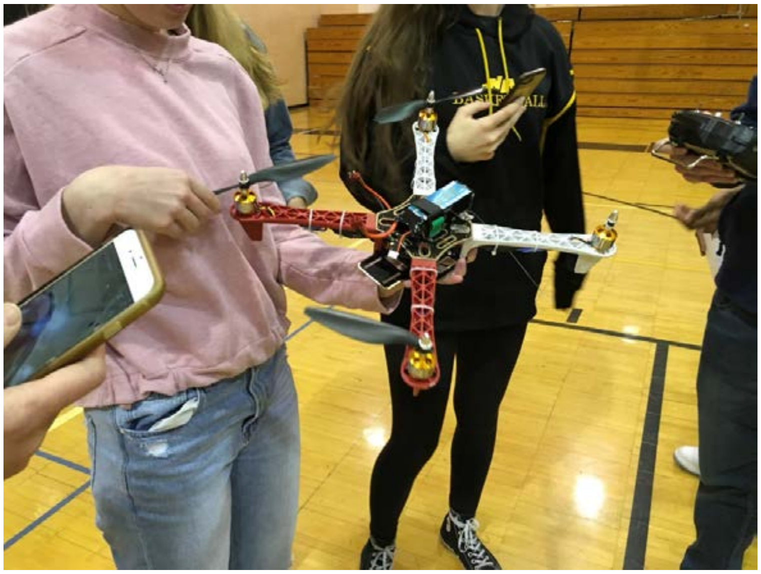


Figure 12 “Beasterella the Drone” has suffered damage during the first flight test.

4.4.1.3 Relying

By mid-February, the team began to see the importance of shared documentation practices to their process and had begun to iterate upon documentation routines, in particular:

- Organizing file access in Google docs
- Using whiteboards to create diagrams and list the team could iterate upon and refer to in future working sessions
- Working together as a team to both video-record and take notes on each flight test, with nearly every member of the team taking a different documentation role
- Labeling the drone and parts to facilitate capturing sufficient information for diagnosis

In the iterating stage of the design process, the team no longer suffered frequent shocks but rather persistent challenges they could learn to counter through documentation practices. Sometimes the drone was unable to lock and they did not know why. The drone spun for weeks. Motors occasionally stopped spinning or spun at unexpected speeds, and at times the controller malfunctioned. They came to expect that problems would arise and understand that resolving their drone's errors would be a matter of much iteration, trial, and error.

Initially, the team lamented a lack of organized photos, diagrams, or notes to access when they sought answers to questions. Several times, after students grew frustrated with the lack of organization, students created files to make it easier to locate related links, lists, or files in Google Docs. Students developed ways of color-coding and labeling the drone parts to make photos and videos more interpretable. After the first few times the first author or teacher prompted them to diagram or write down their thinking, the team became accustomed to using the long, stationary white boards on either side of the conference room to make lists and diagram their thought process. At the start of the project, the team regularly circulated between rooms. Towards the end, they returned to the same conference room, where previous weeks' diagrams waited to be reflected upon, modified, and updated. This proved to be a vital factor in collaboration, as students might not know to search through the online folder for documentation their teammates had created but could walk into a room and instantly see the diagrams their teammates had left on the wall for them. Billie and Nick both commented on the inconvenience of referring to videos and photos in documentation. When asked to refer to videos of tests, Billie said "it's so annoying" and Nick encouraged the group to update their whiteboard diagrams "so we can look at it."

In this phase, the team's documenter took her duties more seriously, iterating upon her note-taking process and even reminding Eliot, who went off alone to work several times, to take notes on his own process. When the documenter was absent the team recruited Eliot to take on her duties. He surprised everyone by producing a detailed reflection of the team's process, in a style very different from Samantha's:

> Pressure of the competition is getting to us and the drone is yet to fly. We decided to remove the legs to take off excess weight. We noticed that the drown wants to spin just when we tested the motours so we brainstormed possible solutions and are still working through that. A problem that came whenever we removed the legs is finding a new spot for the payload dropper as well as the camera. The payload droppers must be vertical to function properly, the camera must be able to see the ground and it can't go in the same spot as we first thought. Removing the leg seemed to help the drone, we decided to do a test flight before class ends. Drone still spins clockwise when trying to take off. Still not 100% sure we believe there may be a problem with motour 4. 9:15ish what the drone is set to. (Air Team's Documentation.)

By the time the final documentation grading checkpoint came, the team worked together to translate their work-product documentation into official documentation to submit. In the end, they received a perfect score on the documentation portion of their project grade (Figure 13, below).

Documentation of Process	Documentation shows the evolution of team ideas/build via minimal means *through little of the process* (4)	Documentation shows the evolution of team ideas/build via multiple means *through parts of process* (7)	Documentation shows the evolution of team ideas/build via ideas, analysis, pictures, video, sketches, models, resources *through entire process* (10)	10/10

Figure 13 Air team's final grade on the documentation rubric.

4.4.1.4 Valuing Documentation

At the start of the study, the team's teacher had mentioned to them the importance of documentation but had not yet graded their practice or modeled documentation practice for them. The students took a survey asking the short-answer question, "Why is documentation important?" Students gave diverse answers reflecting various explanations their teacher had told them, they knew from prior experiences, or had inferred from other questions in the survey about documentation practices. In practice, however, students missed opportunities to create documentation and, as quoted earlier, Billie implied that they had to just "remember" what they had done in previous sessions. At the end of the project, they were asked to fill out a slightly more specific question: "During the Sea Air Land project, in what ways was documentation (recording thoughts, progress, ideas, photos, videos, etc.) important for your team's project?" The students all privately answered the same way: documentation was critical to being able to iterate upon their design, a practical, experience-based shift from parroting instructed answers (see Table 6).

Table 7 Student Pre-and-Post Test Explanation of the Purpose of Documentation.

	Why is documentation important?	How did your team use documentation during the SAL project process?
Samantha	You need to see how you have grown and improved through the project.	It was very important to document things that we did in order to look back and help further our drone building process. An example of this was when we had to change the propellers we looked through old photos and videos to see how they need to change.
Nick	It shows how and when certain points of progress were made. It also shows development and efficiency over time.	Documentation allowed everyone in the group to know what stage we were in throughout the project. We could also look back to it for a better understanding of what we did so far as a group and what we have left to do.
Billie	It allows other people to easily follow your process as well as allows you to go back and see things you have already done or in case of damage/ error know how to fix it	we could look back and see where things went wrong, how they were positioned, and what the drone was doing in slow motion.
Eliot	So we can look back and understand our own process.	Helped us not make the same mistake twice or even three times.
London	Because it allows not only the person who is documenting, but also others to understand what exactly you are trying to accomplish. It is also the easiest way to stay organized.	Helped us to decide what we were doing wrong, and differentiate between various tests.

4.4.2 Noticing During Capture and Referring to Documentation

Two separate but parallel learning trajectories showcase the ways team's collective documentation process evolved through noticing: 1. The use of photos and videos to capture sufficient information to make the iterating process more efficient and 2. The use of specific language and diagramming techniques to ensure that the team was communicating the same ideas.

4.4.2.1 Visual Communication in Documentation

Cameras were a low bar for entry for the Air team; each student had a school-issued laptop and their own smartphones to use during the documentation process. When they saw "pictures" and "videos" mentioned on the initial graded rubrics, students immediately sought artifacts to take pictures of to meet requirements, without considering the purpose it served for their design process. This practice carried beyond the PDR assignment; during the complying and reacting phases, Samantha took general photos of the drone after repeatedly asking the team, "should I take a photo?" The number of photos piled up quickly. Although students in the team occasionally took photos or videos to share with friends, the team did not have a defined purpose for the photos they took until they reached a point in the building process where testing and iterating was daily practice. When Samantha took photos, she demonstrated an understanding that she should attend to the drone, broadly, but applied little to no interpretation to her capture, resulting in photos that were unhelpful in answering later questions, such as propeller placement.

On March 14th, London was programming the drone and removed the drone propellers to perform a tilt test, i.e. a test where someone holds the drone and tilts it sharply to hear the motors compensate for the loss of equilibrium (see Figure 14, below).

Figure 14 Performing the tilt test without propellers.

When the tilt test was over, London looked at the detached propellers and said, “Shoot. I don’t remember what propellers go where.” Attending to the need to see prior configurations, London asked if anyone had photos. “We didn’t write this down, did we?” Nick replied. The group discussed the problem, wishing they wrote it down but not having the information. “We didn’t intend to take the propellers off again,” London remarked. They did not want to have to watch the video again, because it wasn’t clear the first time. “I’m trying to think how we actually did it though,” Nick said, and added that he thought the configuration was different from the video somehow. Without photos to refer back to, there was nothing to interpret; in response, the team had to rewatch the original confusing instructional video, essentially redoing the same work they completed in a week prior and hoping that the configuration was the same. This was but one in a string of instances where students attended to the need to refer back to photos but had not taken photos to interpret. After that point, the team began to make a concerted effort to take a glut of photos and videos in an attempt to ensure that they had information about any configurations they might have used. It then became a struggle of locating the right photo to interpret.

On numerous occasions, when students finally found their photos or videos, they could not interpret from the photo or video what configuration the parts corresponded to. On April 2nd, the drone was once again disassembled post-crash. Nick attempted to figure out what direction the propellers and motors were spinning in during the crash flight to determine whether that was the cause of the crash. “Do we have a picture of what the drone looked like before we flew it?” Nick asked. He said he needed a top view. “Because if it’s the same, that wasn’t what caused the spinning,” Nick hypothesizes. He did not find the photo, despite Samantha’s organization of files in Google Docs. “I have one from before we put the propellers on,” Samantha explained. “I need the propellers on,” Nick insisted. “If you wait one second, Nick, I got you,” Billie offered.

Using whiteboards in conjunction with photos helped to improve the interpretability of photo and video data. At the first author’s suggestion, Nick wrote his hypotheses and diagrammed his understanding of propeller mechanics on the whiteboard. Eliot joined Nick to discuss how air flow would impact flight with his diagrammed configuration, and that the problem with the drone could be motor spin, propeller configuration, or both. The two decided what configuration the propellers should have been in and that they could do nothing more without comparing it to the drone’s crash configuration. When Billie found the photo, they were able to compare the configuration to their diagram and determine the problem. “They’re supposed to be diagonal,” Nick explains. They adjust the propeller design and Samantha writes the new configuration in their documentation, along with the link to the video that Nick found showing a different configuration. As the group came to make more use of the whiteboards, Nick in particular remarked that he found hunting for photos to be ineffective and unhelpful, and preferred to have information out on whiteboards where the team could see it.

By April 6th, during the iterating phase, the team had had enough of the confusion of unlabeled photos and videos. Students began taking photos more frequently and aimed their cameras to take more specific information, such as of parts of the drone rather than shots of students posing with drones. The team observed the new parts at their disposal included red and black propellers they could use to mark spin direction and they noticed their drone now had yellow zip-ties that corresponded to motor spin direction. They numbered the arms of their drone, like they had seen in the instructional video. From this point onward, any video recordings or photographs should contain enough information to determine the precise configuration and make it easier to determine any problems individual motors or propellers were experiencing. As shown in the photograph in Figure 15, next page, the students used colors, numbers, part names, and other labels in white board diagrams to explicitly map out their understanding of part positions and functionality and compare their drone setup to the instructional video they were using to build the drone.

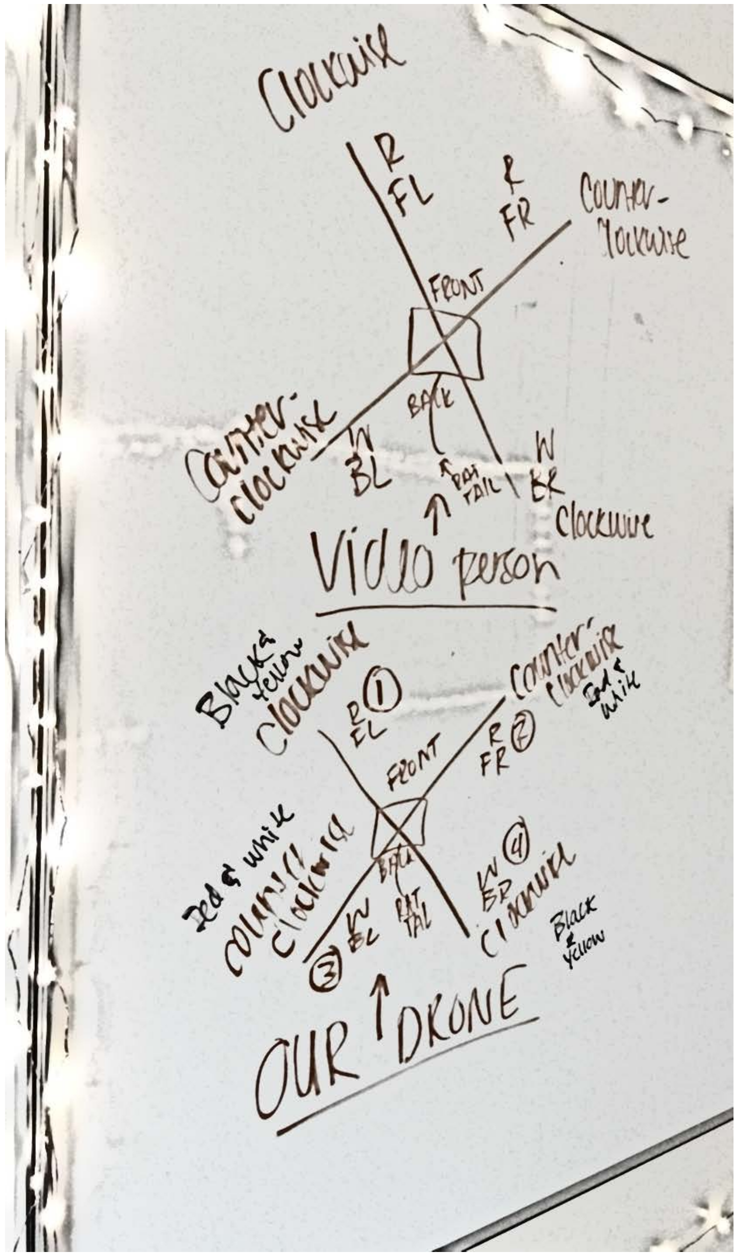


Figure 15 The Air team's labeled whiteboard diagram comparing their drone's setup to that of an instructional video.

When they began testing, they found that even this was not always enough to ensure the capture of adequate information, for one very simple reason; the drone's parts spun too fast and moved unpredictably during flight. Slow-motion capture on smartphone cameras saved the day. Students developed routines of capturing test flights and motion from different angles with a combination of slow-motion and regular video. In addition to the labels, this was enough information to interpret photos and videos, and to further ease the process, students immediately interpreted captured video to modify and update whiteboard diagrams, which proved to be the most convenient source of information for the team.

4.4.2.2 Verbal and Linguistic Communication in Documentation

Although the Air team undertook the SAL project for their physics class, they often had find ways to express concepts and describe parts to be able to work together that were not covered in their physics curriculum. At times, saying "the thing" or pointing was sufficient for the group to work together on attaching parts, but when they reached the point of fine-tuned iterations and testing, the team came to find that without a shared means of communication, working to build on each other's ideas or process was nearly impossible.

In early attempts to modify the potentiometer, a small, round dial on the top of the drone that was responsible both for initial programming of the drone and later calibration of spin during flight, the teacher interchangeably modeled language like "middle," "center," and "50%," producing ambiguity that London then copied and modeled for her team. The ambiguity was infectious, and soon the whole team was using multiple terms for describing potentiometer positions that did not correspond to each other's interpretations.

When only one student was working on adjusting potentiometer positions, it mattered less whether other students could interpret her diagrams. London was in charge of the potentiometer adjustments initially, and she took it upon herself to develop a system for recording potentiometer positions and whether they achieved desired results. She drew brackets and slashes on the whiteboard to indicate whether the line on the potentiometer was horizontal, vertical, or some form of diagonal, as seen in Table 8 below. When the team's documenter asked where she had set it to, she frequently replied "middle" or "horizontal" without clarifying if the dial was pointing left or right, up or down, and how that corresponded to the top of the drone. Initially, this did not interfere with the group's understanding because she was solely responsible for adjusting the potentiometers to calibrate the drone, a one-time step in the process.

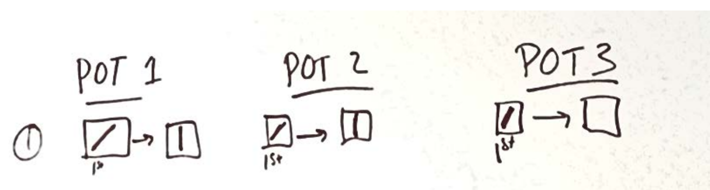


Table 8 London's first attempt at documenting adjustments in potentiometer configuration.

During the initial testing phase with potentiometer adjustments, London adjusted the potentiometer on her own and discussed positions and their effects with the teacher using whatever language she was comfortable with; when the teacher started to struggle to communicate more subtle adjustments to London, he suggested using the positions on a clock to describe the changes. Teammates overheard and attempted to practice the language London and the Mr. Mancina were using in order to share hypotheses. At this point, students were not interpreting documentation or even looking at the drone, merely having a discussion while London made adjustments to the drone.

After the testing, London created a whiteboard diagram to explain what positions had resulted in the drone spinning right or left during tests. The next day, she was absent, leaving teammates to interpret her work. Initially, Billie began to create her own diagram with a different technique, using an x-y axis like she would in math class, to analyze the results of their test and create hypotheses (Figure 16, below).

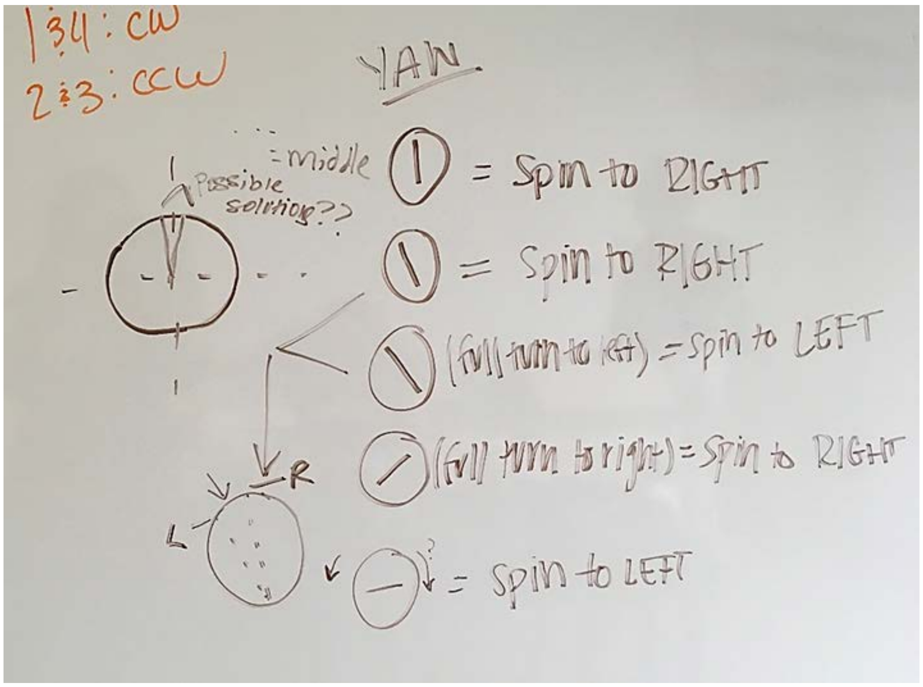


Figure 16 London's initial diagrams are on the right; Billie's diagram is on the left, using an X and Y-axis in an attempt to orient the former's configurations.

After probing questions from the teacher and researcher, Billie realized she was unsure how to orient London's diagrams against the drone; "Here's what we haven't tried: full turn to the right going this way, she spins to the right, full turn to the left spins to the left… Actually, I don't know… I don't know if she turned it all the way, because I just turned it to the left and I was able to rotate it more than horizontal. If we're using quadrants I can get into the third quadrant."

Through discussion and modeling, the teacher and researcher helped Billie to explicitly orient her diagram to the drone using clock positions to describe slight differences in potentiometer adjustment. Billie used her diagram to explain her hypotheses and plans for testing to Eliot, and later to London when she returned. When London came back from her absence, the team was prepared to test potentiometer configurations using the new language the teacher and researcher had modeled, but continued use of “clock-talk” as Eliot later called it revealed that members of the air team were attending to different attributes of the potentiometer.

During the following test flight, London called out clock positions to Samantha to mark what adjustments she was making per test. London tried to figure out where the “middle” of the yaw potentiometer’s full rotation fell. Billie drew a C shape on the ground with her finger and London showed her the range of rotation on the yaw potentiometer using a screwdriver. “I’m not going to call it horizontal but I’m going to call it the X-axis,” Billie said, aware that the first author and teacher cautioned against using the term “horizontal” but unaware that “x-axis” and “horizontal” shared the same ambiguity; from it, one cannot tell if the potentiometer is pointing left or right. Samantha asked if they tried 10 o’clock already, and London and Billie said “Yes.” The first author corrected them, saying they have tested the extremes, 2 and 5 o’clock. London said, “But 5 o’clock is also 10 o’clock. Up top.” A conversation followed in which the team and researcher discussed the miscommunication. As a group, they determined that the labeling only worked if they attended to a consistent point at the end of the line, rather than the line as a whole; as Billie poetically explained it, “You just have to look at the top. You're thinking about where its ass is going, not its head.” With guidance from the first author, Samantha relabeled the diagrams she has been using to document the results of tests, adding arrows to one end of the line to indicate whether it was rotated clockwise or counterclockwise. With the documentation finally consistent and interpretable to multiple group members, Nick and Samantha exclaimed, nearly in unison, that they were all on the same page now.

Shortly after developing a shared communication for explaining potentiometer angles, the team found that Billie's hypothesized "sweet spot" fixed the drone locking problem and were able to eliminate potentiometer position as the cause of their drone's spin, allowing them to proceed after several class sessions to test other variables.

4.5 Discussion

In this study, we explored how students learn to document as a group in a STEM makerspace. We used noticing as a framework for understanding the evolution of students' documentation practices as they were attending, interpreting, and responding to data both at the point of capture and when referring back to their own documentation. We found that although students initially engaged in documentation practices mainly to comply with graded requirements, they gradually transitioned to developing their own practices the more invested they became in the simple task of getting the drone to fly. As students reflected on the interpretability of their captured data, they modified their practices, ultimately owning routines designed to help them meet their goal.

Prior studies have shown that documentation is a valuable tool for reflection both in and on action (Rinaldi, 2006; Forman & Fyfe, 2012; Schön, 1983). The findings in this study are consistent with the prior literature, but emphasize that documentation serves the purpose for which it was created; this is to say that on their own, students developed documentation that served as a clear basis for reflection-in-action (Schön, 1983), e.g. meditating upon photographs and diagrams to develop hypotheses, make adjustments, and then test for outcomes. To suffice as a basis for metacognitive discourse, i.e. negotiated learning (Forman & Fyfe, 2012), much of the documentation created in this study would have needed additional interpretation.

Research in educational psychology often tackles the problem of how to motivate students in school, on the assumption and finding that traditional classroom experiences are often demotivating (e.g. Ames, 1992; Dweck, 2006), while literature on informal learning as in makerspaces often emphasizes inherently motivating experiences (Barron, 2006). Initially, the students in this study were extrinsically motivated to engage in the project and all its processes, including documentation, but over time students' goals shifted from performance (e.g. Billie complaining that she did not want to get a C) to mastery, saying they did not care what happened as long as they could get their drone to fly (Dweck, 2006). In keeping with studies that have been done on documentation and portfolio practices in out-of-school makerspaces (Keune et al., 2017; Brahms & Crowley, 2016), and even on maker practices in general, the students in this study eventually took pride in their work and wanted to capture photos and videos just to share the experience with friends. The transition in their mindset towards the project shaped their desire and need to capture information throughout the process; had the students been working on a project that did not hold their interest, they may never have modified their documentation practices beyond the requirements enumerated in rubrics and guidelines.

4.5.1 Implications for Teaching

The findings of this study bear numerous implications for teacher practice when using documentation to support groupwork in makerspaces or other constructivist learning experiences, particularly in relation to:

- Managing documentation in groupwork

- Modeling documentation and communication practices
- Creating meaningful rubrics and using documentation for assessment
- Determining whether to allow smartphone use in classrooms
- Considerations for makerspace environments to support documentation

Documentation can be a powerful tool for supporting groupwork over long-term maker projects, particularly when students share roles and responsibilities to maximize skill growth, e.g. documentation practices, and benefit from diverse perspectives and skillsets (Cohen & Lotan, 2014). When students work in groups to create documentation, it encourages them to articulate and reflect upon not only how to capture information but also why they are capturing it; as Billie, in particular, developed confidence in her documentation practices, she regularly explained to the group why she was going to document something before she did it, giving them opportunities to give her feedback or learn from her thought process.

Teachers should take care to intentionally model practices for using language and diagramming in documentation; students tend to copy the methods teachers model for them intentionally or unintentionally (Bandura, 1977). In this case, Mr. Mancina unintentionally switched terms to refer to the same concept (potentiometer positions) multiple times and later had to work with students to clarify and address ambiguities. When students are working alone or over a short period of time, they may be able to interpret their own inconsistent or ambiguous notes, but in a group working on a long-term project, miscommunications can set back progress by days or even weeks.

Documentation can form a basis for formative and summative assessment of learning, but as we mentioned previously, without guidance to frame their documentation, the work-product they generate may not be sufficient for teachers to engage with the documentation and decipher students' learning. Andrade (2010) argued that instructional rubrics can serve as a useful basis for framing the skills and thinking teachers expect from students. In this case, the rubrics assigned to the students encouraged students to form a process log rather than documentation useful for reflecting on skill growth. Naturally, students produced photos and notes without a clear understanding of what purpose the documentation served. Teachers might instead use elements observed through the noticing framework to frame a skills-based rubric, such as:

- Documentation attends to specific details relevant to modifying or iterating upon the design.
- Documentation contains sufficient clear labeling and organization to be interpreted by other students and teachers.
- Documentation contains a detailed record of responses such as modifying the design or documentation process.
- Documentation includes student reflections on the skills and thinking students develop both when capturing and referring to prior data.

Students' use of smartphones in classrooms has long been a topic of debate. It is important to note that in this case, the teacher considered his class to be of a maturity and responsibility level to be capable of deciding whether to use their phones for the project or not; in other cases, smartphones may be more disruptive than helpful due to classroom culture or other considerations, e.g. students with ADHD and other attentional learning disabilities. That said, the students in this study were able to access their funds of knowledge about technology and social media (Moll et al., 1992) as a foundation for developing documentation skills; they were already comfortable taking photos and videos, using slow-motion capture, and even narrating videos to a certain extent, all of which were valuable to creating documentation routines. Unlike apps like Snapchat and

Instagram, however, basic photo and video capture apps on a smartphone do not prompt students to tag, label, organize, or otherwise indicate the meaning of the information they have captured. Trying to make sense and use of disorganized, unlabeled photos across several students' phones quickly became problematic. Students would likely benefit from an app that mediates the documentation process into simpler parts; such a program could also prompt students to engage in capturing documentation for metacognitive reflection in addition to process-focused documentation.

Finally, research has established that the means, activities, and people in a makerspace make a difference for student learning (Hira & Hynes, 2018); additionally, we found that stability and reliability of space over time is an additional consideration for developing documentation practices and learning in makerspaces. Here, students were initially rotating between classrooms; it was only when students stopped rotating and claimed a space that they were able to effectively make use of the resources in their "makerspace," a conference room with whiteboards that no one erased for weeks. Despite the school-issued laptops each student had at their disposal, the most effective documentation solution was this access to whiteboards that gave the group the ability to easily see, find, and modify diagrams that clearly indicated the group's thought process.

4.5.2 Conclusion

Ultimately, documentation is a powerful tool for learning that can take on unexpected and creative forms. It can push students' thinking, and although it was beyond the scope of this study to explore, may encourage students to engage in practices to support collaboration and metacognition in other settings. A wide variety of factors influence how richly students learn to capture information, and teachers cannot realistically control them all. Future studies should pursue the development of technologies to scaffold the development of documentation practices in makerspaces in ways that will support individual and group learning, such as apps to mediate the process of documenting with smartphones or tackle the problem of accessing visible, modifiable diagrams in spaces that are shared or temporary. Implementing such designs could support the learning process in classroom settings where teachers can require that students document as well as motivating youth to develop good documentation practices for learning in informal settings, where documentation cannot as easily be required but nevertheless benefits learning.

5.0 Discussion

Learning does not happen in a vacuum; the movement of youth and practices from one organizational context to the next shapes the learning that occurs and the opportunities for supporting learning. When an emerging adult is designing products to meet personal needs in a community space, the skills, teacher practice, and activities that support that learning experience are vastly different from those supplied to a group of adolescents working in a physics class to accomplish an assigned task in hopes of good grades and success at competition. Likewise, the very nature of making and the culture surrounding the practice transforms opportunities to learn when school and OST settings become makerspaces. In particular, the culture of making as a practice is deeply dependent on a kind of community not unlike Lave and Wenger's concept of a community of practice (1991). Here, I explore the underlying theme of *community* shared across all three articles that directly informs a discussion of learning from a practice situated in context.

Community took on diverse forms over the course of the three studies within this dissertation. The resultant outcomes suggest patterns in learning outcomes for youth in maker education and bear implications for teacher practice. I said in the beginning that makerspaces were a critical part of bringing making into education; the interdisciplinary nature of making means, inherently, that makers benefit from access to a greater variety of tools and knowledge than one maker could reasonably access alone. When *making* is introduced to a classroom it is no longer just a classroom, but rather a makerspace. That context is important first and foremost because of the fundamental value of community engagement within the maker movement, a key affordance of makerspaces. As Hira and Hynes (2018) put it, people—and thus, community—is one of the critical components for understanding the value of an educational makerspace:

> The people aspect of a Makerspace refers to the individuals who make or participate in such spaces and the community of people thus created. The individuals' experiences and the experiences shared as a whole by a community of Makers all inform this people aspect of our conceptual framework for educational Makerspaces. (p. 6)

Makerspaces inherently transform making into a community-situated practice. Maker communities exist at three levels: internal communities within a makerspace (e.g. Chapter 4.0), locally-networked communities between makers and makerspaces within a geographic region (Chapter 3.0), and the now global network of creators who share their work and offer feedback and praise online and in maker faires (e.g. MAKE: Magazine). This suggests that successful engagement in educational making requires the intentional incorporation of community (local or otherwise) into educational practice, the development of skills that support rich community engagement, access to resources for skill acquisition and community engagement, and space within the community at all levels for youth to feel represented and experience belonging.

How that community is integrated into educational practice, however, may vary by larger organizational context. Classes in schools, for example, already possess community attributes; students know their peers and teacher, share certain customs and expectations such as time and duration in the classroom, rules, and assessment. Any maker culture the teacher fosters must adapt to preexisting customs, and even students attending the class for the first time will likely come with expectations about what school is and is not. Youth possess very different expectations, if any, when attending an OST program. The differences between situations from one context to the next are a persistent theme in this discussion, at constant interplay with maker culture and the concept of community, which I discuss as an anchor point for discussing the measurement and support of youth learning outcomes in maker education.

5.1.1 Intentional Community Engagement

Learning can happen at different grain sizes of community engagement, but youth benefit most of all when teachers and programs intentionally support community connection as part of the process. This was evidenced in both THF and the SAL challenge team. The residents at THF engaged with a local maker community in association with the internal maker community they had formed within their housing space through regular participation and interaction. At times, the local community visited THF, i.e. guest makers. Other times, residents visited the local community makerspaces. In both cases, the local maker community provided residents with social and engaging experiences with making and encouraged long-term participation and learning. Guest maker nights at the makerspace were among the most popular; on such nights, attendance swelled from four or five residents to nearly the whole building. As Asa described it, "Let's say we go to [a maker faire] or something; I get to step outside of business, boring American 401k plans, and get to genuinely be myself…" (Chapter 3.0).

The air team engaged both with an internal community of makers and drew upon global, online community resources. In a sense, groupwork in making allows a team of students to function as a mini maker community. In the air team, even those students that were not actively involved in building offered advice, feedback, and input. Tool runners learned to identify equipment and materials, even if they were not making. Documenters had to examine the process in front of them and ask questions to effectively capture thinking, progress, and growth. While these types of engagement would not individually lead to the full range of learning outcomes possible for makers, they each supported learning of skills within various maker learning categories, such as process skills like fluency with tools and materials (Chapter 2.0). Students learned from each other as much as from online tutorials, discussing and debating the functionality of designs together. A student who rotated between these roles, then, would likely have opportunities to obtain a full range of maker learning outcomes, including process, motivation, and community outcomes; this strategy is recommended to support learning in other types of groupwork settings for heterogeneous groups of students (Cohen & Lotan, 2014).

In speaking about community, one must also discuss relationships and interactions. Li's (2014) Simple Interactions tool works to identify the kinds of interactions that support developmental relationships; Li and Julian (2012) argued that developmental relationships are the active ingredient in improving education. The types of interactions that youth engaged in within our studies offered opportunities for two-way, reciprocal interactions that benefit growth and development, i.e. a give-and-take between novice and expert, but others resulted in one-way interactions where youth obtained information but did not engage socially with the source of information within the maker community. These were most evident in Chapter 4.0; the air team regularly sought guidance from online sources in the global maker community but did not post comments or questions on the online sources they researched, nor did they answer questions or offer feedback to others. The information they found online did frequently form the basis for the decisions and discussions they had as a team during their design process, ultimately leading to reciprocal interactions. Occasionally, the team also benefitted from the community of makers Mr. Mancina had created across his physics classes; an air team from another class struggle to make their drone fly and offered advice and feedback. These interactions demonstrate one of the key community and learning skills in Bevan et al.'s (2015) Tinkering Learning Framework, a measure found in Chapter 2.0 to incorporate all three categories of maker outcomes; helping and inspiring others are part of what characterizes community interaction as a maker and both bear implications for the kinds of learning youth makers can experience when engaging in educational making.

The residents' engagement with the maker community at THF (Chapter 3.0) were all in-person, social, and potentially reciprocal interactions, although some residents worked alongside facilitators more easily than others. The residents at THF rarely researched information online; there was only one computer in the makerspace for most of the study and youth typically used it only when facilitators directly encouraged them and prompted the researching process. Interactions with the facilitator and social worker formed the primary basis for obtaining feedback, advice, and information in the makerspace. Although residents rarely, if ever, worked together on a project, others' casual comments and projects often served to influence and inspire the makers.

Online platforms in maker education can provide students with a rich basis of learning resources and offer the possibility of being connected to makers across the world, but the kinds of one-way interactions that easily happen in online platforms limit the benefits youth derive from the experience. Take the following example; although MAKE: Magazine does represent a limited perspective of who makers can be and what counts as making, it does illustrate how even online a larger, world-wide community of makers can offer connection, shared intellectual resources, and a sense of solidarity, as evidenced in the image below (see Figure 17). During the COVID-19 pandemic, the hub acted as a platform for connecting makers everywhere to information about how to use making as a weapon to combat the virus, even encouraging makers to think of themselves as the "maker army" (Grinstein, 2020).

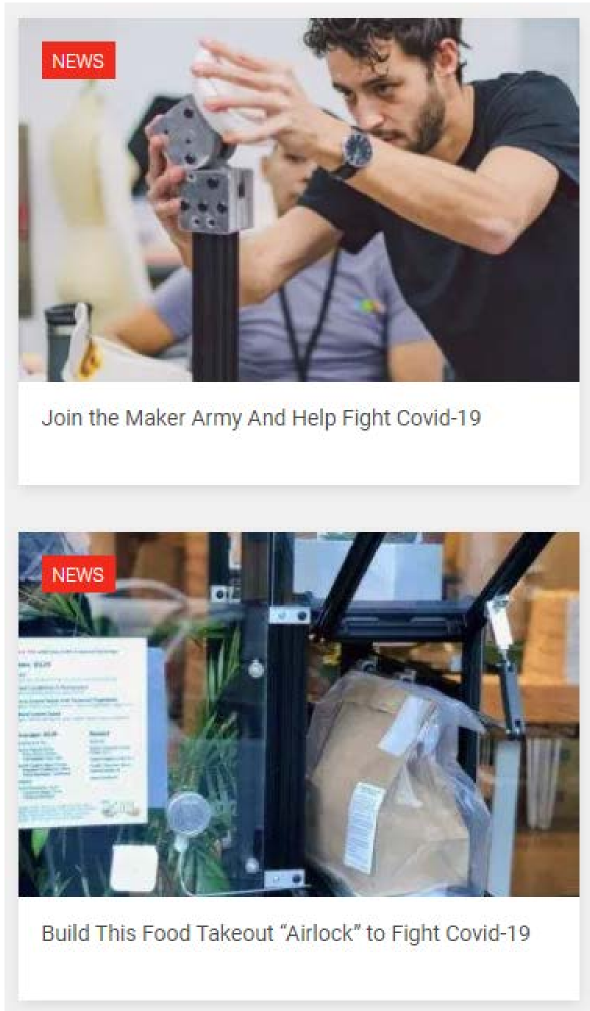


Figure 17 A screenshot of posts from MAKE: Magazine's page demonstrates how the platform encourages solidarity, cooperation, and learning during the COVID-19 pandemic.

Posts such as these encourage makers to feel connected to a larger movement, in this case against a common problem, and offer resources for learning how to make something practical and potentially useful to many makers. On the other hand, these are news articles that do not prompt makers to respond, engage, and ask questions, despite the fact that most online platforms at least offer a comment section for posting replies. In other cases, language barriers may prevent two-way interactions. The students of the air-team relied on a narration-less video produced in China to assemble their drone and experienced many moments of confusion and frustration, but did not find English subtitles and did not try asking questions in the YouTube comments; it is doubtful whether the video's producer would or could have responded to their questions. Although these types of interactions can easily take place in social situations within an internal makerspace community (Akiva et al., 2017), interactions that promote developmental relationships and legitimate peripheral participation online may be more difficult to facilitate. This suggests that when utilizing online platforms, regardless of OST or in-school context, educators should intentionally guide students to participate in reciprocal interactions that support their learning process. Intentional teacher practice and program design could support high quality interactions with internal, local, and global maker communities.

Groupwork, perhaps the smallest grain size of internal maker communities in schools, has recently been celebrated in education for its potential as an instructional tool that allows youth with heterogeneous skills and characteristics to develop social-emotional, 21st century collaboration skills at the same time as learning collaboratively from the varied abilities of their peers. Makerspaces offer exciting possibilities for supporting heterogeneous group work in and out of schools. The youth in Chapter 4.0 were able to push the boundaries of what they thought they could accomplish when working as a group, motivate each other when they were frustrated or confused, and most of them ultimately became friends through the process. As individuals, it may have been impossible for them to complete a mostly-functional drone in 30 hours spread over four months. The youth in Chapter 3.0 could have benefitted from all these experiences, particularly as learning to have healthy social relationships and building social-emotional skills was part of their goals at THF. Despite the potential benefits, contextual factors, group dynamics, assessment, and maintaining motivation in collaborative making can present challenges for instructors.

Context makes a difference for supporting group work in educational makerspaces largely because although the completion of group assignments is compulsory in schools, participation in OST programs and the activities offered therein is voluntary. In the case of drop-in maker spaces, it may not even be practical to ask patrons to work together. In schools, teachers may require students to work in assigned teams and offer extrinsic (external) rewards such as grades and praise for successful collaboration, though potentially to the detriment of motivational outcomes (Ames, 1992; Heyman & Dweck, 1992). Although THF residents typically lived in the same building as the makerspace for months or years and could have engaged in long-term collaborations, collaborating was not actively encouraged and guided. No residents in Chapter 3.0 elected to work collaboratively, perhaps because social dynamics for the recently-emancipated, vulnerable youth were often tense; the social worker who oversaw maker sessions stated in interviews that it was her role to keep the peace and uphold THF policies.

As was true for several students in Chapter 4.0, collaborative maker projects also run the risk of having "too many cooks in the kitchen" (Martin, Dixon, & Betser, 2018). In other words, one or two makers may take over all the building and designing to the exclusion of others. Even if most of the group has a role in the building and designing process, some roles may be reduced to running errands, thus achieving outcomes in only one or no areas of maker learning outcomes (Chapter 2.0), and regardless of in school or OST contexts, young makers may give up on the collaborative project altogether (Martin, Dixon, & Betser, 2018). Drop-in makerspaces like that at THF present a different problem; when youth only engage in collaborative projects voluntarily, the process is not an intentional, guided collaboration leading to specific youth outcomes. Youth may abandon the collaboration or engage only to socialize with peers and may thus miss out on the learning opportunities groupwork affords (Greenberg & Calabrese Barton, 2017). Cohen and

Lotan’s (2014) heterogenous groupwork model suggests that for groups to work as a maker community for supporting learning, youth must be guided to rotate roles in groupwork in order to learn the full range of skills that are necessary to reach non-maker outcomes and to improve engagement in the maker community i.e. legitimate peripheral participation (Lave & Wenger, 1991).

5.1.2 Skills for Community Engagement

With an internal, local, or global community of resources to draw on and share with, making has limitless potential for individual and group growth. Making is public and, as long as there are others around to see it, there are others around to give feedback, offer assistance, ask questions, and inspire (Sheridan et al., 2014; Bevan et al., 2017). Sharing photos and artifacts online is, likewise, an act that simultaneously allows the maker to feel connected to others through their making and has the potential to support an exchange of information that can benefit the learning of both parties (Brahms & Crowley, 2016b; Keune & Peppler, 2017; Papert, 1991). However, it is not a given that youth possess the skills for engaging with the community in a way that benefits their learning. In Chapter 2.0, we identified a series of learning outcomes that directly improve community engagement, such as research skills (Reynolds et al., 2014) and helping and inspiring others (Bevan et al., 2014; Sheridan et al., 2014). In Chapter 4.0, we explored the development of documentation practices, a skill that is critical to allowing makers to share their work and process with the maker community in order to engage with other makers in relation to their work, and is also necessary to support long-term group making as a process skill. Likewise, documentation supports motivation through connection to internal maker and non-maker communities. Other skills like documentation practices may cut across all three forms of learning categories to support learning in maker education, but to date few studies examine the development of skills to promote community engagement.

The findings in Chapters 3.0 and 4.0 suggest that there is a disparity among youth in terms of skills for community engagement upon entering a makerspace. Many youth already possess the knowledge and skills to share information on social media, for example, but do not necessarily know how to record information for practical purposes and share it in a way that supports interpretation and later use, as evidenced by the struggles of the air team in Chapter 4.0. Likewise, the students attending an affluent high school possessed sufficient research skills to find and interpret online instructions to design and build their drone, but residents at THF needed a facilitator's help and encouragement to use a computer for research purposes. These findings call for the need to identify not only a full range of skills that promote meaningful engagement in the maker community but also productive methods of assessment in OST and in-school making to determine whether young makers possess the requisite skills to begin to design and benefit from the resources available from across a world of makers. Extensive research has been done to understand how development in other areas, such as cognitive development (Piaget) or literacy build one skill upon the next in stages; others have endeavored to identify more general skills that build upon each other to allow growth (Stafford-Brizard, 2016). This suggests that for a practice like making, there may be specific skills that interrelate and build one upon the next, and uncovering the categories of maker learning outcomes in Chapter 2.0 may only be the first step to identifying a framework for assessing and supporting sufficient skill development to create rigorous learning opportunities within maker education.

In both of the spaces I studied, there was also an odd tension between the culture of instruction regarding modeling best practices and the use of language and the culture of maker spaces, wherein the ability to use proper vocabulary is often neither priority nor objective. In THF, I observed a resident asking the makerspace facilitator if making sessions could start with vocabulary lessons, but his suggestion was rejected on the grounds that focusing on formal elements like proper vocabulary were not in the spirit of making. Modeling vocabulary became an issue even in the school maker setting, where a teacher unintentionally modeled ambiguous language use that wound up confusing students and hindered efforts to develop a shared basis of communication within a group project. These findings suggest that makers do, in fact, have a use for the more formal vocabulary of the various disciplines from which they borrow tools and skills. Preventing youth from learning these for the sake of preserving the informality and flexibility of making not only hindered learning but failed to take advantage of the motivational effects of curiosity. This problem is not unique to either OST or school makerspaces.

On a related note, and unique to my third study (Chapter 4.0), I found that lack of confidence in drawing skills prevented several of the students from diagramming their ideas or expressing concepts that cannot easily be interpreted in words. Paired with a lack of shared vocabulary, students’ abilities to communicate with one another were often limited and hampered, issues that could've easily been avoided if students were more comfortable with drawing to convey ideas if not familiar with all the vocabulary of the parts they were using. Drawing can help students learn and articulate concepts (Meter & Garner, 2005). The evidence suggests that making is yet another example where drawing could be a useful skill and tool for students to learn and communicate. These findings suggest that both precise language and drawing are valuable communication tools for makers’ use that support researching solutions online, documentation, and groupwork strategies, but that students may lack a sense of self-efficacy in communication skills that are underutilized and not modeled in class. Teachers should carefully and intentionally model vocabulary use, diagramming, and sketching ideas and support youth practicing these skills, not to promote perfect precision but as a tool for facilitating learning and discussion.

In Chapter 4.0, I was surprised to find that tension between adults' purposes for assigning documentation grades and students' personal documentation practices would result in documentation that supported two different kinds of goals; reflection *in* and *on* action (Schön, 1983). Documentation for reflection-in-action primarily supports process outcomes; it is created to allow iterations upon design, e.g. the propeller diagrams students drew in Chapter 4.0 to determine the best position for propellers and reassemble the drone after tests. Documentation for reflection-on-action, on the other hand, inherently lends itself to scaffolding students' metacognitive reflection upon their learning, growth, and motivation to learn and engage, e.g. Elliot's reflection, "the pressure of the competition is getting to us." Except when prompted to create documentation for this purpose, students rarely created documentation for reflection-on-action, suggesting that teachers should model documentation practice and establish clear objectives for documentation to support metacognitive learning.

Although documentation was a required component of students' grades in Chapter 4.0 and a natural extension of school practice, it was neither modeled nor clearly encouraged in the OST setting of THF. In any setting, documenting one's process and thinking could support iteration, cooperation with other makers and thus engagement in a community of makers, and help learners see their own growth over time (Forman & Fyfe, 2015; Keune & Peppler, 2017). Documentation also supports engagement in more complex, long-term projects without getting confused and discouraged, as the students of the air team remarked in post-test surveys; "Documentation allowed everyone in the group to know what stage we were in throughout the project. We could also look back to it for a better understanding of what we did so far as a group and what we have left to do."

Clark from THF, on the other hand, visited a particular project over and again without success and ceased working on it each time he grew frustrated. The findings in Chapter 4.0 and Schön's (1984) theory of reflection-in-action raise questions about how facilitators could use makers' documentation to help youth iterate upon designs before attempting to create a finished, perfect product. As Clark identified as a sculptor and artist more than maker, however, and participated in the makerspace on a voluntary basis, Clark and youth like him in OST places may be reluctant to take on the additional effort of building the formal-looking practice of documentation into their OST practice.

Future research should examine the use of student documentation in maker projects both in OST contexts and for long-term individual projects to understand the learning benefits youth can derive and the best practices for modeling and scaffolding documentation practices. Instructors in educational makerspaces can model and support good documentation both for learning and process in makerspaces by: emphasizing the goals of both types of documentation when engaging students in creating documentation; encouraging makers to incorporate labels, systems of communication, and other techniques to ensure the data they record is useful for whatever goal it was recorded; and encouraging makers everywhere to value good documentation practices independently of mechanisms for grading or associations with formal schooling, as it facilitates help, learning, and engagement with the maker community.

5.1.3 Equity in Community Engagement

Finally, I turn to the subject of equity in maker education and the implications of community engagement for growth and learning. Equity in maker education is not a simple question of giving students access to a makerspace and expensive equipment; it is about the resources and structures that support the kinds of engagement that lead to learning outcomes relevant for the youth they are meant to serve (Hira & Hynes, 2018; Vossoughi, Hooper, & Escudé, 2016; Martin, Dixon, & Betser, 2018). If engagement with the maker community is beneficial to youth, one must determine what resources lead to the development of skills that support community engagement, allow teachers to intentionally build productive community interactions into instruction, and give youth a sense of belonging in the space.

Material and intellectual resources form the backbone of maker practice. Chapters 3.0 and 4.0 present a glaring difference in access to resources and the extent to which resources facilitated or discouraged community engagement. That is to say, not only must one possess tools and materials to create physical and digital artifacts, but to create something new and learn in the making process, one must have access to a variety of intellectual resources such as one's own knowledge, others' expertise, hands-on help from peers and mentors, and the ability to receive feedback. The museum intentionally integrated community into practice at THF; without the museum organizing events, renting busses, and hiring guest makers in order to make these community connections possible, the youth at THF would have had neither opportunity nor access to the local maker community. On the other hand, residents at THF only had access to donated resources and tools selected by the more crafts-focused teaching artists at the affiliated museum makerspace, a limitation of the low-resource context of starting a makerspace in a transitional housing facility for homeless youth. There was one computer for all to share that the facilitator used to play music; the youth were occasionally encouraged to look up YouTube videos or research solutions, but were not encouraged to connect themselves with the maker community through forums or online platforms. In contrast, the students in Chapter 4.0 had school-issued laptops, both owned and were permitted to bring smart phones and cars to school, and had access to not one but two rooms full of tools, three spaces to work in, and permission to order additional parts as needed, regardless of whether students had successfully fundraised for the competition. They used these resources to produce documentation, a practice that supported learning, success in making, and motivation long-term, and to research solutions to problems that came up in testing. They used smart phones with slow motion capture capabilities that most schools would not allow or could not feasibly supply to their students. Eventually, access to white boards that would not be erased from one week to the next also proved integral to their ability to discuss ideas and iterate upon designs, something that programs and schools short on space and resources could not likely provide to all students.

When it came to physical, material resources, the youth in the air team (Chapter 4.0) had far more to work with than their emancipated emerging adult counterparts (Chapter 3.0). Doubtless, it was easier for students in the air team to research tutorials and document their progress than it would have been for the residents at THF, who were often uncertain how to undertake the ideas they generated and dropped projects that took too long to complete. But the youth in Chapter 4.0 were not encouraged to connect themselves to a maker community through trips to museums or guest visits from teaching makers the way the residents at THF were, or to think about making outside of the robotics-focused project they were assigned. Neither were they permitted to choose their own projects or even keep what they made, in contrast to the autonomy of the residents at THF, limiting sources of motivation to intrinsic (internal) rewards and performance-based extrinsic standards for success (grades, winning at competition). Maker learning does not just happen between student and artifact, or student and teacher, but rather in conversation with the entire maker community and all other intellectual resources makers draw on for inspiration and guidance.

This suggests that when it comes to maker learning, the kinds of resources that support making as a *practice*, i.e. process outcomes found in Chapter 2.0, are not necessarily the same resources that encourage long-term community engagement, motivation, or maker-community-related skill development. It is not unusual in schools to find that making is used to support learning outcomes unrelated to making; often, it is a goal of teaching and instruction to use practices like making to trigger interest and promote engagement in the larger class context, e.g. physics (Chapter 4.0). Likewise, OST makerspaces seem more likely to plan for resources that support long-term engagement, community interaction, and motivation to engage in the practice of making. Educators must decide for themselves what kinds of learning outcomes they hope to achieve, but this suggests the following practical applications.

Even with low-tech resources, giving youth autonomy and the ability to keep what they make to meet personal needs can be powerful sources of motivation, supporting long-term engagement (Greenberg & Calabrese Barton, 2018; Sheffield et al., 2017). Space is just as important as tools and materials in understanding the *means* of a makerspace (Hira & Hynes, 2018); when students can shape their environment, e.g. keeping diagrams on whiteboards that will not be erased, they can tailor their learning experience to meet their needs. Space may provide more of a challenge than access to tools for high or low-resourced schools and programs, however, and educators and designers should consider creative solutions for allowing students to modify and preserve their own work environment. Maker education is both better at achieving motivation, process, and non-maker learning outcomes when youth are fully connected to a community of makers who can provide them with feedback, inspiration, and knowledge (Sheridan et al., 2014). Educators in both OST and in-school settings should dedicate time to modeling and encouraging youth use of online and local sources of maker community access, taking care to identify spaces and programs that are welcoming to the youth in question, e.g. makerspaces designed for girls or non-white youth (Vossoughi, Hooper, & Escudé, 2016).

A part of providing makerspaces in education that serve needs equitably includes understanding the purpose youth have for engagement (Greenberg & Calabrese Barton, 2017; Martin, Dixon, & Betser, 2018) and the means necessary to support that engagement (Hira & Hynes, 2018). For vulnerable, impoverished youth like those at THF, the products that the young makers made often served or filled needs that they lack resources to fill by other means, e.g. Clark's products to sell, Asa's paintings for self-expression, and the cat toys and bed Nadia produced in preparation of the arrival of a therapy cat in Chapter 3.0. Likewise, residents were more likely to come if free food was available, a known motivator for many adolescents but especially so in the case of low-SES youth living in fear of homelessness. Their experiences lacked the extrinsic rewards typical of schools, such as good grades, letters of recommendation, portfolios, and scholarships (Eccles & Wigfield, 2002). If the residents had worked in a group to build or design something, likely only one of the young adults would be able to take home and benefit from the product of their making, and with the limited time residents had to spare between resting, socializing, and looking for work to qualify to remain in the housing program, and thus escape or delay homelessness, many residents would likewise likely have felt that making products they could not keep was not worth the time spent making it; viewed under a lens of expectancy-value theory, youth might prioritize spending the time to earn money to acquire the items they need through other, less entertaining means (Wigfield, 1994). The affluent students of the air team, in contrast, were disappointed to learn they could not keep their drone, but still motivated to know that they had succeeded in making a drone fly and that the grades they received could lead to scholarships, good colleges, and brighter futures.

In addition to considering the means necessary for equitable learning, one must also consider how to create learning environments support learning and engagement in the maker community for youth that do not fit the image of middle-class, able-bodied, white, male makers (Vossoughi, Hooper, & Escudé, 2016). In THF, the presence of a social worker allowed youth recently emancipated from foster care to feel safe and co-exist in the makerspace. For the air team, the school itself promoted a culture of college readiness and STEM-excellence for students of all genders and racial or ethnic groups. In the air team, girls and students of underrepresented racial/ethnic groups not only engaged deeply but took on leadership roles. Elliot, a student of mixed ethnicity that lacked confidence in ordinary classes, rose to a position of authority through hands-on learning in his team. These findings suggest that makerspaces can be safe, motivating spaces that encourage youth of different backgrounds and mixed abilities to engage in learning but offer little insight into specific designs for specific groups. Future research should endeavor to fully explore the environmental and community traits that promote a sense of belonging, safety, and self-efficacy for youth that feel marginalized or unwelcome in typical maker communities.

To date, a limited number of studies have discussed the potential learning and developmental benefits of making for youth with disabilities. One of the drawbacks for making with disabilities is that depending on the learners' particular type of disability, social engagement of any kind can be challenging and the process of making itself may present challenges unique to a youth's disability. For example, autistic students can feel overwhelmed in environments that provide too much sensory stimulation (Ashburner, Ziviani, & Rodger, 2008), as can easily be the case in an unfamiliar space full of disorganized, brightly-colored tools and materials, loudly chatting young makers crowded around work stations, and the high-pitched whir machines doing their jobs. However, the ability to explore one's own interests in a hands-on space where social interaction is optional but available may be easier than a traditional classroom format for students with many learning, processing, social and sensory disorders or disabilities. At THF, an autistic resident regularly engaged in the makerspace to make artifacts inspired by the TV shows and fiction he enjoyed, and despite difficulty socializing with others positively in the building, he seemed more at ease and open in the makerspace than he behaved otherwise. This resident was not included in the final study only because he was evicted from the housing program shortly after the beginning of his participation in the makerspace due to difficulties adhering to THF policy and thus resulted in limited, incomplete data. Just as relatively few makerspaces have been designed specifically as environments that welcome and support women and non-white makers (Vossoughi, Hooper, & Escudé, 2016), makerspaces are rarely designed for students and youth with disabilities.

Future research should endeavor to draw on the growing body of expertise for designing learning environments for youth with disabilities and maker learning to create inclusive, motivating learning environments that support inclusion in the larger maker community. For youth with social disabilities in particular, online community engagement may be beneficial to learning if scaffolded and encouraged (Ringland et al., 2017). On a related note, accurately researching the needs and experiences of youth with disabilities in makerspaces presents a methodological challenge that resulted in data loss in the study in Chapter 3.0; one resident who was eager to participate in the study had difficulty with verbal expression and typically nodded or used facial expressions to reply to questions that were not adequately captured in an audio-recording, even with field notes to supplement. Had the video method from Chapter 4.0 been employed in her unexpected case, her story may have greatly added to our understanding of makerspaces and community engagement for youth like her.

5.1.4 Big Picture

Ultimately, making is but one educational practice that exists both in and outside of schools and could be studied to answer the question at the heart of it all—how research can use a situated, contextualized view of learning and educational practice to understand how practices translate across educational spaces and their implications for youth learning and development across ecologies (Barron, 2006). Community engagement is not unique to making; in a situated view of learning, understanding the skills and outcomes related to engagement in any community of practice could likely support learning for youth better across educational contexts should the educators in those spaces value, assess, and promote the development of practice-related outcomes instead of only focusing on the desired outcomes of instruction (Lave & Wenger, 1991). This is why the interdisciplinarity of the learning sciences is important; behavioral changes and knowledge acquisition alone present a skewed, limited understanding of learning that prevents contextualized views of learning that address interactions between practice-based contexts and the educational organization's practices, structures, and expectations for youth (Sawyer, 2014). Context shifts on a constant basis and influences learning for youth and practice in educational spaces (Bronfenbrenner & Morris, 2007). In 2019, *A Nation at Hope* lauded the introduction of OST-style practices and outcomes to in-school spaces, carving out space for making in classrooms (SEAD Commission, 2019). In 2020, schools everywhere moved online in the wake of a pandemic, marking a surge in the evolution of online-teaching technologies and possibilities for remote, distance, and virtual learning while all but eliminating place-based, hands-on learning worldwide. The brave, new world of education is one that must ever adapt to changing technology, policy, practice, and structures. In and out of schools, educators must navigate the tensions and affordances of a marriage between practice and context, but when schools and OST programs work together as part of one ecosystem, learning from practices across settings, youth can thrive.

Appendix A Table for Article 4.0

Table 9 Chronological account of student progress and documentation use.

	Project Progress	Documentation
Jan 25	-Fundraising Researching possible designs	Short, bulleted list of things they discussed
Feb 5	-Documentation guidelines distributed -Researching designs	Trying to find things to take pictures of to meet guidelines
Feb 8	-Team receives 7/10 on initial documentation rubric, frustrated -Ordering parts -Working on Preliminary Design Review	Making list of parts they have found and might need based on previous teams
Feb 12	- PDR - Discussing fundraising - Ordering parts	Color coding to divide work, creating written records retroactively to meet guidelines, highlighting used terms to define later
Feb 15	- PDR, dividing the work - Hunting for missing parts delivery	Consulting order form to find missing delivery; drawing drone diagram for PDR
Feb 19	- Unpacking parts delivery - Inventory - Researching to find silent instructional video for assembly - PDR grade received	Creating inventory system to prevent theft and loss
Feb 22	- Beginning assembly of drone kit based on video	Taking pictures of assembly
Feb 26	- Connecting wires and motherboard, following video	Few notes, no pictures
Feb 28	- Fixing damaged remote controller - Zip ties for cable management, following video instructions	Pictures to share progress on social media; narrated video to add to final project documentation
Mar 6	- Attaching propellers and finishing basic assembly	Documenter is absent; team takes pictures at the end to celebrate and share with her
Mar 8	- Modifying design (adding legs) - Performing tilt test to check motor function - Naming drone	The team takes pictures to celebrate progress
Mar 12	- Class receives access to SAL resource database, including written instructions for kit	Taking pictures; teacher models simple potentiometer diagramming,

	- Waiting to get a test flight appointment - Picking up parts delivery - Programming drone	language to refer to potentiometer, “middle”
Mar 14	- Work on camera (Eliot) - Programming (London) - Tilt testing drone to test programming/calibration - Remainder of team focuses on sponsorship emails	Lamenting lack of documentation; team did not expect to ever have to remove propellers once on; London diagrams as she tests potentiometer positions to calibrate drone’s locking function
Mar 26	- First flight test crashes, drone is damaged - Working on camera (Eliot) - Discussing what went wrong, making plans to modify documentation approach - Ordering new parts	Unsuccessful video capture of first flight; London makes a list of what needs replacing; taking pictures of parts to identify and reorder
Mar 29	- Waiting for parts - Reattaching legs with string instead of zipties - Working on camera (Eliot)	Referring to pictures to see how legs were previously connected; adding videos to Google Docs; using photo to document materials now being used
Apr 2	- Making repairs to the drone (Girls) - Trying to diagnose reason for crash; determine correct motor and propeller positioning and spin (Nick and Eliot) - Working on camera (Eliot)	Nick diagrams the drone motors and propellers to think through the correct position, discuss with Eliot, and compares to Billie’s photos; takes picture of diagram at researcher’s reminder
Apr 5	- Parts are in - Team repairs motor spin and propeller positions - Eliot works on payload droppers	Team uses diagrams to work through propeller/motor position and compare to instructional video
Apr 9	- Eliot works on camera - Team tests drone with teacher and adjusts propellers and potentiometers	Referring to previous photos of potentiometer positions; modifying diagrams to correct mistakes
Apr 12	- Team flight tests drone with mentor and teacher - Team adjusts yaw potentiometer several times in separate tests	Team takes video recordings during flight tests; London memorizes test variables and outcomes and later draws chart of potentiometer diagrams paired with outcomes on whiteboard
Apr 15	- Multiple team members absent - Billie interprets London’s chart and discusses hypotheses with teacher and researcher - Billie reattaches loose wires	Billie interprets London’s chart, modifies on her diagram; researcher models clock labels based on teacher’s prior suggestion; diagrams remain on white boards

Apr 16	- Testing yaw positions in test flight - Resolving miscommunication about yaw potentiometer position - Fixing locking problem	Samantha tries to diagram London's verbalize potentiometer positions; labeling shift through conversation; Samantha takes video with narrated labels of flight tests including hypotheses, number, and adjustments; teammates take video of tests
Apr 17	- Design modifications and testing - Motor test	Eliot plays documenter, taking detailed notes with reflections; team makes list of variables that are fixed vs problems
Apr 23	- Test flying and making last minute changes - Soldering new ESC to drone connectors to improve motor speed (Eliot) - New hypothesis; controller is the problem	Habitually video recording flights by now; note taking and labeling is getting more lax
Apr 24	- Problem solving - Preparing for competition - Trying to correct spin during flight tests with modified controller calibration - Teammates volunteer to take turns working during free periods	Team makes list of what has and has not been fixed; documentation used to pass work from one part of the team to the next
Apr 25	- Competition - Last minute efforts to correct spin, dragging motor - Drone fails to fly twice	None; reverting to "middle" to describe potentiometer positions

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