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Makerspaces for Education

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Makerspaces for Education

by

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For my parents, Kiran and Narinder.

Dedicated to the Makers who inspired this work and will never read it.

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Call it a clan, call it a network, call it a tribe, call it a family. Whatever you call it, whoever you are, you need one.

- Jane Howard

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ABSTRACT

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In my dissertation, I present research examining Makerspaces for education. The concept of a Makerspace has evolved, currently being understood as a space for people to practice the idiomatic term Making, which is to tinker or fabricate. Broadly put, Makerspaces are environments where individuals use technologies to Make physical artifacts within a community of fellow Makers.

When I started this work, stakeholders from a variety of backgrounds had begun to discern the educational potential of Makerspaces. Since then, several resources in schools, libraries, educational research, and community spaces have been directed towards realizing this educational potential. However, despite the belief in their potential for learning and development, there is still little systematic research outlining their educational benefits. My research in this dissertation is not just motivated by the lack of systematic research addressing the education potential of Makerspaces, but also by their potential for being venues for students to develop self-sufficiency and practice agency while working on projects that they are personally motivated to be a part of.

The work comprises three related studies on the topic of Makerspaces for education. In the first study, I conduct a thematic analysis and synthesize publicly available descriptions of Makerspaces to develop a framework for educational Makerspaces. This framework can serve as a tool to support Makerspace researchers and educators in articulating a purpose and setting up an educational Makerspace aligned with that purpose. In the second study, I analyze narratives of Makers to understand their practices and knowledge in comparison to design using a narrative inquiry approach. Via this study, I make a case for the epistemological legitimacy of Making by proving it similar to design. I also find what makes Making distinct from design, which is it being a venue to realize personal purposes and meaning, adding to its educational potential. Finally, for the third study, I conduct a thematic analysis of narratives from a Maker course and an engineering

camp to understand reflective practice and identity formation in the context of educational Makerspaces. This third study can be considered an addition to previous empirical work on connections between engineering, design, identity and reflective practice. The unique contribution of the study is in it being situated in the context of Makerspaces, with implications for how we teach and assess learning in such spaces. The three studies, though distinct, are closely related and inform each other. They are connected via the intent behind them and also their results and contributions.

Beyond Makerspaces, my work in this dissertation explores the connections between identity formation, reflective practice, and personal meaning. It also challenges our current understandings of engineering knowledge, exploring it beyond boundaries of formal classrooms. Though the present work is situated in Makerspaces, I consider this work to add to the intersectional conversations of these areas of interest amongst engineering educators and engineering education researchers.

INTRODUCTION

As an old joke goes,

> *A poultry farmer is showing one of his friends, an engineer, around his farm, taking him through all of the processes and procedures. On seeing all the flurry of feed and feathers, the engineer scoffs and declares "Why, I could increase egg production by at least 89%!" The engineer then proceeds to make various measurements, judiciously recording them in his engineering notebook, and then returns to his office where he runs the measurements through sophisticated software with advanced mathematical models. The next day, armed with a stack of charts and graphs, the engineer meets with the farmer, and begins "So, first we assume we have spherical chickens in a vacuum …"*

Engineers solve problems, often problems that they do not experience.
People live lives, lives that are often full of problems.

The journey of the engineer over the years has been widely stated and celebrated. Parallel to, but not as loud as the journey of the engineer through the ages, is the journey of the doer, the problem-solver, the artisan, and the maker.

My agenda in engineering education is informed by two central tenets: legitimizing knowledge that has historically been unacknowledged in formal education, and facilitating individual's empowerment via education. My work on this dissertation makes humble beginnings in achieving this agenda by making a case for the legitimacy of knowledge amongst Makers, and by examining Makerspaces as sites for empowerment and individualized education.

Research Imperative

In the dissertation, I present research examining Makerspaces for education. The concept of a Makerspace has evolved, broadly being understood as a space for people to practice the idiomatic term Making, which is to tinker or fabricate. Broadly put, Makerspaces are environments where individuals use technologies to Make physical artifacts within a community of fellow Makers. In my dissertation, I refer to these terms as capital-M Making, Makerspace, and Makers.

When I started this work, stakeholders from a variety of backgrounds had begun to discern the educational potential of Makerspaces. Since, then, several resources in schools and libraries (Abram, 2013; Delaney, 2015; D Dougherty, 2012; Maker Media, 2012, 2013) educational research (Bilkstein & Krannich, 2013; Halverson & Sheridan, 2014; Meehan, Gravel, & Shapiro, 2014; K. Peppler, Maltese, Keune, Chang, & Regalla, 2015; Sheridan et al., 2014) and community spaces (Gunby, 2015; Makerspace North, 2014; Makespace Madrid.; Mathilde, 2015) have been directed towards realizing this educational potential. However, despite this belief in their potential for learning and development, there is still little systematic research outlining their educational benefits.

At the Maker Impact Summit (2013), the Deloitte Center of the Edge and Maker Media reported that the Maker movement had had an impact in the areas of manufacturing, education, public policy, citizen science, and retail. Outside of this report, the Maker movement is considered promising for education as Making is claimed to be an inherently human activity, which provides a venue for people to Make what is personally meaningful to them (Barniskis, 2014; Durham, 2015; D. L. Rendina, 2015). Also, as a practice that it is driven and sustained by human agency, it acts as a practice which could assist with social emancipation (Delaney, 2015; Foster, 2015; Schwartz, 2016). Furthermore, Making as an educational activity has roots in established theories of learning and development such as constructionism (Papert, 1980), social cognitive theory (Bandura, 1989), and experiential learning (Dewey, 1938), and similar activities such as technology education and shop class which have been practiced in educational settings in the past.

In addition to the reasons that make Making educationally interesting at large, Making is particularly valuable in the context of engineering education. Makerspaces present themselves as promising sites for open-ended Problem Based Learning Activities (Kim, Sharp, & Thompson, 1998) and are being adopted in other informal learning environments such as libraries and museums with a focus on engineering education (Barniskis, 2014; Bevan, Gutwill, Petrich, & Wilkinson, 2015; Gonzalez, 2016). The intimate connections that the practice of Making shares with design knowledge and practice, and its capacity to invoke innovation, all point towards Makerspaces being useful sites for engineering educators and engineering education researchers.

My research in this dissertation is motivated not just by the lack of systematic research addressing the education potential of Makerspaces, but also by their potential for being venues for students to develop self-sufficiency and practice agency while working on projects that they are personally motivated to be a part of. I am also interested in understanding the nature of practices that produce artifacts with social roles that support communities (Krippendorff, 2006), and the culture of the doers and the Makers who engage in the physical construction of artifacts in response to social needs (Cross, 1982). Finally, I am interested in understanding how students can be reflective about their experiences, to carve their professional identities. I conduct three related studies to understand these dynamics within the context of Makerspaces for education.

Educational potential

Several educational theories can serve as lenses to understand the educational potential of Makerspaces. In this section, I expand on relevant theories that have in the past been alluded to in academic literature on Makerspaces and other theories relevant to educational Makerspaces. I divide the following discussions into the individual and social nature of learning. The individual nature refers to learning that is incumbent on the people in a Makerspaces, and the social nature takes into consideration the world outside of the individuals, including the tools and technologies they use and activities they undertake in the space. However, it is important to acknowledge that the individual and the social nature

do not exist in isolation from one another, but rather are closely related as we will see in the following descriptions.

The individual nature of learning

The educational theories related to the individual nature of learning in a Makerspace are constructivism (Piaget, 1970), constructionism (Papert, 1980), situated cognition (Brown, Collins, & Duguid, 1989), and transfer (J. Bruner, 1966a). To be put simply, the theory of constructivism posits that people gain new knowledge by building on what they already know and have experienced. This building of knowledge is done by process of assimilation, and accommodation by altering and constructing new cognitive structures (Ginsburg & Opper, 1988). Constructionism as a theory posits the importance of constructing to learn. The theories of situated cognition, and acquiring and transfer, are related to gaining skills in a particular context and using them for other contexts in the future as a secondary activity.

Firstly, the theory of constructivism helps us understand how new knowledge is gained by an individual while being part of a Makerspace. According to Piaget (1970), the cognitive structures develop through four phases namely, maturation, experience (this can be physical and logicomathematical), social transmission, and equilibration. It is only when an individual passes through these processes and develops cognitive structures via the processes of accommodation and assimilation of knowledge in his/her cognitive schema, he/she reaches the next stage of development. This development of cognitive structures via the aforementioned processes is Piaget's theory of individual constructivism. This theory can be used to understand the processes of assimilation and accommodation that Makers go through as they develop and build on new knowledge gained at Makerspaces. In an ideal Makerspace environment, opportunities for development through these processes are abundant as the individualized nature and pace of learning supports individuals to go through the different stages of developing their cognitive schema at their own pace.

Secondly, we can understand how individuals learn by making artifacts, supported by the theory of constructionism. Papert and Harel (1991) write about how constructionism and constructivism are related but different:

> Constructionism--the N word as opposed to the V word--shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe." (p.1)

In addition to writing about the connections between constructivism and constructionism, they also acknowledge that as a theory even though constructionism does not forward claims of scientific truth, it offers an alternative for traditional theories of learning that are focused on the instructor. They write that even though there is no agreed upon "best way" of learning, this theory presents itself as a candidate for individuals to learn in ways they consider meaningful. This theory is operationalized by suggesting a move from verbal-based formal knowledge to knowledge gained by doing and conscious engagement of the individual. The essence of Making can be understood via this theory, as Makers construct entities which embody different meanings for them. Depending on the context and their motivations, Makers can be constructing a myriad of artifacts, from something for their personal entertainment to something that helps with the needs of their community. As Makers in Makerspaces construct physical artifacts, they learn. This learning can be regarding the context they are building for, the skills they use to build, or something that we have not hypothesized yet. An environment that supports and sustains making to learn embodies constructionist values.

Thirdly, individuals learn in situated contexts and transfer their learning to other contexts. Brown, Collins, and Duguid (1989) make a case for the importance of situated cognition in learning and put forth that our educational system engenders a breach between the knowledge of concepts, and knowing how to use these concepts. The possibility for transfer, in this view, usually requires abstract and decontextualized learning of concepts. Further, Bruner (1966) writes about how structure, rather than mastering of facts and

techniques, is at the center of the classic problem of transfer. He writes that learning should be useful to an individual in the future, and not just for the particular context in which it is acquired. Makerspaces present themselves as an answer to this problem of transfer, by serving as sites where individuals do not learn skills in decontextualized ways. Rather individuals hone skills such as Computer Aided Design (CAD), computer programming, machining, wood working, etc. in contexts that are meaningful to them. This makes learning different from that in a formalized setting with no real-world applications. Brown, Collins, and Duguid write that when education is decontextualized, one can talk about the purpose and way to use a tool, and yet fail actually to use it. Similarly, students may manipulate algorithms, routines, and definitions and fail to use them in real application tasks. In contrast, active use of these tools in a Makerspace, foster a rich understanding of the tools themselves and of the worlds in which they are used. Ideally, Makers have the freedom to acquire the kind of knowledge that they deem important and be able to transfer it to contexts that matter to them.

The social nature of learning

The next three theories pertain to the social nature of learning and are posited by Dewey, Vygotsky, and Wenger. According to Dewey (1938), learning is a democratic and social process, and at the same time should embody what is personally meaningful to individuals. According to Vygotsky (1962), knowledge is socially constructed and gained by means of a Zone of Proximal Development (ZPD). Wenger's (1998) theory pertains to the shared beliefs and support for learning within communities of practice.

Firstly, Dewey's theory of experiential learning helps us understand how an individual's social experiences which could occur in a Makerspace setting affect his/her learning. Dewey (1938) proposes a theory of experience to guide educational methods and experiences in places of learning. He also critiques progressive reform in education taken up for the sake of opposing traditional education. He writes how it is imperative to create better educational systems rather than rejecting and doing the opposite of the current system. Given this framework, it becomes crucial for educators to be more intentional

about new curricular practices, and not ascribe to new methodologies by assuming their novelty. This idea can be extended to Making. A considerable body of critical research and practice is required before assuming the benefits of Makerspaces. Dewey believed that the trouble with most education is that even though educators take upon themselves the responsibility of providing an environment to their students, they often do not consider other factors that create experiences for the students. These factors include the powers and purposes of those being taught. In the case of Makerspaces, the people being taught are the Makers, and it is their purpose that Makerspaces ideally serve by providing a venue to Make what they want. In addition to the communal experiences, individual experiences are also valued in a Makerspace as there is no correct answer to a problem, and thus Makers create their own experiences contingent on the environments they find themselves in.

Next, we delve into how knowledge is socially constructed, and the role Making can play in this construction of knowledge. According to Vygotsky, the mind mediates between the external world and individual experience, and the mind does not exhibit a logical calculus (J Bruner, 1997). He posits that culture's symbolic tools from the outside permeate into the inside of our thoughts. Pedagogy and intersubjectivity enter the Vygotskian picture in the form of the ZPD. The ZPD can be understood as the zone that a learner crosses with the support of a more knowledgeable other to learn something new (Chaiklin, 2003). He writes, "[t]o put it bluntly, the ZPD recognizes that Homo is the only species that uses teaching in any systematic way and asks what it takes for somebody to teach or be taught by another" (p. 39). Chaiklin purports the ZPD as an instrument that promises limitless growth. This essence of the ZPD can be seen in environments such as Makerspaces, where different people have different expertise. The social nature of learning in a Makerspace is represented by everyone having access to others' shareable expertise, and having the opportunity to grow.

Lastly, in the social nature of learning we look at how a community of Makers supports learning. According to Wenger's (1998) theory of communities of practice, community members meet because they find value in their interactions. They create artifacts and develop tacit understandings that they share. Elucidating on the nature of a community of

practice, Wenger, McDermott, & Snyder (2002) write, "they accumulate knowledge, they become informally bound by the value that they find in learning together … They even develop a common sense of identity" (p. 5). This theory focuses on the shared resources, beliefs, and practices shared amongst a group of people. In the purview of Makerspaces, Makers define and understand commonly shared values concerning what they do and their motivations. They also have access to the resources housed within the community. Thus, Makers in a Makerspace and also those in virtual communities, exhibit characteristics of a community of practice.

Thus, the educational potential of Makerspaces is grounded in several well-established theories of learning and development that relate to the individual and the social nature of learning. Further, strengthening my motivation behind the studies, I undertake in this dissertation.

Introduction

This dissertation comprises three related studies on the topic of Makerspaces for education. In the first study, I conduct a thematic analysis and synthesize publicly available descriptions of Makerspaces to develop a framework for educational Makerspaces. In the second study, I analyze narratives of 10 Makers to understand their practices and knowledge in comparison to design using a narrative inquiry approach. Finally, for the third study, I conduct narrative and qualitative analysis of data from a Maker course and an engineering camp to understand reflective practice and identity formation in the context of educational Makerspaces. The three studies, though distinct, are closely related and inform each other. Figure 1 is a depiction of the connections between the studies. The inquiries are connected via the intent behind them and also their results and contributions.

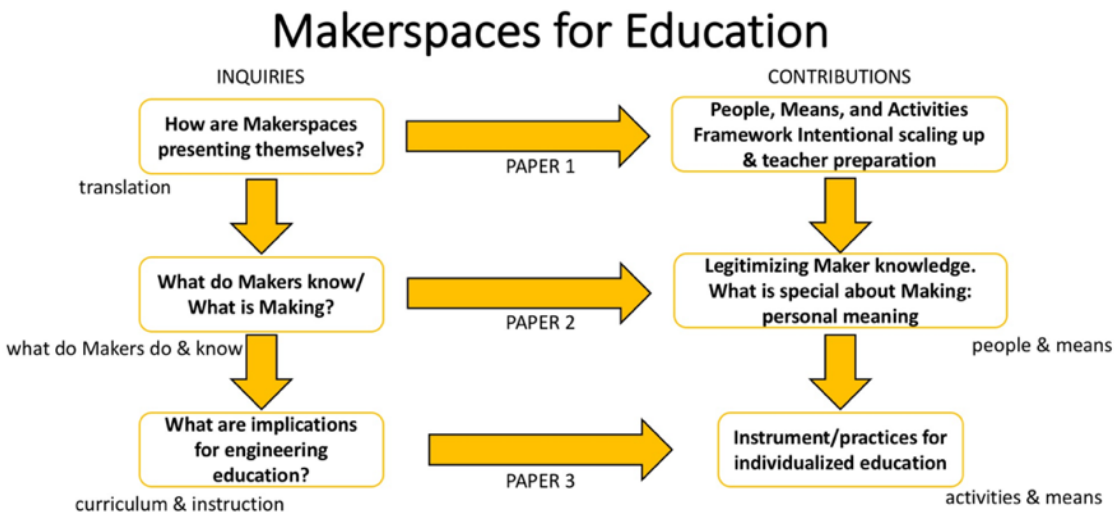


Figure 1: Schematic representing connections between the three studies of this dissertation.

Positionality

In qualitative research, it is important for researchers to declare their positionality as the research is often closely linked to their beliefs, attitudes, perceptions, and priorities (Milner, 2017). In this section I situate myself in relation to the topic of my research, the participants, and also the context and process of the research design and implementation.

I studied Aerospace Engineering at the Bachelor's and Master's levels. Looking back at my engineering education, I think that Making things such as aero models and being part of communities such as college-level clubs and international non-profit organizations, had the most significant impact on me during school. I believe that being an engineer who went through the traditional educational system as well as someone who recognizes the importance of the people aspect of engineering affects how I understand engineering and my vision for engineering education. I think of engineering as a profession of service, the service of people to make life better.

In addition to being an engineer and a Maker at different times of my life, I am also an educator, and conduct research and volunteer at venues related to engineering education. This positionality makes me question engineering beyond enacting it in professional settings and think of ways to educate engineers to live their motivations and ambitions. My agenda in engineering education is informed by my interest in (1) creating engineering education opportunities for people from all backgrounds; (2) understanding learning practices that value knowledge and skills of all participating; and (3) empowering people through formal and informal education to make social change that is personally meaningful. I believe that engineering education and particularly practices of design and Making are well-suited for research and curricular interventions to appeal to this agenda due to the broad range of contexts they can cater to, which, in turn, acknowledge and respect learners' personal beliefs and values.

Having benefited from it personally, I believe in the educational potential of Making. This belief along with wanting to create engineering education opportunities for people from diverse backgrounds inform my work in Paper 1. The conceptual framework can aid in intentionally scaling-up educational Makerspaces that can cater to varied interests of people from different backgrounds. My understanding of and experiences with design and agenda of understanding learning practices that value knowledge and skills of everyone inform my work on Paper 2. With this study, I initially aimed at legitimizing knowledge of Makers which I hypothesized as them practicing design unintentionally. The emergent theme from this paper of Makers seeing personal meaning and purpose in their practice also makes a case for the value of different individuals' knowledge. Finally, my identity as an educator and agenda of empowering people through formal and informal education inform the design, development, and inquiry in Paper 3.

In addition to situating my research, my positionality also informs tensions that I have felt during my work on this dissertation. The Maker in me often tries to resist the act of theorizing the practice of Making. Contrary to which, the researcher in me seeks to theorize, understand, and neatly pack what I know of Makerspaces, with the goal of reproducing them. Finally, the engineer in me wants to see positivistic rigor in the research

process and often questions the validity and contribution of mediums such as conversations and stories.

Paper 1 – PEOPLE, MEANS, AND ACTIVITIES: A CONCEPTUAL FRAMEWORK FOR REALIZING THE EDUCATIONAL POTENTIAL OF MAKERSPACES

As depicted above in Figure 1, the first paper examines how present-day Makerspaces present themselves. I conceptualize how Makerspaces have been adapted to educational settings by looking at the growing numbers of Makerspaces and their associated websites, articles in popular media, curriculum, and empirical studies. I propose a conceptual framework comprising three aspects of educational Makerspaces, namely, the people, the means, and the activities. The three aspects are tied together by the purpose of the space, which can be variably focused on one of the three aspects or some mix of them. The contributions of this study are twofold. First, the people, means, and activities framework helps determine directions for future research. Second, along with theories of learning and development that align with the three aspects of the framework, this work provides a foundation for determining best practices for learning and development in a Makerspace. I provide examples of such practices in the final chapter of the dissertation. The first study serves the purpose of translating educational Makerspaces across contexts. It also serves as a framework for the next two studies which focus on the people and the activities aspects of Makerspaces. The means aspect, which comprises the tools, technologies, skills used in a Makerspace, is present in both the studies.

I started working on this conceptual framework in response to the lack of a unifying definition or framework for Makerspaces. Schools wanting to set up Makerspaces and allocate resources to them would often look to researchers like us to advise them on how to get the spaces up and running. Questions like, what is a Makerspace, what goes into a Makerspace, what do we do with our students in the space, came up often. Hence, I started working on this study as an attempt to understand what a Makerspace is, what are its key features if any, and if possible, how can we reproduce them for educational settings. The

connections with established educational theories that I describe in the previous section also augmented the promise of their educational potential. The framework as presented in this dissertation goes beyond conceptualizing Makerspaces but also details operationalizable features that can be used to intentionally scale-up Makerspaces in formal and informal educational settings and prepare teachers to facilitate educational activities in the spaces.

Paper 2 – MAKING AS UNINTENDED DESIGN

Following the framework proposed in the first study, in the second study, I focus on the people in a Makerspace. I conduct a narrative inquiry to understand the practices and knowledge of Makers in comparison to designers. Makerspaces are not explicitly characterized as spaces for the practice of design. However, given the human-centered nature of the practices and the ways of knowing exhibited by Makers, a design lens can be adopted to understand these practices. I choose to focus on the nature of the prevalent practices, and the knowledge generated within such spaces via a conceptual framework I synthesize from Krippendorff's (2006) work in human-centered design and Cross' (1982) designerly ways of knowing. In answering the research question, how do Makers practice human-centered design and designerly ways of knowing, I analyze narratives of the participants that provide rich and compelling accounts of their Making practices and knowledge. These are compared to design practices and knowledge, in accordance with the conceptual framework. The similarities identified contribute to legitimizing Making epistemologically as the forming of design knowledge. However, this leaves us at an exciting crossroads asking, if Making and design knowledge are so similar, is there anything educationally meaningful about Making that is not satiated by design? To delve deeper into this question, I ask how the participants distinguish between design and Making, and what Making means to them. One common theme across the narratives of all the participants is using Makerspaces as a way for them to realize personal meaning which ranges from fighting consumerism, invoking reactions in people by the use of materials, having their own space to work, to transforming the world. Thus, this study contributes to the topic of educational Makerspaces by first, legitimizing Maker knowledge by presenting

similarities to design knowledge and practice, and second, identifying how Making is distinct from design.

My motivation behind this study was two-fold: the similarities I noticed between what Makers and Designers do and know, and schools and colleges using spaces like Makerspaces such as fabrication labs and shops for design education. These thoughts overlapped with reading work by Krippendorff and Cross in a course on Design, Cognition, and Learning which I was taking at the time. I found the connections between Krippendorff's characterization of the material culture of the Design and the Maker movement undeniable. Also, Cross' work on legitimizing the epistemology of design and the similarities between his characterization of design and Making, presented an opportunity to understand the similarities between Making and design, and also potentially make a case for the legitimacy of Maker knowledge using the already established nature of design knowledge. As I was conducting the research study, a new theme of Makers seeing personal meaning and purpose in their practices emerged. This theme is now one of the significant contributions of this study.

Paper 3 – THE ROLE OF REFLECTION IN STUDENTS' CONCEPTION AND DEVELOPMENT OF MAKER IDENTITIES

In the third study, I focus on the activities aspect of the framework and seek implications for engineering education. The first study provides the framework for understanding how the people, activities, and means interact while the second study legitimizes the educational benefits of Making and the opportunity the provide for helping people realize meaning in their work. The context-dependent and individualized nature of Making activities merit an inquiry into Maker identity formation and reflective practice to better understand what individuals get out of a Making activity. The first case includes students enrolled in a Making related college course. It follows Ibarra's (1999) theory of provisional selves, a theory of identity formation, as these students go through the process of identifying and understanding the identity they want to develop, experimenting with it, and reflecting upon the alignment between what they understand Makers do and what they do while

experimenting being Makers. The study presents how the course was designed to follow Ibarra's framework and reports on incidents leading to positive Maker identity formation. This study makes empirical contributions to the existing research literature around identity formation and reflective practice in open-ended engineering and design settings, and also proposes identity formation and reflective practice as curricular tools to realize the educational potential of Makerspaces and similar studies, while preserving the students' individualities.

The first time I designed curriculum to support individualized education via reflective practice was for the Content, Assessment, and Pedagogy (CAP) course in the first year of my Ph.D. I was interested in designing curriculum for a design course that supported individualized education because of its potential to aid people in living up to their personal stories and acknowledging and celebrating differences between students even in formal educational settings. Over time, the curriculum I designed for CAP, the understanding I developed of Makerspaces, and the opportunity to be a co-instructor for a Maker course, resulted in the curriculum and research study I present in the third paper of this dissertation. In addition to being able to test reflective practice as a pedagogical tool for Makerspaces, this study also helps me bring to light ways to initiate individualizing Maker and engineering education.

Beyond Makerspaces, this dissertation explores the connections between identity formation, reflective practice, and personal meaning. It also challenges our current understandings of engineering knowledge, exploring it beyond boundaries of formal classrooms. Though the current work is situated in Makerspaces, I consider this work to add to the intersectional conversations of these areas of interest amongst engineering education educators and researchers.

PAPER 1: PEOPLE, MEANS, AND ACTIVITIES: A CONCEPTUAL FRAMEWORK FOR REALIZING THE EDUCATIONAL POTENTIAL OF MAKERSPACES

Hira, A., & Hynes, M. (in press) People, Means, and Activities: A conceptual Framework for Realizing the Educational Potential of Makerspaces. *Education Research International.*

Abstract

Makerspaces are environments where individuals use technologies to Make physical artifacts within a community of fellow Makers. There has been growing interest in the educational potential of Making activities which has resulted in many schools procuring tools and technologies to set up their Makerspaces. However, there is scant research investigating the efficacy of Making in these newly emerging Makerspaces intended for learning. With our work in this paper, we narrow this gap in knowledge between the claimed educational potential of Making and its attainment. By synthesizing prior work and publicly available data on Makerspaces, we introduce a framework to: situate the educational considerations for Makerspaces; and recommend directions for future research on educational Makerspaces. Being cognizant of the Maker culture having emerged outside of academic literature, we synthesize publicly available data from 53 untraditional but relevant sources. These sources include definitions of Making forwarded by 3 well-established Maker initiatives (Makerspace, Hackerspace and Fab Lab), 18 relevant sites of Making activities across the United States, 17 sites from other countries (namely China, India, Morocco, and Spain), and 15 Maker initiatives at schools in the United States. After proposing and detailing the framework, we recommend directions for future research to attain the potential of educational Making.

Introduction

Makerspaces are emerging as educational spaces in schools, libraries, and museums all over the world. Some proponents of educational Making believe that it sparks innovation and critical thinking skills in students by engaging them in hands-on learning experiences

(Bannan, 2016; Kylie Peppler & Bender, 2013). Educators have begun to adopt this belief and are developing new curricular activities and materials for Making as an educational endeavor (Maker Media, 2012, 2013; McManus, 2009; K. Peppler et al., 2015; D. L. Rendina, 2015). However, there is scant research investigating the efficacy of Making in these newly emerging Makerspaces for learning. The limited nature of the research is the motivation behind our work. By synthesizing prior work and publicly available data on Makerspaces, we introduce a framework to: (1) situate the educational considerations for Makerspaces; (3) and recommend directions for future research on educational Makerspaces.

In the following sections, we discuss the oft-cited potential benefits of Makerspaces for education as well as the potential challenges in realizing these potential benefits. The potential benefits are rooted in a number of theories of learning and development such as, constructionism, experiential learning, self-efficacy, and agency. The challenges relate to issues of cultural and ideological differences, and the precarious quality of self-directed design learning.

The promise of Makerspaces for educational settings.

Dale Dougherty characterizes Making as inherently human (Dougherty, 2012). Making can be traced throughout history as we continue to make tools and technologies aimed at creating more fulfilling lives. Mark Hatch who authored the Maker Manifesto (2014) invokes a similar belief stating, "(m)aking is fundamental to what it means to be human" (p.1). Characterizations such as that of Dougherty and Hatch have also made their way to write-ups in popular media about Making and the role of Making in the democratization of invention. For example, Dubrow (2015) posits “[t]o its advocates and participants, the Maker Movement resonates with all of those characteristics that we believe makes America great: independence and ingenuity, creativity and resourcefulness”. Many community Makerspaces seem to adopt similar ideas with statements such as “if you can think it up, you can bring it to life here” (Make It Lab, 2016) making way to their agendas. Given public concern about a growing disconnect between people and the objects with which we

interact (a concern often attributed to consumerism), Making has the potential to engage learners in ways that bring them closer to these objects reconnecting to the basic human aspects of engaging with the world.

Makerspaces have also become to be known as places where people can pursue their creativity by Making things that are personally meaningful to them no matter their utility to the broader public. This has manifested in the implementation of Makerspaces that are described with phrases such as "Making future dreams a reality" (Durham, 2015). Barniskis (Barniskis, 2014) also writes about how Making as a hobby manifests from the everyday needs and wants of individuals. Having a space to be able to Make what is personally meaningful to an individual, is often the biggest selling point of newly constructed commercial Makerspaces (Rendina, 2015), which has translated into the promise of educational activities that connect to students' interests and passions. This promise of Makerspaces can roughly translate to the idea that a learner who is choosing what they want to make is bound to be more interested in seeking out the knowledge, skills, and abilities to make their dreams a reality. This interest in seeking out knowledge relates to the idea of agency which we expand upon in the following paragraph.

Makerspaces are promising venues for supporting agency (Keune, Gomoll, & Peppler, 2015) and endeavors that are personally meaningful to the Maker. Makers experience that they can be agents of change for themselves and their lives, and even for issues affecting others. In-line with the idea of Making being natural to people, we posit that human agency is at the core of Making and is necessary in the individual's pursuit of whatever they make. You can see Maker's agency and what they see as personally meaningful in the diversity of the artifacts they make, as well as the diversity of the reasons people get involved in Making. At First Build, a General Electric Appliances backed initiative, in Louisville, the artifacts push the boundaries of electrical appliances technology (Wollerton, 2014). While at the LVL1 (2014) hackerspace down the road in Louisville, many Makers approach Making from an arts and crafts perspective, which is common among many community Makerspaces. Following this theme of agency, the initiation of some Makerspaces such as the Philippines Communitere (Bulthuis, 2014), the Maker Movie ("Maker - A documentary

on the Maker Movement," 2013) and the Maker Map (Hwstartup, 2012) which is a map of different Maker initiatives all over the world, have been crowd sourced. The agency that the participants of these and many other initiatives exhibit is a testimony to the power of human agency in Making. Realizing personal meaning and being agentive are contributing factors to individuals' intrinsic motivation (Deci & Ryan, 1985). Participants in a Makerspace being intrinsically motivated to engage and learn, adds to the promise of their educational potential.

Potential challenges in realizing the educational potential of Makerspaces

Educators and writers we cite in this section have expressed caution regarding current and impending challenges in realizing the educational potential of Makerspaces. We elaborate on the following challenges: (1) a lack of diversity within the Maker movement; (2) ideological disconnects between the democratic ideals of human agency and change and the capitalistic forces at play in some Makerspaces; and (3) the challenges associated with replicating successful exemplar spaces in different contexts (e.g., locations, cultures, etc.).

Issues of diversity and inclusion in Makerspaces resemble issues of diversity and inclusion in the field of engineering where the dominant culture is masculine, technocentric, and White. Chachra (2015) in "Why I am not a Maker" writes about how the Maker culture promotes differentiation between those who claim to Make and those who do not. Further, she comments on the gender disparities prevalent in the Maker communities. Many of the activities that constitute Making have been associated with men, whereas, the values of caring that are often associated with women are devalued by the movement. Buechley added to this concern by her presentation at the MIT third annual Fablearn conference at Stanford University (Quattrocchi, 2013). She noted that the covers of Make magazine depicted narrow and skewed themes. 53% of the covers depicted electronics, 31% vehicles, 22% robots, 8% rockets, and 5% music. Thus, promoting and valuing certain types of Making activities that historically ascribe to masculine, technocentric characteristics. To overcome this challenge and avoid reinforcing cultural and gender stereotypes that has led to this already blooming homogenous Maker culture, educators will need to be thoughtful

as they seek out and develop educational Maker activities. Pro-Making educators will need to be intentional about not recreating an environment that favors masculinity as has been observed in Technology Education (Bame, Dugger, Jr., & McBee, 1993) and Shop Class (Collinson, 1988).

The democratic ideals of personal meaning and agency, often seen as potential benefits of the Maker movement, have also been challenged. Morozov in his article in the New Yorker (2014), which sparked multiple commentaries and critiques, claimed that even though one tends to associate Making with Marxist values of equal division of capital, it rarely plays out this way. He writes that in a capitalistic society, capital is the best way of getting heard. The rosy ideals of democratization via Making are supported by peoples' abilities to procure funds and get attention for themselves and their artifacts counter to traditional Marxist values. Along these same lines, Driscoll (2012) comments on Maker media receiving funding from DARPA in 2012 and the strained historical relationship between military funding and the DIY culture in the United States. Driscoll highlights DIY enthusiasts have held ideological beliefs that support them in conducting research and development activities for the military. These ideological breaches threaten the educational potential of Makerspaces that aim to serve the broader population of students from diverse and, sometimes, economically disadvantaged communities. Ideally, Making should not depend on access to capitalistic resources; however, the reality is that tools, materials, and resources are needed, and as Morozov (2014) warns gaining access may require engaging sources who may have other capitalistic intents. As Makerspaces become more common in educational settings there is a responsibility to ensure that students in a Makerspace are engaging in the pursuit of knowledge and development of self rather than engaging in a focus on economic benefits to the resource providers.

It has also been proposed that Making empowers people to Make what they like, but that can also jeopardize the fabric of invention and development by reinventing things badly (Galloway & Hertz, 2015). In an interview to Jeremy Hsu (2012), Neil Gershenfeld, the director of MIT’s Centre for Bits and Atoms said:

> … what's wrong with DIY is if you do it by yourself, it's easy to do dumb things … If you learn with other people, you can do it better. A place like MIT is organized but it doesn't scale. We want to scale to a few billion people on the planet and harness the enthusiasm of the Maker movement, but don't want to reinvent dumb things (para. 14).

Thus, there is a distinct challenge to scale those things that work in unique and particular settings to new and different settings with different people who have different motivations and needs. Resources for developing Makerspaces include procedural manuals (Fab Foundation-a; Maker Media, 2012, 2013) that describe the equipment and materials to be procured for a school Makerspace, but little to describe the learning objectives they should address or for how to adjust the design for whom they intend to serve. The existing information on educational Makerspaces is insufficient as we have few resources that bridge the divide between the educational benefits of Makerspaces that we describe above, to classroom design and pedagogies. The potential benefits of educational Makerspaces we mention above have not been captured in resources for educators to support the scale-up of Makerspaces in schools. This leaves a gap between the ideal nature of Makerspaces and those emerging in educational settings. This gap can be narrowed with more research and practice that leads to the development of resources to aid this scaling-up.

Many proponents of the Maker movement (Costanza, 2015; Doherty, 2014; Mirra, 2015) have responded to the critiques we highlight above. Common across these responses is the need for dialogue and healthy critique. As Justin Reich writes (2014), “we want the Maker movement to inspire changes in schools, that change will come through challenging conversations not purchases”. Thus, where there exist many potential benefits of Making, there also exist challenges that require attention and action by researchers and educators. There is a need for critical work that addresses these challenges before we make decisions regarding the adoption of these spaces more commonly. The conceptual framework we introduce below serves as a way to frame the various considerations educators can work through as they develop educational Makerspaces for their unique contexts and settings.

Rationale

The first aim of this paper is to propose a conceptual framework to characterize Makerspaces as educational spaces. Though previous empirical studies in the area of educational Makerspaces (Abram, 2013; Bevan et al., 2015; Gravel, Tucker-Raymond, Kohberger, & Browne, 2017; M. Hynes & Hynes, 2017; Meehan et al., 2014; Morocz et al., 2015; Sheridan et al., 2014; Wardrip & Brahms, 2015) answer pertinent questions regarding the implementation and assessment in Makerspace environments, no particular work captures the meaning of Making, and more narrowly Making in educational environments. With this work, we synthesize 53 sources representing Makerspaces in informal and formal settings to propose a conceptual framework to make meaning of educational Making.

Jabareen (2009) defines a conceptual framework "as a network or a 'plane' of linked concepts" (p.49). Since many sources used to synthesize the framework are not from research literature, which is in its infancy for this topic, this conceptual framework could be considered non-traditional for its reliance on popular culture and more informal, self-reported data from Makerspace sites, and philosophies of the curators of the phenomenon of Making. However similar to traditional conceptual frameworks and the methods of their creation, it remains a network of linked concepts generated using a methodology of synthesizing sources in which the phenomenon of Making is grounded. Precedence for the development of such a non-traditional conceptual framework exists. Pintrich (2004) developed a conceptual framework for understanding the different types of self-regulated learning based on the assumptions associated with common models of self-regulated learning. Eshet-Alkalai (2004) forwarded a conceptual framework to accommodate the multiple ways in which the term "digital literacy" presents itself in literature. Previously misunderstood as either only technical or cognitive and socio-emotional, Eshet-Alkalai synthesized existing literature and practices to propose a framework that accommodates the multiple dimensions of digital literacy, such as "photo-visual literacy; reproduction literacy; branching literacy; information literacy; and socio-emotional literacy" (p. 93). Lin's (2011) framework on creative pedagogy uses a confluence approach to illuminate the relationship between creativity and pedagogical practices, and is informed by the ways in

which creativity is nurtured in educational settings and the assumptions present behind prevalent theories of creativity. In the field of engineering education, constructing frameworks and presenting syntheses of newer concepts has also been accepted. Several new phenomena have been conceptualized by researchers to propose future directions for research and practice. For example, a synthesis by Brophy, Klein, Portsmore, & Rogers (2008) to detail the future direction for Engineering Education in P-12 classrooms is a synthesis of classroom models and educational engineering practices existing in academic literature. Similarly, Feisel & Rosa (2005) synthesized available literature on the history of laboratory education in engineering, assessment, introduction of computers, and hands-off laboratory learning, to propose fundamental objectives for laboratory education for undergraduate engineering students, and also possible future directions for research. Given these examples and the relative lack of academic literature on the topic of Makerspaces as educational learning environments, we believe there is sufficient justification to embark on the development of such a conceptual framework that can continue to be tested and evaluated as more research is published.

Method

A considerable portion of the development of Makerspaces has happened outside of the realm of academic literature. Cognizant of this, we undertook a synthesis of definitions of Making forwarded by 3 well-established Maker initiatives (i.e., Makerspace, Hackerspace and Fab Lab), 18 relevant sites of Making activities across the United States, 17 sites from other countries (namely, China, India, Morocco, and Spain), and 15 Maker initiatives at schools in the United States. All Maker experiences can be educational. The 15 Maker initiatives at school represent formal in-school experiences, and the other sources represent informal experiences. This inquiry into the nature of educational Making yielded the conceptual framework we present in the paper, the framework of People, Means, and Activities. Our process of synthesizing this framework from all 53 sources is, in part, demonstrated by the synthesis of three definitions of Making by established Maker initiatives. These definitions (below) all address the aspects of who uses the space (people), what is used in the space (means), and what is done in the space (activities). Upon realizing

that these common themes of people, means, and activities emerged from our demographically and geographically diverse sources, we ceased further data collection. We can hypothesize the same for other sites of Making, and hence use our framework to situate them.

Makerspace

Simply put, Makerspaces are community centers with tools. Makerspaces combine manufacturing equipment, community, and education to enable community members to design, prototype and create manufactured works that wouldn't be possible to create with the resources available to individuals working alone. These spaces can take the form of loosely-organized individuals sharing space and tools, for-profit companies, non-profit corporations, organizations affiliated with or hosted within schools, universities or libraries, and more. All are united in the purpose of providing access to equipment, community, and education, and all are unique in exactly how they are arranged to fit the purposes of the community they serve (Make).

Hackerspace

Hackerspaces are community-operated physical places, where people share their interest in tinkering with technology, meet and work on their projects, and learn from each other. (Hackerspaces.org, para. 1)

A hackerspace is basically a co-op work area that happens to be oriented around digital technology. Moreover, these can involve electronic art as well. Particularly lavish hackerspaces may include machining technology, servers, oscilloscopes, and even raw materials for creating electronic devices. (Vega, 2013, para. 1)

Fab Lab

Fab Lab is the educational outreach component of MIT's Center for Bits and Atoms (CBA), an extension of its research into digital fabrication and computation. A Fab Lab is a

technical prototyping platform for innovation and invention, providing stimulus for local entrepreneurship. A Fab Lab is also a platform for learning and innovation: a place to play, to create, to learn, to mentor, to invent. (Fab Foundation-b, para.1)

The three common themes when looking at the above definitions from an educational perspective are that of, who uses the space (people), what is used in the space (means), and what is done in the space (activities). These themes were also present in our remaining 49 sources, and began mapping well to corollary themes in education, namely that of, educators and students, technology and resources, and curriculum and assessment. In Table 1 we offer a breakdown of the definition within this framework of people, means, and activities.

Table 1: A breakdown of the definitions of Making forwarded by established initiatives within the framework of people, means, and activities.

	People	**Means**	**Activities**
Makerspace	Community	Access to tools & equipment	Design, prototype, create & educate
Hackerspace	Community-operated/ Co-op	Digital technology, electronic art, other tech (servers, oscilloscopes & other raw material)	Share, meet, work & learn
Fab Lab	Place for [people] to play, create, learn, mentor & invent	Technical prototyping platform	Innovation, invention & stimulus for local entrepreneurship

Work by Sheridan et al. (2014) explored three Makerspaces through a comparative case study where they asked the following questions: "Who participates in these Makerspaces; How and to what ends are tools, materials, and processes used in each Makerspace; and What are the arrangements for learning, teaching, and collaborating in each space? (p. 507)" This work also supports the aspects of our framework—people, means, and activities. The first two aspects of our framework relate well to the first two research questions by Sheridan et al., with emphasis on the people and the means used in the space. However, with many spaces not explicitly partaking in teaching and learning activities, the third aspect of our framework includes all activities that may occur in such spaces, but we

will often refer to educational activities. Our analysis of recent academic literature in the field of educational Makerspaces also provided support for the people, means, and activities framework for conceptualizing Makerspaces. We cite this work in the directions for future research in a later section.

The Conceptual Framework

Figure 2is a representation of our proposed conceptual framework[1]. As depicted, the three aspects of people, means, and activities are interconnected via purpose. The people in a Makerspace provide, request for and dictate the means used, the means determine the activities that may be possible in the space, and the activities contribute to people's experiences which include their learning experiences. At the same time, the people and their interests, goals, and experiences dictate the activities that take place in a Makerspace, the activities determine which means are needed, and the means influence what people do in the space. Depending on the purpose behind the space, each Makerspace could be variably focused toward either the people, the means, or the activities of the space. We illustrate examples in Figure 3 and explain the role purpose plays in the following subsection on purpose. Further on in this section, we detail the nature of the people, means, and activities aspects of the framework, and their interconnectedness with examples from our data sources. We also cite examples from Sheridan et al.'s study to show congruency between our and their findings.

[1] The conceptual framework has evolved since its inception. Refer to the previous introductory chapter for information on the original intention behind its construction, its evolution, and its current implications.

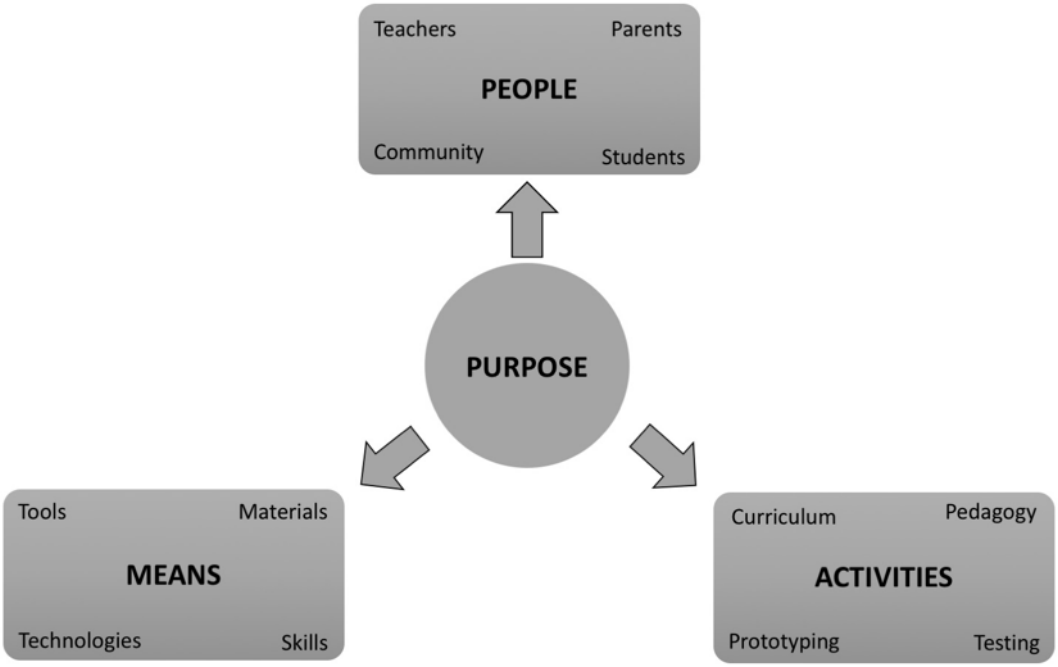


Figure 2: Representation of the proposed people, means, and activities framework for educational Makerspaces.

Purpose

As represented in Figure 3, the purpose of a Makerspace defines which aspect(s) the space is focuses on. The purpose of a space could be people-focused, means-focused, or activities-focused, or some variable combination. All aspects of the framework always exist but sit at tension with the variable focus of the space. The purpose of a Makerspace could be defined when the space is initiated, such as Makerspaces in educational settings, which are set up for meeting educational needs or outcomes. The purpose could also be continually evolving as many spaces redefine their nature depending on the contexts they are situated in. Examples of such spaces include community spaces which are not set up for a particular reason but dynamically evolve.

The first image in Figure 3 represents Makerspaces that are focused toward the people aspect of the framework. The purpose of such spaces is informed by the goals of the individuals or the community of individuals the space serves. Such spaces include those which are set up to serve a community, city, geographical area or online network. The

Maker Library Network, the Makerspace North in Ottawa and the Maker Camp are examples of some such spaces, which we detail in following subsection on the people aspect. The means and the activities of such spaces are defined by the people who engage with the spaces.

The second image in Figure 3 represents Makerspaces focused towards the means aspect. The purpose of such spaces is to house certain tools and technologies that aid Making. Such spaces attract enthusiasts who are drawn to the novelty of rapid prototyping and using innovative tools and technologies. Spaces set up in accordance with manuals from Maker Media, Fab Lab and other online documents and blogs, which we detail in our discussion on the means aspect, are examples of such spaces. The means attract people interested in using them, and the means inform the activities the people end up engaging with.

The third image in Figure 3 represents Makerspaces focused toward the activities aspect of the framework. The purpose behind such spaces is to serve as venues for activities of a particular kind. Activities could include educational activities, such as those in schools and libraries. Makerspaces at the Steward Middle Magnet School in Tampa, Mountain View Elementary School, and First Build in Louisville are examples of such spaces, which we detail in our discussion on the activities aspect. The people entering the space, and the means procured are dependent on the activities being conducted in the space.

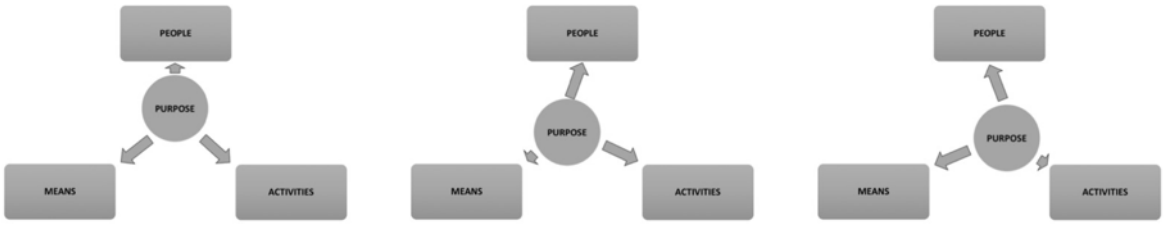


Figure 3. Representation of the conceptual framework as people-focused, means-focused, and activities-focused, respectively.

The conceptual framework we propose in this paper and particularly the aspect of purpose can be used as a tool by educators and facilitators to be more purposive about the

Makerspaces they are initiating or working within. Depending on the context, educational Makerspaces are likely to be focused on the activities aspect. Knowing this focus, we can decide upon the other aspects. For example, a Makerspace in a school should procure means informed by the educational activities they want to undertake, which might not always necessitate the purchase of expensive equipment.

The people

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. Sheridan et al. (2014) noted the most distinct feature between Makerspaces was the diverse learning arrangements which were defined by the individuals in the space and how they came together. They reported that at Sector 67 the people in the space are "the most valued aspect of the space" (p. 513). The Director of the space reports that there had been a transformational shift as to how they understood the purpose of the space. When they began they thought of it as a place with tools for people to build things, but they came to understand that the space was about the people participating in the space and the interesting things they did to attract others to come in and engage. At the Mt. Elliott Makerspace, most of the Makers are between eight and nineteen years of age, which dictates the ways the space is managed, the hours of operation, and its philosophy. The only full-time employee is the founder of the space, other adults and younger interns take on paid roles that require particular skills as required. The space operates the entire day on Sundays, after school, and twice a week in the evenings. The people aspect of the Makeshop in the Children's Museum in Pittsburgh, Pennsylvania is very different as compared to Area 67 and Mt. Elliott. The Makers at this space are museum-goers mostly ranging from toddlers to teens. These Makers are often accompanied by their families, and of the more than 260,000 visitors to the museum, 50,000 are students and families from low-income backgrounds. The space does not have one person at the helm of affairs, rather teaching artists who have experience in Making support the projects and other workshops at the space. Participants come in for a limited amount of time to

Make and receive support and facilitation from the teaching artists. Just from Sheridan et al.'s comparative case study we see variety in how the people shape a Makerspace.

Makerspaces are places for people from different backgrounds to come together and share expertise, experiences, and instruments. Some of these communities are purely virtual, such as the Maker Library Network (The British Council) that spans across continents and connects designers and Makers internationally to share ideas and resources. Other communities share a physical space where Makers congregate to gain access to space and equipment for their Making. The community of Makers that come together at Makerspace North in Ottawa (2014) host regular events so Makers can showcase their work and to collaborate amongst the members. These communities then share a virtual space over the Internet to organize the development of camps and other events. The Maker Camp (2015) is one such initiative for people to find Maker initiatives around them, and create new ones. Thus, as is apparent in these descriptions, the people involved are what make the Makerspace possible in the first place.

Similarly, the people in a school Makerspace drive the experiences for themselves and their classmates. At Stewart Middle Magnet School in Tampa, Florida 10-15 students gather together in their library outside of class sessions to work on projects (Rendina, 2015). They collaborate with students from the Lamar Middle School in Texas over web-based video conferences. At the Summit Elementary in Oconomovac, Wisconsin students who showed little to no leadership and interest in schoolwork are becoming leaders through their participation in the school Makerspace (Ullman, 2016). The students are becoming more social and developing moral character traits. Before the Makerspace, at the Big Walnut Middle School in Sunbury, Ohio some days only ten or fewer students entered the library. After setting up the Makerspace, the school claims to have increased its library's traffic by 1000 percent (Gonzalez, 2016). Like most curricular interventions in schools, Maker activities are often designed and implemented by the teachers. The teachers' conception of Making directly impacts the kinds of activities students engage with. For example, at Mountain View Elementary School the teachers design activities around the engineering design process and to meet National Educational Technology Standards (NETS) objectives

(Mountain View Elementary School, 2017), at Summit Elementary the teachers use Making as an opportunity for younger and older students to pair-up, and at Longfellow Middle School the teachers plan to use Maker activities as an opportunity to lead activities that cater to the diverse interests of their students such as knitting, robotics, web coding, and coloring (Minske, 2016).

The means

The means of a Makerspace refers to the tools and materials used within the space to produce artifacts. The means are not limited to expensive technologies such as 3D printers, which in certain groups have been the face of the Maker revolution (Parker, 2013; Phillips, 2014). Any tools, methods, or materials used to create artifacts represent the means for creating in a Makerspace.

As a common theme across the three Makerspaces of the comparative inquiry, Sheridan et al. note that "Makerspaces' multidisciplinarity fuels engagement and innovation" (p. 526). In this section, we present the diversity of means across Makerspaces and how they play an important role in defining the space. The means within a Makerspace are defined by the people in the space, and the purpose they have set for the environment. With the membership at Sector 67 being mostly adults, the means are defined by the projects and the needs of the Makers. The space is adapted as per the requirements of the community and the needed equipment is purchased. At Mt. Elliott the founder, Jeff Sturges, aims to develop a model for Makerspaces that can thrive in under-resourced neighborhoods by minimizing expenses and ensuring no financial barriers to participation, which leads to certain means being available. Located in the basement of a Church, the space is separated into shops for different purposes such as repairing bikes, woodworking, electronics, and silk-screening. These spaces, however, are converted from what already existed at the church. For example, a storage room full of junk was cleared out to make room for a woodshop. Like Sector 67, Mt. Eliott also responds to the continuously changing needs of its members by acquiring new tools and materials when possible. As compared to Sector 67 and Mt. Elliott, Makeshop follows more structure with the resources it houses. This

structure is attributable to it being in a museum with a continuously changing membership leaving little room for acquiring tools and materials corresponding to the users' demands. The Makeshop is strategically divided into three parts – to introduce Making to young children, the Digital Dream Lab to understand object-oriented programming in an interactive manner and a workshop with tools that require adult supervision.

The means available in Makerspaces vary from space to space and are dependent on the purpose and objectives of the space, such as community engagement, educational attainment, skill building, or entrepreneurship. Where some institutions may find it helpful to procure tools and materials prescribed by Maker Media and Fab Lab in documents such as (Fab Foundation-a; Maker Media, 2012, 2013). Other blogs, manuals, and documents (Gunby, 2015; W. Hynes, Hynes, & Hira, 2015; McManus, 2009) are less prescriptive with the tools, materials, and internal layouts they suggest. Thus, where some sites abide by established initiatives defining the means of their space, others choose means by other methods. Further within Makerspaces, Makers have different levels of control over procurement depending upon the setup of the space. Though the means across Makerspaces are different, they all utilize tools and materials to Make. Like the people, the means in a Makerspace play a critical role in defining and guiding what is possible in the space.

At the Summit Elementary, the Making resources are stored in a mobile engineering cart. This cart has K'NEX, LEGO, magnet blocks, and tubing connectors, and is taken to the students rather than the students coming to it. At Stewart Middle School, students have access to an open Making area where they can use K'NEX, build on their LEGO wall, and sketch on whiteboard walls and tables. They can also use other Making related products such as the LittleBits, MaKey MaKey, Cubelets, and Spheros. The Longfellow Middle School also recently renovated their library with a $17,200 grant from the Education Foundation of Wauwatosa for the 2016-17 school year. This renovation involved equipping the library Makerspace with tools and technologies for students to be able to tinker, invent, and solve problems. The means in the school Makerspaces are not just limited to the usual candidates for rapid prototyping such as 3D Printers and Laser cutters, but some schools such as the Mountain View Elementary School have procured means that best suit their

teaching and learning. They have laptop workstations, Smartboards, a Hue projector, and student cameras, in addition to a 3D printer and scanner, building materials, and other tools. Thus, schools adapt the tools and materials that form the means aspect of a Makerspace, according to their needs. Depending upon the prevalent curriculum, extra-curricular activities, interests of student, parents, and teachers, the means in the Makerspace are procured and used.

The activities

Activities represent all that goes into the Making of an artifact (e.g., planning, research, prototyping, building, testing, etc.). These may be formal, curricular activities that help Makers learn different skills and/or knowledge, or they may be informal activities the Makers engage with to Make their artifacts. All the activities that occur in the space via the interactions between and among the people and the various means constitute what we define as the activities part. In this section, we elaborate on the different kinds of activities that members and non-members are privy to in such spaces.

Since different people make differently, the learning and other related activities are as unique as each individual. As is noted by Sheridan et al., the "learning is in and for the making" (p. 528). The Making activities in Sector 67 range from Making for personal use to larger industrial design projects that the members are working on for their startup companies. The members working in this space are trained on the use of the equipment by other more experienced members. The activities at Mt. Elliott cover varied contexts such as “transportation, food, digital tools and electronics, design and fabrication, music, and art” (p. 516). Many of the younger members of this space became regular members after attending structured workshops on Making. Similar to Sector 67, the members are expected to share skills with other members, including the younger members. The activities at Makeshop are defined by the transient nature of the members, and thus there is no evidence for sharing knowledge among members. The teaching artists who are considered experts support the Making projects within the space.

Similar to the means, the activities across Makerspaces also differ. These activities include, but are not limited to, personal learning, community formation, and corporate innovation. Locally-owned Makerspaces such as Artisan's Asylum in Somerville (2016) provides a space, amenities, and a community for members. The Fab Lab in the College of Architecture in Seville, Spain focuses on solving problems faced by other residents of the city (Escuela Tecnica Superior de Arquitectura, 2016). At a space like First Build, Makers, work to come up with state-of-the-art solutions using cutting-edge technology supported by GE Appliances (1B First Build, 2016). The activities aspect of Makerspaces is deeply connected to the people and the means aspects. The activities that Makers partake in are dependent on the individuals who Make or participate in such spaces, the community of people thus created, and also the tools and materials used within the space to produce artifacts.

In schools such as Summit Elementary, Making activities are a part of the school work and the teachers design STEM activities to take place in their Makerspace. They also organize STEM challenges and buddy classes that pair-up younger and older students. Similarly, at Stewart Middle Magnet School their pop-up Maker stations often are connected to the curriculum. They also scaffold the Making by leaving appropriate design prompts next to materials. An instance of connecting Making to their curriculum is a "Design a Rocket" station for the annual Space Week celebration. In the first year of their new library Makerspace at the Longfellow Middle School, the school planned to cater to diverse student interests. They planned to introduce projects such as knitting or crocheting, robotics, web coding, and coloring books. At Agnor Hurt Elementary School in the Albemarle County in Virginia, students from different grades Make together (Madda, 2016). They encourage students to choose their projects as they believe that to be the best way to Make. At the Mountain View Elementary School, the lessons in the Makerspace are related to the engineering design process and NETS learning objectives. Thus, the activities that students in school Makerspaces partake in are contingent upon the affordances allowed by the existing curriculum, and resources spent on extra-curricular activities.

Directions for future research

The conceptual framework we propose in this paper along with theories of learning and development that align with the three aspects of the framework can provide a foundation for determining best practices for learning and development in a Makerspace. These best practices will have important implications for developing educational programming at Makerspaces in schools, colleges, museums, libraries and other educational settings.

We believe that the people, means, and activities framework can also help articulate directions for future research. The concerns of Vossoughi, Hooper, & Escudé (2016) and Chachra (2015) regarding Making not being equitable relate to the people aspect of the framework. There is a need for research on how different people want or do not want to engage in educational Makerspaces. Further, issues of broadening participation and social justice arise as we consider who has access to such spaces in their schools and communities. In addition to researching questions pertaining to equitable access to Makerspaces, research is needed to understand how Making affects people from different age groups, whether it is better suited for informal environments than formal environments like schools, and what their meaningful implementation in educational settings looks like. With our work and recommendations, we initiate this conversation of meaningful Making.

Another series of questions to be addressed to make Making more equitable and accessible are related to the technological means used in the space. Using new and innovative technologies is one of the primary reasons many Makers make. The educational potential of Makerspaces explained by constructionism also relies heavily on the use of technology. Meehan et al. (2014) report that while working on a card-sorting task in a Makerspace environment their participants' focus moved from the task they were working on to the technology they were using. The means aspect of Makerspaces is heavily understudied and needs to reach beyond the prescriptive pieces on means to procure to set up a Makerspace. Fundamental questions such as what educational affordances do different means provide, how may some means limit learning, and what means are most affective for school/classroom use, need to be answered.

The activities aspect is the most studied aspect of Makerspaces so far. Literature has helped shed light on opportunities for Makerspaces at libraries (Abram, 2013), potential learning opportunities (Morocz et al., 2015; Wardrip & Brahms, 2015), diverse exemplar sites for Making (Sheridan et al., 2014), and examples of tinkering at such spaces (Bevan et al., 2015). However still, the activities aspect of educational Makerspaces will benefit from clearly defined curriculum, best practices, and an understanding of the efficacy of different educational activities with respect to different learners. Adding to this, we believe that the community will benefit from large-scale work that captures the Maker movement in different cultures, understands and captures lessons to learn from various sites, and seeks to understand psychological and sociological phenomena behind the success of Making that we might be missing in our present conversations. The people, means and activities framework that we propose can form the basis of such conversation and a virtual repository of structured information from Makerspaces all over the world. Such information can merit further analysis to answer the pertinent questions we raise in this section, and other questions from pro-Making educators and researchers.

Conclusion

Situated in the growing numbers of new Makerspaces, articles in popular media, curriculum, and empirical studies, this work conceptualizes how Makerspaces have evolved and are being adapted to educational settings. We propose a conceptual framework comprising three aspects, namely, the people, the means, and the activities. The three aspects are tied together by the purpose of the space, which can be variably focused towards either of the three aspects.

This framework can be used as a tool by educators and facilitators to be more purposive about the Makerspaces they are initiating or working at. The framework is synthesized from a breadth of sources that include definitions forwarded by established Maker initiatives, relevant sites of Making activities in the United States, sites of Making from four other countries, and Maker initiatives at schools in the United States. We culminate our discussions by suggesting directions for future research that pose meaningful questions

to realize the educational potential of Makerspaces, and also take into consideration the challenges associated with the phenomenon.

Our proposed framework is a much-needed contribution to the gap in knowledge that exists in current Maker education literature. Work in this paper conceptualizes Makerspaces and provides considerations to realize their purported educational potential. The terms used in the framework are flexible, the framework can be modified as the phenomenon of Makerspaces evolves, and helps understand the phenomenon rather than predicting it. All three of these characteristics, flexibility, capacity for modification, and understanding are advantages of a good conceptual framework (Jabareen, 2009). All three aspects of the framework, people, means, and activities, are amenable, which will prove beneficial to develop the phenomenon further. An example of this amenability are the recommendations and future research paths we highlight in this work. Also, one of the biggest challenges that educational Makerspaces face in the present day is to attain equitable access for all people rather than a few communities that the movement has favored. Our framework to a great extent isolates Makerspaces from the qualities that lead to only a few engaging with them. We do not suggest who is Making, what is being Made, what is being used to Make, or where the Making is happening.

PAPER 2: MAKING AS UNINTENDED DESIGN

Introduction

Makerspaces are environments where people use various technologies to Make physical artifacts within a community of fellow Makers. In this paper I seek to understand how Makers practice human-centered design and designerly ways of knowing. I distinguish between design practice in settings where it is explicitly called so (e.g. classroom, corporate or research facility), and places where design practices are adopted implicitly or unintentionally (such as Makerspaces). Makerspaces provide rich experiences for individuals to conceptualize, ideate and fabricate physical prototypes in response to personal and community needs. In the recent past, there has been a movement that posits the educational potential of such spaces (Abram, 2013; Halverson & Sheridan, 2014; Kurti, Kurti, & Fleming, 2014; Maker Education Initiative, 2016; Martin, 2015; Meehan et al., 2014). However, this posited educational potential so far has been limited to the acknowledgment of the existence of educational opportunities, with little insight into the knowledge and skills people learn and develop at Makerspaces. The conceptual framework I develop in this paper is based on the premise of unintentional learning and development in these spaces. With this work, I take a step toward detailing a protocol to understand the learning and development that happens in Makerspaces through a lens of design practice.

Makerspaces are not explicitly characterized as spaces for the practice of design. However, given the human-centered nature of the practices and the ways of knowing exhibited by Makers, a design lens can be adopted to understand these practices. Different aspects of Makerspaces can be studied to understand the learning and development they support. The two characteristics that I choose to focus on are the nature of the prevalent practices, and the knowledge generated within such spaces. In Paper 1, I presented a conceptual framework consisting of three main aspects of educational Makerspaces as the people, the means, and the activities. A human-centered design (Krippendorff, 2006) lens for the practices in such spaces caters to both, the people and activities aspects. Further, since this framework derives motivation from the unintended nature of learning and development in

Makerspaces, I adopt Cross' (1982) work on designerly ways of knowing. In addition to Cross' work being a theory about the nature of knowledge which is a contingency for learning and development, Cross' characterization of design as that of the man-made world, in contrast to the natural world (sciences) and human experience (humanities), makes it valuable given the man-made nature of the artifacts produced, and the rich contextual human experiences that Makerspaces invoke.

In the next section, I draw on tenets from both the theories of human-centered design (Krippendorff, 2006) and designerly ways of knowing (Cross, 1982), to connect them with the context of my interest, which is the practice and the ways of knowing in Makerspaces. I then synthesize different aspects of design knowing and practice from the informing theories to construct a framework of design as unintended practice. Even though my encouragement to develop this framework is rooted in Makerspaces, this framework has the potential to be adopted in other informal learning environments (such as museums and libraries) to understand human-centered design practices, where the design practices are unintended by the participants.

From the framework, I suggest lines of inquiry that would culminate into a framework for Makers to reflect upon and narrate their experiences. The overarching research questions for this inquiry is:

> RQ1: How do Makers practice human-centered design and designerly ways of knowing?

Two other research questions evolved during data collection and analysis, which help understand my participants' Maker stories and how they distinguish design and Making:

> RQ2: How do the Makers in my study distinguish between design and Making?
>
> RQ3: What does Making mean to my participants?

I explain how these questions evolved and how I answer them in this study in the upcoming section on methodology.

Makerspaces as spaces for design

As I mention in the introduction, the human-centered nature of the practices and the ways of knowing that Makers exhibit, merit an inquiry into the unintended design practices in a Makerspace. In this section I further detail the connections between these theories and Making. Figure 4 represents a conceptualization of the framework. In Paper 1, I elucidated on the educational potential of Makerspaces, and the need to realize this potential via educational research and practice. There exists a congruency between the practices in a Makerspace and human-centered design (Krippendorff, 2006), and the ways of knowing exhibited by Makers and designerly ways of knowing (Cross, 1982). These congruencies merit an inquiry into understanding the unintended design practices and nature of knowledge prevalent in a Makerspace. In this section, I build credibility for the resources I use to synthesize this framework.

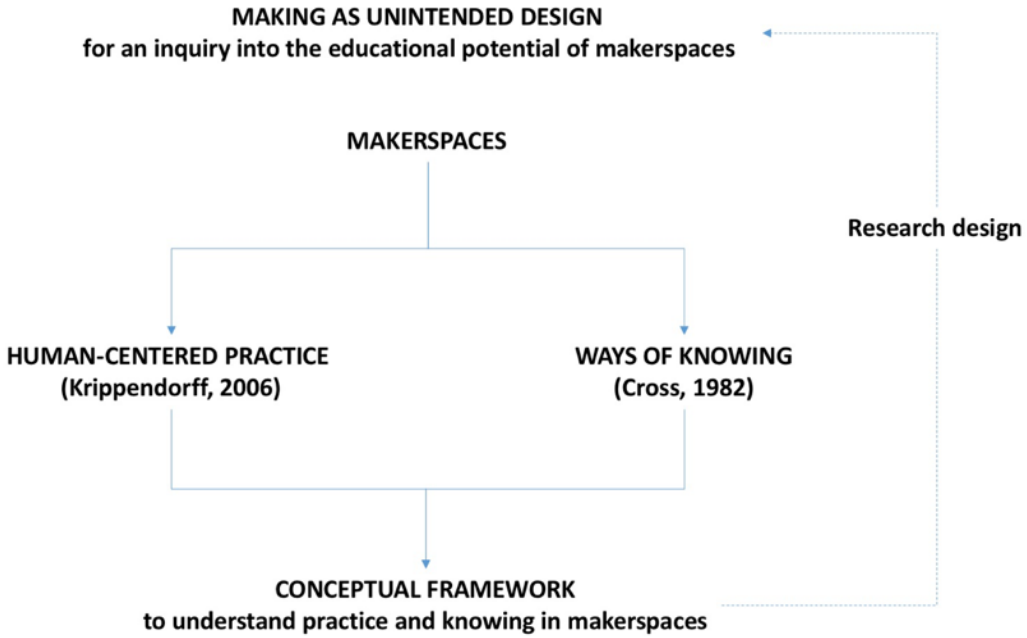


Figure 4: Construction of the conceptual framework: Making as unintended design.

Human-centered design practice in Makerspaces

To begin, I quote Krippendorff explaining the semantic turn from technology-centered design to human-centered design. Acknowledging the humanness of design and going beyond merely the construction of an artifact, to the engagement of the mind, being and doing, he writes:

> the semantic turn recognizes the human involvement in the artifacts of design, acknowledging not only that designers are humans, communicate with others through and about the technology they develop, and participate in the social constitution of reality, but also that all those affected by technology bring their humanness to bear on what they do with it. Artifacts are prostheses of the human mind, being and doing. (p. 40)

He characterizes participation in human-centered design as participation in the social construction of reality by: designing artifacts that have social roles and support the community of users, acknowledging the role that language plays in creating words specific to communities, allowing the use of technologies by people on their own terms, working along with the stakeholders and users, and an awareness of process (ontogenesis) as compared to attention to artifacts (ontology) (p. 39). Makerspaces embody much of what allows a Maker to engage in the humanness of design Krippendorf espouses. On the point of designing artifacts that have social roles and support the community of users, Makers Make for themselves and/or for a community they find meaningful. For example, the Makers at the Fab Lab in Seville (Escuela Tecnica Superior de Arquitectura, 2016) design architectural innovation for their city. Makers do this in the community of Makers that make up the Makerspace and in this way each artifact contributes to the entire community of Makers. One Maker's artifact may inspire another Maker or provide insights into how that other Maker can do something different or better in what they are Making. The underlying ethos of the Do-It-Yourself Culture which Makers ascribe to is for people to use technologies how they see fit to build things for themselves, hence allowing people to use technologies on their own terms. This results in the engagement of the mind, being, and doing.

Designerly ways of knowing in a Makerspace

Cross (1982) proposes design education as a third culture for human knowledge and ability after the sciences and the humanities. In this section, I compare Cross' conceptualization of design education to activities in Makerspaces, to support understanding knowledge in Makerspaces as designerly ways of knowing in the context of a Makerspace. In accordance with this theory, design as a phenomenon of study looks at the man-made world. The appropriate methods of gaining design knowledge include modeling, pattern-formation, and synthesis. Also, the culture of design knowledge and ability values practicality, ingenuity, empathy, and concern for appropriateness. Much before the popular culture emergence of the word Maker, Cross while detailing the nature of design as technology wrote, "This ‘material culture' of design is, after all, the culture of the technologist – of the designer, doer and maker". The practice of technology stands for synthesizing knowledge from the sciences (e.g., physical laws) and the humanities (e.g., context and perceptions) to develop artifacts of practical use. This definition of technology sits very closely with the conceptualization of a Makerspace as environments where individuals use technologies to Make physical artifacts within a community of fellow Makers. Also, as a phenomenon of the man-made world, that values practicality, ingenuity, empathy, and context, to build, model, and fabricate physical artifacts, designerly ways of knowing provide a constructive scaffold to begin understanding the designerly ways of knowing in the context of Makerspaces.

The framework

Having situated Makerspaces in theories of human-centered design methods (Krippendorff, 2006) and designerly ways of knowing (Cross, 1982), I synthesize core operationalizable tenets of these theories to construct the conceptual framework for Making as unintended design. I group together similar practices from Krippendorf’s work and ways of knowing from Cross’ work into five aspects, and name the aspects – need, adopted process, making meaning, connections, and goal of the practice. Figure 5 illustrates this framework and its five aspects I synthesize from work by Krippendorf (2006) and Cross

(1982) that guide the framework[2]. The top half of each of the blocks in the figure is a tenet from Krippendorff's work and the bottom half from Cross' work. So for example, I synthesize (re)designing the characters of artifacts (Krippendorff, 2006) and tackle 'ill-defined problems' (Cross, 1982) as the need aspect of the conceptual framework. I synthesize designing human-centered design strategies, and their mode of thinking is constructive as the adopted practice aspect. Similarly, I synthesize the making meaning, connections, and goal of the practice aspects. In this section I detail lines of inquiry for each aspect in the context of unintended design practice and knowing in Makerspaces. The final semi-structured interview protocol I use for Makers to reflect upon and narrate their Making practices is attached in Appendix A.

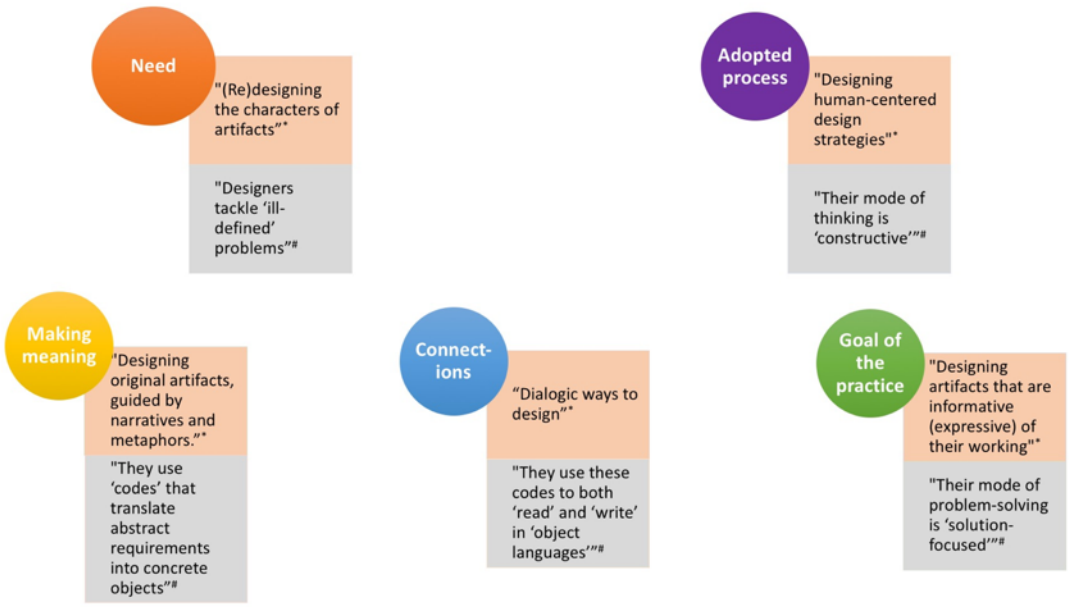


Figure 5: A conceptual framework for design as unintended practice for an inquiry into educational Makerspaces.

[2]Refer to the introductory chapter for information on the evolution of this framework and its grounding in the field of design.

Need

The need aspect of the framework considers how Makers understand and operationalize the need of the artifact they Make. As a method of practice, "(re)designing the characters of artifacts" (Krippendorff, 2006, p. 231) involves detailing and creating contrasting values of the artifact, and then testing them to reconcile incompatibilities between the values. Designers know how to "tackle 'ill-defined problems" (Cross, 1982, p. 226) in the real-world that are not pre-defined or are straightforward to define. The suggested lines of inquiry from Figure 5 that help understand the aspect of need in Makerspaces are: (1) How do you decide the needs your artifact should cater to? (2) How do you go about solving real-world problems (as compared to a text-book word problem)?

Adopted process

Adopted process refers to the processes that Makers adopt in their Making activity. Quite simply put, the practice of "designing human-centered design strategies" (Krippendorff, 2006, p. 231) brings to the forefront the human-centered nature of design, designing for and with human beings. Designers know that "their mode of thinking is 'constructive'" (Cross, 1982, p. 226) as it is continuously evolving considering experiences and new knowledge gathered. The lines of inquiry in that could help understand the processes Makers adopt are: (1) Do you include the users of your artifact in the process of making? How? (2) Have you learned new things since you started making? If yes, could you share some of your experiences?

Making meaning

Making meaning is aimed at understanding the meaning the Makers and others give the artifacts. The practice of "designing original artifacts, guided by narratives and metaphors" (Krippendorff, 2006, p. 231) takes into consideration the role of language in the form of narratives and metaphors, to design meaningful artifacts. Designers know the use of "'codes' that translate abstract requirements into concrete objects" (Cross, 1982, p. 226).

These codes are unlike detailed well-articulated descriptors but rely on models, diagrams, and artifacts to communicate. They do not always bear resemblance with common parlance but are understood within the community of designers. The suggested lines of inquiry that can shed some light on how Makers make meaning are: (1) What is the story behind your favorite artifact? (2) What do you consider the best way for you to explain to someone what you are making?

Connections

Connections represent the relationships Makers make with each other, the users of the artifacts, and the artifacts themselves. Designers engage in "dialogic ways to design" (Krippendorff, 2006, p. 231) in their practice by being open to unpredictable outcomes from connecting with users and/or participants via dialogue. Designers know how to understand and express design by using "codes to both 'read' and 'write' in 'object languages'" (Cross, 1982, p. 226). Again, initiating with the suggested lines of inquiry and probing further with a technique like dialogic conversation with roots in educational theory by Bakhtin (Koschmann, 1999), could bring this aspect in perspective for Makerspaces. The lines of inquiry are: (1) Do you always know what to make from the beginning? Do you talk to others about it? (2) When someone else in the space explains their work to you, what means do you consider most helpful?

The goal of the practice

The goal of the practice is largely concerned with what the artifact being created signifies, and the role it plays for the designers in the process of it being made. By including the characteristic of "designing artifacts that are informative (expressive) of their working" (Krippendorff, 2006, p. 231) in design practice, the working and functioning of the artifact are to be made evident by the artifact itself. Designers know that "their mode of problem-solving is 'solution-focused'" (Cross, 1982, p. 226), which makes achieving the needed functionality of the artifact so produce of upmost importance. The proposed lines of inquiry are: (1) Interacting with your artifact by itself, would I be able to tell its use? (2) When

starting to make something, what would you say is the most important thing you think about?

Methodology

For this study, I employ the methodology of narrative inquiry. Narrative inquiry as a methodology is understood as an umbrella methodology to understand the human experience (B. Smith, 2007). As a methodology posed to understand the human condition which is continually emergent as humans actively make meaning of their experiences (McAdams, 2006; McLeod, 2006; Polkinghorne, 1995; Riessman, 1993; C. Smith, 2000), the methodology accommodates methods and techniques which support understanding these experiences. Another perspective offered on the meaning-making by humans which is inherent to the methodology is of narrative inquiry eliciting the back stories that inform the narratives recorded for research. From Bourdieu's (Bourdieu, 1977) perspective of habitus, these narratives being studied are understood as embodiments of the participants' habitus.

Narrative inquiry has been intimately connected with education. It is claimed (Case & Light, 2011) to have a basis in Dewey's (Dewey, 1938) work relating experience and education, which has led to its widespread adoption in educational research. Additionally, Bruner, also an educational theorist, wrote about (1986) "narrative cognition" as a fundamental human activity via which humans make sense of and represent their lives to others. This conception of narratives presenting the truth of individuals is the traditional cognitive approach to understanding the meaning behind narratives (Gergen, 1994). This conception, however, has evolved and now also takes into consideration the culture or the plot in which the narratives are situated as an important aspect of the nature of knowledge being studied (Kellam, Gerow, & Walther, 2015; Polkinghorne, 1995). As Polkinghorne writes, "*narrative* refers to a discourse form in which events and happenings are configured into a temporal unity by means of a plot" (p. 5). In my study, I seek to understand both, the truth of the individuals and the culture and the plot of their Maker experiences which they uncover in their narratives.

I choose this methodology as this study is in line with the core inquiry question of narrative inquiry as articulated by Patton (2014) “how can this narrative (story) be interpreted to understand and illuminate the life and culture that created it? What does this narrative or story reveal about the person and world from which it came?” I seek to understand the practices and experiences of my participants situated in the conceptual framework of unintended design, which I explained in the previous section. In this study, I employ the research methods analysis of narratives and narrative analysis. I detail the procedures and significance of these methods below.

Making as Unintended Design

I employ analysis of narratives as a research method to answer the research question:

> RQ1: How do Makers practice human-centered design and designerly ways of knowing?

Analysis of narratives is one of the most commonly used research methods within the methodology of narrative inquiry. The point of view in this type of narrative is of the 3rd person with the researcher’s voice having higher authority over the narrative as compared to the participants'. This type of narrative has high narrator reliability as direct quotes from the participants are used, and high authorial distance as the voices of the researcher and the participants are though presented within the same narrative, they are explicitly distinct (Polkinghorne, 1995).

I use this type of narrative to answer the above-stated research question because in answering the question I forward my understanding of my participants’ narratives. My participants do not tell the reader via me, how they practice human-centered design and designerly ways of knowing, instead I analyze their narratives to communicate to the reader how my participants do so. This shift of perspective from the participants to the researcher

is characteristic of analysis of narratives. When presenting narratives in this way, I take away control of my participants' stories from them and present my story of their stories.

This method consists of the researcher reading through the narratives multiple times and identifying themes and stories to answer the research question. The presentation of the narrative includes reporting direct quotes from the participants along with the researcher's interpretation of how it answers the research question. In this inquiry, I take a similar approach. Under the section, “Making as Unintended Design” in the discussions to follow, I answer how Makers practice human-centered and designerly ways of knowing by analyzing narratives of my participants. I collected these by conducting narrative interviews using a protocol informed by the conceptual framework shown in Figure 5 and the lines of inquiry associated with each of them.

Making and Design

In my pilot interviews for this study I observed that my participants attempted to make distinctions between Making and designing. This observation made me curious about how my participants understood and distinguished Making and design, and also if they were more inclined towards owning one identity over the other. It also made me realize that conversation aimed at understanding the distinctions between the two could potentially help me in forwarding a case for Making as an educationally meaningful activity beyond proving its similarities with design, which I do in answering the previous research question. Unlike the inquiry of the previous research question, which is my interpretation of my participants' narratives, to uncover these two new themes I discovered, it was essential to not separate my participants from their narratives.

Bearing in mind the above-stated importance of reporting their narratives as is, I ask the following research questions:

RQ2: How do the Makers in my study distinguish between design and Making?

RQ3: What does Making mean to my participants?

I employ narrative construction with direct quotes to answer the above questions from my participants' perspectives.

Unlike analysis of narratives, which I use to answer the previous research question, narrative construction with direct quotes as a type of narrative reports in the point of view of the 1st person (participants), has medium narrator reliability, and low authorial distance. It does not result in the most coherent and smooth stories like analysis of narratives but add to the authenticity of the stories reported, and the narrative is reported in the voice of the people to whom the narratives belong.

In the discussion, under the section "Making and Design" I present narratives of my participants to understand how they distinguish between design and Making and what Making means to them. The narratives primarily consist of direct quotes from my participants with a few words added for ease of reading and coherency. After presenting each of my participant's narratives, I discuss and analyze the similarities and differences between their narratives.

Data

The primary mode of data collection is via narrative interviews. Using the lines of inquiry from the conceptual framework I constructed the interview protocol and iterated upon it via pilot interviews. The interview protocol is attached in Appendix A. In addition to the narrative interviews, I asked my participants questions to clarify parts of the interviews, and some of them shared pictures and videos of artifacts they had Made.

Thus, I collected data from my participants in the form of narrative interviews, clarifying questions, and pictures/videos of artifacts they felt comfortable sharing with me. My participants are adults (over the age of 18) who are aware of Maker culture and identify as Makers themselves. Their eligibility to be a part of the study was determined by them self-identifying as Makers, and not necessarily their association with a particular Makerspace. Where relevant, I have included the name and location of the Makerspace along with the

description of the participant below. In addition to identifying themselves as Makers and being aware of the currently prevalent Maker culture, all my participants have college degrees in the fields of engineering or design. Their background gives them additional context to be able to situate and distinguish their stories from their understanding of engineering and design.

Participants

Aaron

Aaron identifies as a Maker and a pro-Making educator. He was a high school chemistry teacher in St. Louis when MasterCard donated 30 laptops to his classroom. The donated laptops were missing operating systems, and some of their other parts also needed replacing. In response to which, Aaron started Tech Army comprising interested students who were able to get the laptops up and running quickly. After which, the club continued to be a community for students who were interested in technology, engineering, and Making. After advising this club, Aaron pitched the idea of a Makerspace to a neighboring school and became a full-time Makerspace teacher (2012). Since then, he has moved from St Louis to Indianapolis and teaches design thinking in Makerspace environments. Personally, he claims to have been a Maker all his life. One of the projects from his Maker journey that stands out according to him is a robot that played tic-tac-toe against a human.

Baden

Baden associates with Making as someone who Makes handicrafts. His earliest memories of Making date back to when as a child he helped with the construction of his family's house. He remembers dissembling and trying to put back watches, and also modifying his bicycle to install a fan on it. He first went to college to study engineering, but soon after left and started taking courses at a design school. It was in the city where he attended design school (Ahmedabad, India), that he attended his first Maker Faire. At this point, he thought of the Maker Faire as a venue that brought together anyone who enjoyed Making. He

currently is in the process of setting up his own studio in his hometown of Jammu and wants to run it as a Makerspace. He is also involved with the Craft Development Institute in Srinagar (in the same state as Jammu), where his preferred Making methods include Papier-mâché and leather work.

Chloe

Chloe is associated with a few different Maker initiatives and her Makerspace of choice is her living room. She originally identified more as a designer than a Maker, however, she started to develop her Maker identity after having access to a space where she could Make. Though now associated with several Makerspaces and similar environments, she tells me that the Makerspaces she most frequently works at is her own living room. Her Making endeavors are situated broadly, from Making art to Making educational curriculum. For her, having a space to call her own played an instrumental role in her developing and being cognizant of her Maker identity.

Gerardo

Gerardo is an engineer and runs his own Makerspace as a company. However, he has identified as a Maker from before having started the company. He remembers Making things with his hands since high school. He mentions his high school teacher, who encouraged students to make and build things, played an instrumental role in him becoming a Maker. His primary site of Making now is his company which he started with his partner to Make laboratory equipment. At this venue, they strive to Make what is needed by their clients and give life to new ideas that they come up with. A few people lead initiatives in the space, and they hire interns from local schools and colleges to work with. He genuinely believes that for his country, Brazil, to do well, they need to be Making more technologies in-house than procuring them from other countries. At his facility, they have designed several of their own equipment such as 3D printers and drill presses.

Kandra

Kandra is the founder of a pop-up Makerspace in Indianapolis. Her Makerspaces runs educational programs for students in the Indianapolis area. The primary mission of the initiative is to expose underrepresented students to STEM via Making activities and providing them access to collaborative learning environments. The pop-up Makerspace encourages and provides tools to the future generation of students to make the world we live in, a better place. With a background in working in the engineering industry, Kandra was inspired to step away from her job in the industry and work to provide access to and support underrepresented students to pursue careers in STEM. Her work is based on the belief that students' inner geniuses can help come up with innovative solutions to make the world a better place to live.

Mario

Mario's Making was inspired by his curiosity for working with different types of materials and not necessarily solving a problem. The Maker artifacts he talks about are furniture pieces made of newspapers. What started off as his thesis project in design school, he explicitly mentions, "[it] was unlike the usual process of [design,] starting with the problem. [L]ike we have a user who's … going through an unfavorable situation, and then we have to come up with a product which delivers a pleasurable experience. My thesis was unlike this regular approach and it started with an inspiration rather than a problem. The final outcome was more of a handcrafted, handmade object, rather than the usual association of making with digital fabrications." He likes the idea of invoking surprise in people by using materials innovatively. When people first see the pieces of furniture he Makes with newspapers, they do not expect them to be strong, but then they turn out to be.

Layla

Layla stumbled upon Making when she was thinking about what area of product design she wanted to specialize in. She was inspired to change the wasteful nature of consumerism

and decided to work in the area of sustainability. So, thought that instead of designing new things, she could be teaching people how to be less consumerist. Since then she has designed and implemented workshops where they take apart things and teach people how to fix them. She is also involved with a charity called Skill Share in Dundee where along with others she teaches people different Making skills, and also works with a Maker related charity in Glasgow which serves people with a history of addiction. She finds working with people who have had had difficult lives in the past and teaching them carpentry and woodworking to make better lives for themselves, inspiring. She can be found fixing most things and had finished disassembling and putting back her computer shortly before our call.

Shaan

Shaan's Making adventures range from opening things up and fixing them when he was younger, designing and building aero models with friends, participating in Formula SAE competitions with his friends while pursuing a Bachelor's degree in Mechanical Engineering, doing a Maker project in prison, setting up Makerspaces in several schools, running Maker workshops at a Maker festival in London and more recently his own enterprise for which he handcrafts speakers made of wood with minimalist designs. Shaan's interest in Making is rooted in bringing artists and craftsmen to the forefront of developing economies where they are often not given due credit for their work and Making customized things for people which they associate personal meaning with.

Saaj

Saaj is inspired by materials to Make. He experimented with different paper crafts throughout middle and high school. His paper craft of preference now is paper quilling, which he learned about as he was looking for innovative ways to make someone a card. At first, he was unaware that he could buy quilling paper strips and so spent evenings cutting them up himself. His most recent undertaking in paper crafts is "100 days of paper cutting". At first, he was unsure if he would be able to come up with a new thing to make

using paper every day. However, as he progressed through the days he saw himself going from simple to more complicated designs, He attributes this development to him being able to understand the material of paper and its different properties better as he Makes more with it.

Tanya

Tanya works for a big electronics company in Seattle and finds time in between her busy work schedule to Make. She was initiated into Making as a child and recollects feeling like she was wasting her time if she was not Making something even as a child. As a guitarist and Ukulele player, the artifact that she is most proud of is a Ukulele, she made using wood. She posted the plans and instructions for making the Ukulele on Instructable, for others to have access to. When she was in college, she got together with some friends to start thinking of ways to fight the consumerist culture and the waste it produces. They started to Make a way to reduce waste production and supported the idea of "one man's trash is another man's treasure." Currently, she Makes by experimenting with electronics, Xylo bands, and sketched illustrations. She hopes to one day go back to Making full-time.

Table 2: Pseudonyms and brief descriptions of participants.

Participant Name	**Description**
Aaron	Pro-Making school teacher who Made a robot that played tic-tach-toe against humans
Baden	Makes handicrafts and his preferred Making methods include Papier-mâché and leather work
Chloe	Originally identified more as a designer, but started developing her Maker identity after having access to a space to Make
Gerardo	Runs his own company as a Makerspace and believes that for his country to do well they need to be Making technologies within the country
Kandra	Founder of a pop-up Makerspace and stepped away from her job in the industry to support underrepresented students to pursue careers in STEM
Mario	Inspired by his curiosity of working with different materials and Makes furniture pieces made of newspapers

Table 2 continued

Layla	Inspired to change the wasteful nature of consumerism and works with a Maker charity serving people with a history of addiction
Shaan	Handcrafts speakers made of wood and Made a theft-proof bag with people in prison
Saaj	Inspired by materials to Make and recently undertook a "100 days of paper cutting" challenge
Tanya	Works as a designer for a big electronics company and thinks of the Maker in herself as the child who's hobby the professional designer supports

Analysis and Discussion

Making as Unintended Design

In this section I analyze my participants narratives to answer the research question:

> RQ1: How do Makers practice human-centered design and designerly ways of knowing?

In this section, I analyze each of my participants' narratives following lines of inquiry detailed in the conceptual framework. A majority of the narratives I report are my participants' responses to the questions from the interview protocol aligned with the lines of inquiry in the conceptual framework. Where needed, I draw from other parts of their narrative interviews, and information they shared with me as part of the data collection process.

Need

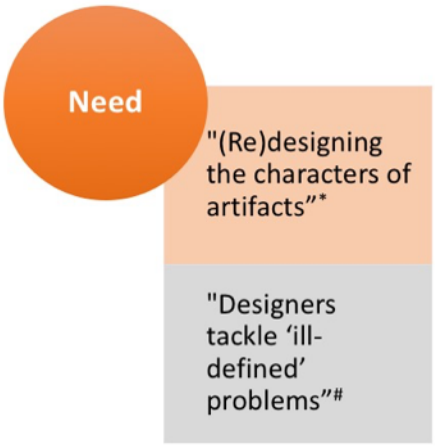


Figure 6: The Need aspect of the conceptual framework represented in Figure 5.

(Re)designing the characters of artifacts

I asked my participants how they decide the needs their artifacts cater to and followed-up by asking how they negotiate competing needs and requirements. Their responses shed light on the theme of redesigning characters of artifacts under the aspect of need. They responded as follows.

Aaron conveyed that when his students Make, they detail the different values of each of their brainstormed ideas. The criteria they evaluate their solutions against are of desirability, feasibility, and viability. Even after they decide as a team which idea they want to go ahead with, when encountered with incompatibilities, they go back to the drawing board and consider working on one of the other ideas

> [the students] come up with as many ideas as possible to solve your specific problem statement. We really emphasize radical diverse ideas. From there, they converse upon ideas based on their desirability, feasibility and viability. As a team they decide which solution that they're going to pursue. Once they have chosen that solution, because they have to think ideas that they generated initially, if they realize upon prototyping their solution, that is not feasible or viable then they can always refer back to that, that list of ideas or generate more ideas.

The characteristics of the artifacts that Aaron's students Make constantly evolve. As Aaron tells me that often times even after finalizing on an idea, his students realize the need for another problem to be solved. For which, they go back to brainstorming and redesigning the characteristics of the artifact.

> Actually, often times what happens is [that] a student will develop an idea and then realize there's a problem embedded within that idea. Then [they] conduct another round of brainstorming for how to solve that particular problem within the initial solution.

Similar to Aaron, Layla coaches people she works with at her Maker workshops to reconcile incompatibilities between contrasting values. She tells me that she ideally wants the group to come to a consensus as it is their artifact but also steps in when needed. One of the ways she gathers people's opinions is by taking a vote.

> It's quite hard cause they'll be working in a group and so you need to come to a consensus. So, we usually do a vote, and also a discussion about the vote. [We talk about] the benefits of each side and usually half the people like one side and the other half like the other side. Like if we only have time to do one side, I'll say unfortunately even though option B is a great idea we only have time to do option A and so that is what we will do.

Baden talks to me about his practice of Making bags and working with wood to explain how he works through contrasting values and reconciles incompatibilities. For him it is important for the quality of the leather and chains he uses on a bag to match. This could be enacted by him by either using a lower quality leather if the chains are not of very high quality or the opposite. When working with wood, if he doesn't use the kind of screws that are the best fit for the artifact, it "pinches" him. He tells me that it is about finding the "sweet spot" between the contrasting values.

> [S]uppose you are making a bag which has really nice leather on it, but the chains that you are using, they are really bad in quality so that doesn't work. So, then you either use the chains like that or you find, a mediocre sort of leather for that. But, those sorts of things happen every day whenever you're making. Even if you are

> working with wood, if you don't get the right set of screws, it's weird, you feel weird because it is something that pinches you in a way. So then you try to figure it out, you can't compromise [on either of] them. I mean because you've talked about it that's the first thing you are going to notice, when you are looking for products. So, it really pinches, so you have to. It guides you to find the right thing, then find a sweet spot between viability and then aesthetics and all of that.

Saaj experiences competing values when deciding materials to Make with. He tells me about how he thinks through colors and textures of paper to find a good compromise to produce the end result he wants of his paper craft. Also, from his experience with participating in "100 days of paper cutting", he often had to turn in a product that he wasn't pleased with. He ended up prioritizing time over quality.

> I think that does happen. If I'm not getting say a particular color or a particular kind of texture. Somewhere I do have to compliment on the output. If I'm not getting the end results because sometimes it's not our responsibility to find the right speakers or color that we're dealing for. It was a hundred days so I had to do one difficult thing a day. There used to be times when I had to finish it so that I post on the same day.

Gerardo relies on the philosophy behind his work to decide how to prioritize between quality and price. His colleagues and him prioritize quality over anything else in their Making practice. The reason for this as he explains is that the region in Brazil that they are from is one of the poorer regions in the country. Because of this, others might often assume that any artifact made in that region would be of poor quality. To combat this belief, he believes that it is essential for them to prioritize quality over price.

> We focus on quality. Our prices are [much] higher because of that, but it was a decision we had [made] at the beginning, as I mentioned. We need to be good, because if we are not good, as we are from [name of place], from a poor place. We are so poor.

To substantiate this, he narrates an example of when a university wanted them to decrease the price of an artifact that the university wanted to buy. He tells me that they didn't, as it has always been more important to them to make good quality artifacts than cheap artifacts.

> One university tried to buy our product. They said, "I can only pay X" and our price is, like Y," and we said, "No, we cannot reach this price." "You can reduce the quality, you can do [that], and you sell it." We said, "No, we don't. We don't have to provide you with that equipment," because we believe that we need to produce quality equipment if we want to be successful.

Shaan's priorities for working with competing values are similar to Gerardo's. He would rather buy a product which is of better quality and would run longer than a cheaper product. He brings this value system to his Making too. He does, however, keep a track of how expensive his artifacts are getting, and if they go beyond a threshold, he works on bringing their value to an accessible price.

> So I'd rather buy an object which is going to serve me for a longer time than buy a shitty one. So like I already have a benchmarking in my head. Like sometimes it does come down to a level that it's becoming too expensive [and then I] try optimizing.
>
> But for me personally I always give importance to things which lead to a higher product life. Higher product life, higher meaningful existence in our user's life. So I'll always make choices, or I'll always pick options which are doing that. So rather than doing something for momentary like instant gratification, I don't believe in that.

Kandra reconciles incompatibilities by catering to her users' inputs. Kandra believes that her users' priorities are more important to meet than her own.

> If it's something that I'm making for, hopefully, a purpose of either becoming a product or for somebody else, I'll try to manage those through the user and really have-- Try to ask them questions in ways of, they rank them without knowing they're ranking these things. Because I feel, if I can get your top five, even though

> they might have not been my top five, we're probably in a good place, and then we can cut the rest.

When detailing and contrasting values of the artifact, Kandra thinks about the market and the salability of the product. Her products' marketability is one of the prime questions she asks herself when finalizing the artifact and deciding between contrasting values.

> I think it's really about figuring out what really is, A, priority of, "If I were to build this out as a product, would it even sell?" That's one. We just have to be there to just meet that, and then what separates it. Usually the users do a really good job of sifting through what they're willing to pay for and not pay for.

For Tanya, her initiation into Making can be considered as finding common values and purposes across three different ideas that her and two of her friends wanted to take up for a class project. She wanted to understand how humans behave as users and how that could be accentuated using design. One of her friends wanted to work with different materials, and her other friend wanted to work in the area of singularity and understand the probability of Artificial Intelligence (AI) takeover of the world. When they tried to reach a middle ground between all their interests (reconcile incompatibilities), they realized that they all were interested in Making in some way, especially from a perspective of fighting the consumerist culture.

> So like I wanted to work on the user behavior and human behavior and how one could augment it but the use of design, so I was looking at how originally humans are programmed-so that and tire nature versus nurture thing…[friend]started off by making something with paper he's a great paper artist, he makes a lot of cool things with he makes a lot of cool things with paper. And [other friend] started off with singularity, so something like what happens when AI takes over. So these three tangents what are the things that we started off with. As it progressed we started thinking about what was common in all of them – Makespace – the Maker culture. Another common point was that we were all kind of upset – maybe not the right word, but we were all kind of disturbed with the consumerist culture that almost all of the urban cities are headed towards. Especially in the western land so much

> plastic is being consumed, so that was kind of like the driving point for all of us… so this is kind of our meager but heartfelt attempt at solving what some might call a wicked problem.

Chloe experiences contrasting values when managing her various tasks as a Maker. For her it is important to be working on tasks that are in her "flow" as compared to working on tasks because they need to be done. On most occasions she tries to make herself feel in the "flow" of doing particular things, but she tells me that sometimes she is left with no choice but doing what needs to be done.

> I believe in flow. So I believe in doing what I feel like doing and nothing else. Usually, I tried to build up the move to certain things if I know I have no choice but when it's time to get into it, I think I get into it because there something like -- this desire to be in that state of doing.

She brings up an example from her poetry writing to explain these contrasting values better. When writing poetry, sometimes she wants to go with the "flow" and not care about how what she is writing or sketching will be transferred to a computer for publishing. However, she also realizes the importance of publishing her work for her career as a poet. She then reconciles the in compatibilities between what she needs personally and what she believes her career needs, by prioritizing what appears to be more important.

> [T]ake my poetry, for example, I understand value free writing, I understand the value going through something and just sketching on how I feel about it. I also understand that there's a process of taking things from paper to computer so that I could publish it, and that in and of itself is its own editing process. Then going from what's on the computer to book form is a whole another thing.
>
> Often times when I'm writing, it's hard to write because I'm like, "I don't feel like typing this at some point." In order for me to want to type this eventually it needed to be written with a decent enough handwriting … In that moment I have to push past the value of the next stage to just kind of be present at this stage. Let me not think about how irritating this is going to be to read afterwards, let me not whatever, whatever. Let me just focus on this.

Mario tells me that he hasn't had to consider competing values in his Making yet but sees how he would have to in the future. Since currently, he is just focusing on Making the artifact without thinking of the real-world implications, he is not concerned by incompatibilities. But sees how later he would have to make such considerations.

> I'm trying to convert my artifact into design, but there I'll have to consider the price and then the effort that goes into making the material; like what a person in a business would consider. Things like these won't be a concern in the first half of the project, where I'm trying to just make stuff, the translate the inspiration into object. Yes, they will definitely be important [later].

In the above narratives, we see how the participants (re)design the characters of their artifacts as they Make. Their practices of (re)designing by detailing and creating contrasting values and reconciling incompatibilities vary depending on the contexts in which they Make and the personal ethics of their Making practices. Aaron and Layla mentor their students and workshop participants to consider contrasting values in their work. Aaron's students often end up solving additional problems while solving the original. Layla encourages her workshop participants to consider contrasting values themselves, but she steps in when she thinks that they are constrained by time. Both, Baden and Saaj, reconcile incompatibilities while deciding the materials they use to Make. For Baden, it is important for the different materials he uses to make his artifacts to be congruent. For Saaj the choice of material is important as it plays an instrumental role in producing the final effects he would like to produce with his artifact. For Gerardo and Shaan, bring their personal ethic of prioritizing quality over other concerns such as price, to their Making. For Gerardo, prioritizing quality is important to combat the perception that artifacts made in his region of Brazil are of poor quality. Even while prioritizing quality, Shaan tries to keep his artifacts financially accessible. In contrast to Gerardo and Shaan, Kandra looks to her users for inputs to reconcile incompatibilities, which includes the quality and pricing. Tanya and Chloe shared their experiences of being a Maker, and not Making a particular artifact. Tanya's initiation into Making can be understood as her (re)designing the different ideas her and her friends had for a project in college. Chloe manages her different practices as a Maker by (re)designing her practice and life around it. Mario does not believe that he

currently reconciles incompatibilities between contrasting values in his Maker practice but can see himself doing so in the future.

These narratives inform a part of my answer to how Makers practice human-centered design. My participants practice (re)designing the characters of their artifacts by mentoring and coaching their students in doing so, by choosing the materials they Make with, and aligning their practice with their personal ethics of prioritizing quality over other criteria. Two of my participants address this theme by connecting it to their broader journey as Makers, and one does not believe that he has done so in the past but envisions himself doing so in the future.

Designers tackle 'ill-defined problems'

I asked my participants if and how they went about solving real-world problems which are ill-defined. For participants well acquainted with the terminologies of ill-defined and wicked problems used these terms at times in their responses. Their responses are as follows.

Aaron conveys that the students at the educational Makerspace where he leads activities are always solving real world and hence "ill-defined" problems. He further tells me that since they are always working on real-world problems, they often fail and get frustrated. However, solving such problems is part of their Maker curriculum by design.

> If there was a simple solution to feeding the world in 2050, somebody would have come up with it by now and so there's intention to rigor up the challenges that we're putting in front of our students. Yes, we expect them to get frustrated and to fail with their ideas and struggle. Yes, some students definitely have demonstrated that they are craving the textbook process of knowing when you're right and so on.

The students that Layla works with during her Maker workshops do not solve the kind of ill-defined problems that Aaron's students solve at school, and so her workshops are often their first experience at solving such problems.

> I wouldn't really say that the students I know solve [these kinds of] problems at school … So I would say that it's kind of their first experience where they're doing this kind of a thing as a process in the Dundee workshops that I'm doing.

Solving ill-defined problems has contributed to Baden's Maker identity and practice. Since he first started Making, he now feels more confident about tackling problems that are not defined. He believes that the hands-on nature of Maker activities has been a major contributor to this confidence and says that he would prefer solving such problems as compared to straightforward or theoretical problems. He has also over time developed a strategy to tackle such problems by deconstructing them into simpler parts and solving them one step at a time.

> I feel now, I'm a lot more confident. I have the confidence that [things] can be done because of the maker culture, because of the hands-on experience for things. You become a problem solver. It's not just the approach, you actually do it. You figure out solutions, but you actually make the thing, and fix the thing. Now you have the capability and confidence to fix the thing and that is what actually matters. Even if you are a brilliant physicist or whatever, as a scientist you know how to solve a problem. It's no good for me. So, now after experiencing the maker culture and working with makers and making myself, I've developed the approach of taking the problem, deconstructing it and making it simple for me, making into parts. And then actually finding solutions, the right type of solutions for them.

Gerardo's confidence in his ability to work on ill-defined problems manifests in his confidence to be able to tackle any problem he encounters. He says that this attitude is something that he has in common with his partner from his Makerspace. He believes that even if they do not know how to solve a problem at first, they are able to gain new knowledge and figure out a solution. He believes that this curiosity and can-do spirit makes a big difference in their practice.

> One thing I have and my partner also have, sometimes we [feel that] we are really different, but the difference we have is like the mindset. We really believe we can

> do whatever we want. We can go, what we don't know we can learn how to do … We really believe we can, so this makes a big difference. We have curiosity.

Several of the artifacts Shaan tells me about are solutions to ill-defined problems, such as the wooden speakers he Makes and sells in order to reduce electronic waste. Shaan believes that people feel more attached to wood than plastic, and so they might not be as inclined to throw them away. The theft-proof bags which Shaan worked on with people in prison is another example of a project which started ill-defined. Also, he teaches students in schools to introduce them to and encourage them to find problems from the real world to solve, which are often ill-defined, and he coaches the students to work through them.

To share her experiences of solving ill-defined problems, Tanya tells me of a time when she was Making with some of her friends. They were attempting to Make something to reduce the trash produced by practices of consumerism, a problem they all cared about. As they started delving deeper into the issue, they realized that instead of Making new artifacts that would accentuate the problem further, they could empower people to solve their own problems, thus creating less waste from mass-produced objects. This is an example of how the problem Tanya and her friends were solving was ill-defined and she in her own words calls it a "wicked problem."

> [W]e were all kind of upset – maybe not the right word, but we were all kind of disturbed with the consumerist culture that almost all of the urban cities are headed towards … so much plastic is being consumed, so that was kind of like the driving point for all of us… so this is kind of our meager but heartfelt attempt at solving what some might call a wicked problem.
>
> So we thought that instead of buying things, just give the people power to make their own things. So like the 3R like either reduce our reuse or recycle. So, one thing was like one man's trash is another man's treasure. We thought we could have a repository where people could bring things that they did not want themselves anymore, so that others could reuse it or repurpose it. These are some of the ideas that kind of started with this project, and then we thought about how we should actually pick a project and start working on it to realize where people face hurdles

> when they start working like this. So that's kind of how we went about it. There were lots of things. The ukulele was one of them. They started making paper lamps. So there was a lot of lighting stuff happening, fixtures, and wooden toys, so yeah a couple of things.

Chloe's experience of solving ill-defined problems is different from what we understand as design or engineering problems, but they are ill-defined prompts and challenges for paintings. She gives an example of a time when someone told her that they were looking for clouds and fire in a painting, and that they liked peacocks. It was then up to Chloe to Make her a painting that she liked, from the set of "ill-defined" instructions.

> I was doing a piece for this woman who wanted like -- she just gave me a bunch of clouds, fires and then left, and talked about -- she's super excited about peacocks. I'm like, "All right. Cool. Peacocks are what we're going for." So, though it was just technically painting a peacock possibly with some clouds and fire, there was nothing straightforward about it because I could decide how I want to do it and what colors and all those other stuff. Even within the straightforward things, if you're adding value, I think you're adding value in the decision that you make which makes it not a straightforward thing.

Kandra tells me that she works on ill-defined problems for a majority of her practice, and so do other Makers that she can think of. However, she also thinks that Making can be "more defined" or structured than the usual ill-defined problems that they solve. When so, the practice would entail practicing a particular skill and not necessarily triggering a change.

> I tend to tackle more ill-defined problems, but I could see there being space for more defined problems in maybe a teaching space or education space … I think it's more about skills at that point. The more defined you make it-- You're going to get some abstraction as far as conceptual changes but you're really going to get mostly skills, and at times, how to work with others in a communal space, which is equally valuable. I would say, for the most part, even when I think about what other people

> are making, they're usually very ill-defined problems that are usually way larger than this one solution.

Upon being asked the kinds of problems he solves with his Making, Saaj responds that his Making doesn't serve a particular purpose or solve a problem, but he Makes just because he enjoys the process of Making.

> No, I don't think my making is solving any purpose, it's more of me enjoying the making part like making process.

Similar to Saaj, Mario too does not conceive his Maker practice to solve any problems. He is inspired by objects and materials which he translates to artifacts.

The above narratives elucidate how my participants while Making solve ill-defined problems. Aaron's students are always solving ill-defined real-world problems. Layla's workshop participants on the other hand do not solve such problems at their schools, but at her workshops they do. Baden solves ill-defined problems and he believes that solving them has made him more confident as a Maker. Similarly, Gerardo along with his partner solves ill-defined problems often. Based on his prior experience, he too believes that no matter what problem they are encountered with, they will be able to solve it. For both Baden and Gerardo, solving such problems have contributed to their Maker identity and confidence. The wooden speakers that Shaan Makes and him encouraging school going students to solve real world problems, speaks to his Maker knowledge being able to tackle ill-defined problems. Tanya and Chloe narrate examples of different ill-defined problems they have worked on in the past as Makers. Tanya and her friends worked on different kinds of programming to deter the consumerist culture and Chloe responded to a set of rather ill-defined prompts from a customer to Make her a painting. Kandra and other people she Makes with solve ill-defined problems most of the time. Though she does believe that there are ways in which individuals can be Making and not be solving ill-defined problems, such as when they are practicing or learning a particular skill. Unlike, the rest of my participants Saaj and Mario do not believe that their Making contributes to any purpose

external to their own affinity towards the process Making and their want to invoke surprise in people by the use of materials, respectively.

Thus, the above narratives provide a part of the answer to how my participants know in designerly ways by solving ill-defined problems. They do so by mentoring their students and workshop participants through ill-defined problems, by solving such problems successfully which in turn contribute to their confidence as Makers, by scoping problems and probing to find the hidden assumptions in the way they understand their problems, and by responding to ill-defined requirements and needs. These ways in which my participants solve ill-defined problems and become better at doing so can also be characterized as the engineering habit of mind (Katehi, Pearson, & Feder, 2009) of optimism. These engineering habits of mind, including optimism, are skills and ways of thinking associated with engineering, making it important for them to be developed during students' engineering education. Two of my participants do not solve ill-defined problems as doing so does not align with the purpose behind their Maker practices, which are encouraged by the process of Making and the use of materials in ways that are personally interesting to them.

Table 3: Summary of the participants' narratives related to the Need aspect of the conceptual framework.

Participant Name	**Need**	
	(Re)designing the characters of artifacts	**Designers tackle 'ill-defined' problems**
Aaron	Mentors students to consider contrasting values and reconcile incompatibilities	His students are always solving ill-defined real-world problems
Baden	Decides materials to match or contrast with each other	Solves ill-defined problems and believes that solving them has made him more confident as a Maker
Chloe	Manages her different practices as a Maker by (re)designing her practice and life around it	Responded to a set of rather ill-defined prompts from a customer to Make her a painting

Table 3 continued

Gerardo	Prioritizes quality over the price of the artifact to combat the perception of his region Making poor quality artifacts	Solves ill-defined problems along with his partner often
Kandra	Uses user inputs to reconcile incompatibilities in the artifacts she Makes	Her and other people she Makes with solve ill-defined problems most of the time
Mario	Does not believe he does so currently, but can see himself doing so in the future	Does not believe that his Making contributes to any purpose external to his want to invoke surprise in people by the use of materials
Layla	Mentors workshop participants to consider contrasting values and reconcile incompatibilities	Her workshop participants do not solve such problems at their schools, but at her workshops they do
Shaan	Prioritizes quality while still keeping final artifact financially accessible	Makes wooden speakers and encourages school-going students to solve real-world problems
Saaj	Decides materials to produce the wanted effects with his artifacts	Does not believe that his Making contributes to any purpose external to his own affinity towards the process Making
Tanya	Her initiation into Making can be understood as her (re)designing her and her friends' ideas to work on a project	With her friends worked on different kinds of programming to deter the consumerist culture

Adopted Process

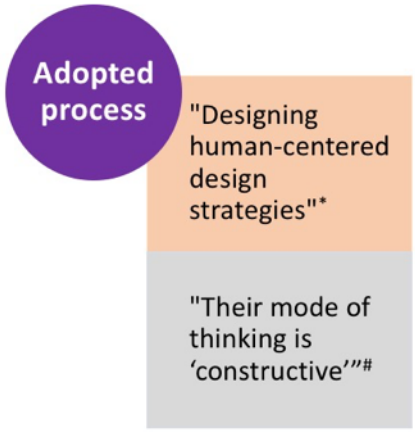


Figure 7: The Adopted Process aspect of the conceptual framework represented in Figure 5.

Designing human-centered design strategies

To understand if my participants use human-centered design strategies I asked them if they include the users of their artifacts in the process of Making, and how. This line of inquiry addresses the human-centered design strategies theme in the adopted process aspect. Their responses are captured below.

Shaan Makes with the people he Makes for. For him it is important to do so as he believes that people always end up using products in their own ways and so he thinks that Making with them ensures that their ideas are a part of the final product. He also thinks that it is important to be Making something that people will end up using, and not just something which will end up lying around unused.

> I'll say I'm making with them, because at the end of the day, the way anything is designed is not necessarily going to be used like that. People are really smart, they come up with it -- like a lot of creative ways of using things. Rather than saying that this is the thing and you're going to be using it like that, I rather involve people while making that thing that I know that these are the possibilities. These could be the constraints, these could be the high points and these could be the low points and

> we take care of those things. If humans are not involved in the entire process then I think that's a very mechanical thing to do. Make something which works for them, rather than something sitting in a bookshelf or a cabinet. An object is supposed to be used, so if you make something which is just for the aesthetics, that doesn't work for me. At the end of the day, it all comes down to what people want.

In response to whether him and his students Make for or with their users, Aaron tells me that his students Made artifacts for people in Kenya, for which they collected feedback from a cricket farmer in Canada and a doctor who worked in Kenya. They assumed that the two people they solicited feedback from knew enough about the context and the people they were designing for, as that is important to their practice of Making.

> It was not deployed with the specific end user. However, feedback was collected from a cricket farmer in Canada and a doctor who works in Kenya to assess its feasibility and viability.

On principle, he considers gathering feedback and supporting his students to do the same when Making for others essential. He tells me that as a general practice they dedicate almost a week to gathering feedback from their end users and use multiple ways to collect this feedback such as end-user interviews and empathy building practices.

> The end user is a crucial component to our design thinking process. We spend at least a week strictly focused on end user interviews and empathy building practices to inform the generation of the problem statements and development of the solution. I'd say at least a week because in so many cases-- actually in this cricket hotel example, the doctor and cricket farmer were looped in multiple times throughout the making process for feedback.

Gerardo's experiences of Making for other people have been limited to the few times a client has shared the vision for products they want Made. Until recently, their work was focused on creating new and cheaper machines for engineering laboratories. They were not necessarily Making things per specification. He tells me how they first started Making machines, they were informed by their own interests and inspiration from different places in the world,

> What normally happens is … We started just creating. I love to be doing stuffs. I want to build my own office in my home. We start [by saying], "Okay, let's [Make] a 3D printer". What happened at that time was, I came to US for a visit, and that time the maker movement was really small, was just starting. Then I went [back to Brazil,] talked with the people, and [also] brought back one [3D printer] to Brazil and said, "Let's see how this system works, and let's see if we can do a similar one."

Baden's conception of the Maker culture is deeply associated with the idea of establishing personal and emotional connections between the Maker, the user, and the artifact. According to him, we have been losing connection between objects and people, and the Maker culture is one way to revive this connection. While Making, he ensures that he gathers insight from his users and incorporate it into the artifacts he Makes.

> What is happening today in the world is, we have products which we are not emotionally connected to. In the maker culture things, you can take these insights and make things very personal for the people you are making for. Even for yourself. Maker culture is primarily about the connection you have to the process and the making of it. The things that I make for other people, I make sure that there are some very key insights that I've had, speaking to them, or with them.

He gives me two examples of how he has done so in the past. The first, an example from home: he overheard his mother saying that her lunchbox didn't fit in her bag. He thought to himself, "Why not make her a bag which fits in her lunch and her other things also?". He ended up Making her a bag that not only fit her lunch, but also her other belongings such as books. The other example he shares is from his work as a craftsman. He tells me that he Makes watch straps too.

> I make straps also for … watches and other things. I took an insight from … the cold here in Kashmir. I have steel bracelets for my watches, but I thought, "Why not make one from wool for winter?" That was one insight that I took … into my making process. That makes it very easy. Personal and it has meaning which then goes into the product. You connect to the product in a better way.

In Kandra's practice at her pop-up Makerspace, it is considered important to consider the user or clients' perspective in all the projects they work on. In addition to learning about the user's perspective via conversations and empathy interviews, they sometimes also test the prototypes within their community of Makers. They use the feedback they receive from the users and other Makers to reassess the alignment between the need and what they ended up Making, resulting in them Making several more prototypes.

> I would say, in everything that I do we include the user. We often run lots of smaller, either pilots or, "Hey, can you try this out so that we can make tweaks to it?" Even on the front end of that, we've used surveys or conversations. Like small, we call them, empathy interviews, of just trying to understand what the user really needs versus what we're trying to make and how those two things align. Then, we try to bring it full circle as we start to have prototypes along the way.

Kandra believes that the Making "with" and "for" people are inseparable. However, she also tells me that in her practice they are weighted differently depending on the context. Sometimes people feel more involved as they are working on a social problem together, and other times the feedback could be limited to something like an internet survey.

> I would say [we Make more] with [people]. I feel ... we can't make for them without their input. I feel the "for" becomes an after-effect of what we're doing. I would consider their input to our designing and our making, at that point as with them. Whether or not they see it that way is different.

When I asked her to share an example of contexts where they Made more "with" people than "for" and vice versa, she responded,

> It depends on what project I'm working on. I think there are some avenues where we do things around more social issues that they do feel a part of the process. Whereas there are some avenues that they're not really sure. Like when someone sends you a five-minute e-mail in Google and says, "Hey, can you tell me how you liked your service?" [chuckles] People don't necessarily always see that as with in the process. I think there's a combination of the two. I have seen people that we've worked with, more in the social spaces, that felt we were more with them.

Interestingly, the people Layla Makes for are often Makers as well. She enjoys working with people who are either already Makers or are interested in Making. She tells me about how she Made a Making kit, which was intended to get people interested in and exposed to Making practices. Her narrative speaks to how she thinks about the people she is Making for, who could quite likely be Makers themselves. She feels similarly about the Maker workshops she facilitates – she Makes the workshop for her end-user who is often a Maker.

> I designed a kit like a making kit. So that was very much thinking about the people who would be using my kit. They've build a wind up mobile phone charger with the kit that I designed, but they also might not be the end-user but they are the user of my kit if that makes sense. Yeah, I mean since then I've been doing workshops, so in the workshops I might be teaching people how to make things where the end-user is the maker, if that makes any sense. I think I'm doing that a lot, and I enjoy doing that, it's quite challenging. Yes, I'd say definitely.

Chloe, whose Maker identity is related to her identity as an artist and an educator, brings in her users' perspectives in her Making of art and curriculum. For artwork, she "meditates" on picking up the "vibes" of the person she is Making for, and for curriculum, she understands the mind space people are in via conversation.

> For artwork, I usually try to get as much of their prospective as possible, even when I am doing my commission pieces I try to meditate on that person and what vibe they have. For curriculum, it is directly tailored towards the people who are going to be involved in the curriculum. I don't often think about the spaces they are going to be in, but I do think about the mental space they are going to be in and how they receive the stuff that I am doing.

In her practice, she considers working more "with" people, than "for" people. However, she also thinks that the two often are inseparable.

> A lot more "for" because often people pay me because they don't want to do it themselves but it is almost impossible for me to do "for" without the "with" because they are directly affected by it I have to check in with them regularly.

For Mario, Making does not necessarily originate from the people he is Making for, but from some other form of artistic inspiration. After converting his inspiration into a tangible artifact, he starts thinking about more pragmatic concerns such as the proof of concept and situating the artifact in contexts and amongst people where the artifact could hold special meaning. He tends to go from the inspiration which is usually abstract, to actually Making the physical artifact.

> I divide my process into two parts where the first part is about making staff, where I start with an inspiration and try to translate it into tangible artifact or object. Then the second, the later part of any project is about making sense where I use these artifacts as a proof that those particular objects can be made. Then I look for the context these objects can be fit in, or the users these objects can be meaningful to. That's the part where I try to make something meaningful out of these objects, and this is where I transform these objects into design. It's about inspiration to object or artifact to design.

He gives an example of how after Making paper furniture, a Making activity he has been most involved with, he has considered sharing the artifact and the skills behind creating it with a group of people who make a living by Making baskets out of newspapers. He believes that his artifact and the skills he gained while Making it, can help the group of people to Make more efficiently, and be able to earn more money. So, what initially started off as Making paper furniture for him, could help people feel more independent.

> There is a craft cluster … where they make baskets out of newspaper, using the same technique which I have used. What I would like to do is, introduce them to this new category of newspaper furniture and then they can expand their existing social enterprise based business. There are these ladies, these men, have their self-help group where they produce these baskets and then they sell it and that's how they earn their income. If they have a new range of furniture which can be sold at a little higher price compared to what they were earning from baskets, it's an additional revenue and then it's contributing to something meaningful like women social enterprise where they're trying to become self independent and [support] the perspective about women in the society.

He sums it up best,

> In the bigger picture, my objects are serving not just the end user that will be using the furniture, but also the makers who are involve in making of the furniture. That's the meaning I would like to give through my objects. That's it.

Similar to Mario, Saaj's Making begins with an inspiration which is usually invoked by a material too. In Saaj's case, this material is usually paper. However, unlike Mario, Saaj only talks to me about his Making as his reaction to seeing materials and patterns

> If I just saw a pattern which immediately my brain starts imagining that this could be a good option to explore. I would come home, I would try it immediately on paper with initial draft cuts and see how it looks and then I can go ahead with it.

I cannot rule out Saaj seeing the significance or connections of his work with and for people, however, he does not tell me about them. On a related not, he tells me about soliciting advice from a friend who works with textiles to learn more about a pattern, but that discussion is better suited for the section on dialogic ways of designing.

Tanya, who is a professional designer thinks of her design and Making practices in related but different ways. For her, when she is Making, she is the client or end-user of her artifact, and so she Makes for herself. On the other hand, when she is designing, what the user or the customer needs is of high priority. So where Making and the intention behind it are personal for her, she doesn't think of design in the same way.

> Making I realized that it kind of has of a personal chord to it. So when I made the ukele or the xylo band that I told you about, I am the client I am making the end product for myself. The end product is aimed to be used by me. So at the end of the day it is personal, so there is an extremely clear so there is an extremely clear flow of communication between what I want and what is being made. But when I design it is usually for my clients on something like that.

In the above narratives my participants share how they either Make for or with others. For Shaan, engaging with his users is imperative while Making as he believes that the users have the best ideas for how the products he Makes could be used in actuality. Aaron teaches his students that collecting and addressing feedback from the users and other relevant

sources is important to Making. He also facilitates his students in doing so. Gerardo's experiences so far have not included Making for others beyond a few times but sees value in the practice for the future. Along with his colleagues he has so far been Making machines inspired by interest, but as they scale up their enterprise he can see them Making for others' requirements and not just with each other at the Makerspace. Baden shares examples of artifacts he has Made for others. For Baden, Making is often about making gestures for people he cares for. He also considers Making to be a way to revive connections between humans and objects, which he believes we might be losing. For Kandra feedback and input from people she Makes for are important. She also believes that Making for and with people are inseparable acts. Layla too Makes for others, and interestingly several things she Makes like Maker kits and workshops are artifacts she Makes for other Makers. Chloe too Makes for others and uses tools such as "meditation" to understand her users' needs via "vibes." She too, like Kandra believes that Making with and for people are inseparable acts. Mario, Saaj, and Tanya Make for themselves. Mario and Saaj Make to realize their interest in working with Materials, and Tanya distinguishes between Making and design by conceiving of Making as something she does for herself and design as something she does for others. Mario considers the implications of his Making for others after having Made his artifacts, and Saaj talks with others for gathering new knowledge, but primarily Makes by himself.

The above narratives help us understand how my participants design human-centered design strategies. They do so by working with the people they Make for, by soliciting and addressing feedback from their users, and by enacting human-centered techniques, some of which exist in design literature such as interviews, observations, and collecting feedback from the users (Ideo.org, 2018) and others that they adopt from other fields such as signals and vibes from sociology (Myers, Buoye, McDermott, Strickler, & Ryman, 2001) and mindfulness from law and education (Murphy, 2016; Riskin, 2004). My participants who do not explicitly claim to Make for or with people, Make for themselves as that aligns better with their purposes to Make. This Making for, with, or as people is also aligned with the framework of engineering being a practice for, with, and as people (Fila et al., 2014).

Their mode of thinking is 'constructive'

I asked my participants if they Make differently or think of Making differently since they have started Making, and if they think they learn new things while Making. Responses to this question shed light on the theme of 'constructive' mode of thinking within the adopted process aspect. Their responses were as follows.

On being asked if his and his students' understanding of Making and how they Make has evolved, Aaron replies affirmatively and tells me that it has evolved to understanding Making as an activity with a purpose and not just an activity related to art and craft. He believes that in popular media Making is presented as more of an artistic activity than an activity with a functional purpose. He tells me that his students contrary to what is espoused by popular media, understand Making as informed by purpose.

> Yes, because of our focus and making as a tool for prototyping, I think our students definitely conceive of making in a different way and I do as well. I think currently popular media depicts making as crafting or a more artistic making for making's sake. Here within school we're making for a purpose, to solve a specific problem.

Aaron tells me about he learns new things while he Makes by asking for feedback often and soon after beginning to Make. He gives an example of a Maker project he has been working on to frame pictures on a wall at his home in a particular way. Before he finalized the positioning of different pictures, he asked for feedback on positioning them by placing pieces of paper on the wall temporarily. The feedback made him change the arrangement on the wall for the better,

> This concept that if you do make something quickly then go out and get some feedback on it to then improve your design. For some specifics now. When I'm doing this framing project at home, what I did first was tape pieces of paper on the wall to show where the pictures might be, then I got some feedback on that and realized I needed to tweak my idea a little bit. Then I iterated by changing the way the papers were laid out before I even ever touched a frame or a picture.

Mario's conception of Making too has evolved. At first, his understanding was informed by posts on social media which often represent Making as "making for the sake of making,"

which Mario understands as Making for nor relevant reason. This, however, changed for Mario. He has now started pushing back against the waste created when we Make for the sake of Making.

> Initially, how I've been making sense of the word, making was this DIY culture where everyone [has] their own 3D printer or laser cutter, laser cutting machine and then they are making anything they want. Sometimes with a purpose or sometimes just for the sake of doing it. I was not really seeing-- some sense was missing, people are creating just for the sake of creating and I saw a lot of waste getting generated out of this. Was it curiosity or wanting to make things just for the sake of making it.

In her practice, Kandra finds being able to deal with uncertainty as a vital prerequisite to thinking constructively about a problem. She mentions how not necessarily knowing where you'll end up as you start Making is an important lesson she has learned about Making over time.

> I would say yes. I would say mostly in managing the uncertainty. One of the fun things I enjoy about making is you don't really know where you're going to land all the time. You might have this big picture, but as you're working through it, different things come up, and so you're not sure what the output is going to be. I didn't think earlier in my making career-- I didn't really know how to do that as well.

She reflects on her past experiences to think about how up until she started Making, her experiences of solving problems had been very facilitated, where more often than not she knew how solving the problem would end. Even if encountered with challenges, in these previously facilitated experiences, the perfect solution to the problem was always known. Her Maker experiences on the other hand have been very different, where she has been figuring out each step as she reaches it.

> My experiences, at that point, had been very facilitated-- Like, “This is what you're expecting at the end." Even though you ran into some hiccups, you pretty much knew what that gold star was going to be. Whereas when I'm in my makerspace, I'm making-- I have an idea but it never has to be that thing. I get to change it based

> on me or input that we're getting. That part gives me a lot of flexibility that I didn't have in other realms.

As per Chloe, her Making practice has changed over time. Earlier, she Made things that made her happy or things that she wanted to Make for herself. However, now she thinks about her practice more like an enterprise. She is intentional about the materials she uses and constantly thinks about how to make the most of her available resources.

> Originally, I think I was just making things that made me happy or things that I wanted to do. I have grown since then I have found a way to enterprise the stuff that I do, so now I'm making more intentionally, thinking more about the materials I am using, trying to save stuff as opposed to just throwing crap together like I did when I was younger.

Not only has her practice evolved over time, the way she solves problems is also constructive. She says that she does not need to know how to solve a problem the moment she sees it and is good at sitting comfortably with the problem and working her way through it. She narrates an incident of how her friend's sandal broke once and she found a way to fix it by thinking about what she needed to fix her sandal and procuring what she needed from her surroundings.

> I have noticed that I am really good at sitting in problem spaces for a while and imagining solutions. That's kind of where I started with the first question because the world is my makerspace. For example, I was out with a friend of mine and her sandal broke and she was freaking out, while I just kept thinking about what part of the sandal was broken and what would need to be fixed about it. I started imagining what kind of thing could possibly do that and asked the bartender for a rubber band, he did not have one but remembered that I had two on my head, then it came more of how can I use this? I think the skill-set is more so being comfortable with the problem space and not jumping to a solution but repeating to myself what the issue is from different perspectives and trying to figure out different solutions that could possibly fix it.

So as per Chloe, to be able to solve problems by thinking constructively, it is imperative to be able to first sit comfortably with the problem, and then start figuring out different ways

to solve the problem, not giving up, but to continue to think about different ways to solve it.

Gerardo can explicitly see how his and his fellow Makers' practice has evolved. He mentions that in the beginning they all made a lot of mistakes and didn't always know how to use all the equipment they had. Over time they developed their knowledge and skills related to Making and also procured more resources. He adds that this continuous learning is why him and his colleagues have not turned their enterprise into just a business, but keep working on machines, as they learn a lot as they work on them.

> What happened was that in the beginning, we didn't have much experience. We had the will. We want to do that, but at that time, we didn't have all the resource or the knowledge. We committed a lot of mistakes, and a lot of trial and error. As the time went on, we reduced this kind of stuff. We become more experienced in doing this stuff. We learned a lot with 3D printer. That's one of the reasons that we decided to not reduce our machine to be like, doing business. We learned a lot because this has many maintenance problems, and people don't know how to use, and they do wrong stuff.

Saaj's mode of constructive thinking comes across in his practice of paper quilling. He tells me that he wanted to give someone a card and so instead of buying one he looked up different ways of Making one on the internet. He came across examples of paper quilling but didn't know there was a name for it. He replicated what he saw in the pictures on the internet, and also cut paper strips for quilling himself. It was much later that he found about the art and that he could buy quilling strips instead of cutting them up himself. Over time his expertise at paper quilling has grown, having learned from the internet and other communities.

> It started with, I wanted to gift someone a card. I just went through the Internet and came across this new technique called paper quilling, which I did not know that there is a name or there is a specific technique to it. I just tried to replicate it. From there I started, I really got interested into quilling. Even at that time, I did not know there are dedicated. You can get those quilling strips ready-made. I actually sat

> down one evening and I cut the paper into strip so that I can use it for quilling. It was much later that I found out that I can just go and buy these quilling strips.

For Tanya, Making has meant different things at different times of her life. She remembers that when she was a child she would Make things around the house. From her narrative, I gather that her entire household was Making or tinkering in some capacity. She speaks about how her father is a Maker too, and it was expected that they Made things and not sit around idling time and getting bored.

> The first thing that comes to my mind is that I think I started making things when I was very young like my father used to be into model making so I always adored what he did. So I used to be making paper models as a kid. I think it kind of runs in the family. Like my dad is quite a maker too. He used to have all of his personal projects, so I used to do those kinds of things too. So it was pretty ingrained as a kid, for me making was a part of life, that's what you did to not get bored.

She speaks of two distinct ways in which her Maker practice has changed over time. She tells me about how over time she has started valuing documenting her Making. She claims to not be very good at it yet, but it is a practice that she has been intentional about embedding in her Maker practice. She at the least documents moments that she considers milestones in her Maker activities.

> So earlier I would just make something, but now I make sure that whatever I do I keep some photographic proof or at least keep some kind of version control which kind of provides a flow and narrative do what I have done to show it to anybody else. I'm still pretty bad at it, I haven't really mastered the art of doing it but it definitely is a thing that has changed. That is intended in it so intentionally now when I reach a milestone in a project I make sure that I know I jot it down. Yes, that this is how it happened and what were my train of thoughts.

Similar to Chloe, Tanya now also thinks about the enterprise of Making. She aligns her growth as a Maker with her "adulting". As she *adults* she thinks about how she can capitalize on Making and go beyond just having fun with it. She says that she hasn't quite worked out how she would go about doing this, but it is something that she sees value in figuring out.

> I've always meddled in a lot of different forms of medium painting and things like that. So when you can just come to this point, the term in my mind is when you start adulting and start thinking of a way to kind of monetize it so that's something that you think of. Even though it is very difficult and doesn't happen. But that's just something, like back then for me making was like having fun. Now I am like is it worth doing, is there going to be some form of I don't know, is there going to be some kind of an outcome from this.

Baden learned about Making from the different Makers he engaged with and the various Maker activities he became a part of. He tells me how the most significant change he has noticed in his Making practice is how he approaches problems. Over time he has learned to deconstruct problems into smaller parts and tackle them individually. He believes that this has helped him take on more complicated problems by breaking them into smaller and simpler parts, consequently working on and solving problems which he previously might not have considered solving.

> Now, obviously looking at all the things those people were doing in those maker things, obviously I changed my approach in a way that, now when I look at a problem, I try to deconstruct it. Because I saw so many small little parts that people have taken apart and used in many different ways. That sort of changes the way you look at things. If you want one particular thing you can -- or there's a complex situation, you tend to break it down into smaller things and then try to approach it in individual things to break down the complexity. I think that is very key to figuring. Otherwise you just take things like that, "This can't be done", or "This is too complex for me." But when I looked at different sorts of approaches people are taking, it effected my approach of looking at complicated things and making them easier.

Layla's thoughts on her Maker practice have changed as she has started feeling more comfortable with equipment used in Makerspaces. She tells me about how when she first entered the university and had access to tools for Making, she did not feel confident about using them. However, over time she began to gain confidence in her abilities to use the

machines. This competence of using machines and the consequent confidence she felt make her feel empowered to Make what she considers complicated artifacts using tools and machines.

> I think a lot of people had a father who taught them how to use tools, at least amongst my friends their fathers taught them how to, all of them who are good makers started when they were very young. So I went to the university and really enjoyed doing woodwork, but I felt really unconfident there. It took me a long time to boot up that confidence, especially because it was mainly a lot of men who knew what they were doing around there. So maybe I think one thing that has changed is my confidence to do something and my ability to do something. That's been really important for me, but I still have lots of way to go, but I feel very proud of myself when I build something and when I make something more complicated that is not knitting or something cute like that.

Through his Maker journey Shaan has learned why personalized and customized objects are more expensive. He shares that earlier he would often wonder why something made by hand in a personalized way was costlier and took more time to Make than regular objects. He has now realized the time and effort that goes into Making things with his hands.

> Whenever we see any object which is done by hand, or which is done in a personalized manner, we question that why this thing is expensive, or why it took so much time? After getting into the entire mindset of making things on my own, it makes me realized that things take time and there's a lot of effort which goes in behind that. That was one thing which I pay attention to nowadays consciously and I know that if something is done by hand, it would have taken a long time.

It also started Making him think about materials and objects in more frugal ways. Instead of throwing things out, he started seeing value in repairing them or at least salvaging parts from them.

> Also, to an extent, it also gives you sort of ownership on the things you do, because once you make -- Initially, it was like, you could throw this thing or that thing, but once you start making things, you start looking at things in a very open way. You think that okay I can repair it or I can open it and I can salvage some parts out of

> this. That was when a thing becoming using pro, you start looking at it in a different way. You start looking at it in a way like more frugal way.

In the above narratives my participants explain how their conception of Making and their practice of Making has evolved over time, informed by new experiences and knowledge. Aaron now understands Making as an activity with a real and functional purpose, in comparison to an activity only related to art and craft as he had perceived before. Even in his practice he finds ways to continuously learn ways to Make better, for example, the photo-wall project in which he solicited feedback to find a better way of completing the project. Mario's change of conception is similar to Aaron's and he too has started seeing the purpose behind Making, beyond what he calls "making for the sake of making." Kandra's understanding of Making and her practice has now evolved to her being comfortable with the uncertainty often associated with Making. She no longer expects to find solutions to problems that already exist. Chloe's evolution as a Maker is in part similar to Kandra's. She feels comfortable not knowing the solution to a problem immediately. She has also started thinking of Making now as an entrepreneurial venture. Gerardo and his fellow Makers have learned how to Make better, in the physical sense of the word. They now Make fewer mistakes while fabricating and have also procured more machines and tools. Saaj has learned new techniques of paper quilling over time. Tanya, who has been Making since she can remember now documents her progress better and thinks of Making in more entrepreneurial ways, similar to Chloe. Baden has learned how to approach the problems he is solving differently. He has learned to deconstruct complicated problems and understand them as parts. Layla has become more comfortable using Maker equipment, which Makes her feel more confident about her skills involving tools and machines. Shaan has learned both the emotional and financial value of hand-crafted objects. He has also learned being more frugal with resources and reducing waste by salvaging and reusing materials.

All in all, my participants' conception of Making and Maker practices have evolved over time, which proves their constructive modes of thinking. All my participants do not address how they have learned new skills involving tools and materials, and several explain how

their understanding of Making and how they engage with it has evolved over time. This too provides evidence for constructive modes of thinking. For Aaron and Mario, Making now is a practice with a purpose behind it. Kandra and Chloe have learned that they do not need to leap to a solution the moment they encounter a problem but can rather work through it. Chloe, Gerardo, and Tanya have now started thinking about Making in entrepreneurial ways. Saaj has learned new techniques for paper quilling, and Tanya has learned the importance of documenting what she Makes. Baden and Layla have learned how to approach problems by deconstructing them and using new equipment, respectively. Shaan has learned why custom-made artifacts are expensive and now he is more conscious about repairing products and salvaging them for parts. In all the aforementioned ways, my participants exhibit constructive modes of thinking, a theme linked to designerly ways of knowing. Similar modes of constructive thinking as a result of constant negotiations between the thought and object languages have also been reported as a crucial aspect of engineering design (Bucciarelli, 2002). As per Bucciarelli design artifacts are elements of the design process that serve as a medium of conversation between the object-worlds of engineering design, which are both technical and the non-technical. In the case of Makers, their artifacts perform a similar function of serving as a medium as they negotiate and deliberate with themselves and others over the physical artifact.

Table 4: Summary of the participants' narratives related to the Adopted Process aspect of the conceptual framework.

Participant Name	**Adopted Process**	
	Designing human-centered design strategies	**Their mode of thinking is 'constructive'**
Aaron	Teaches his students that collecting and addressing feedback from the users and other relevant sources is important to Making	Now understands Making as an activity with a real and functional purpose, in comparison to an activity only related to art and craft as he had perceived before
Baden	For him Making is often about making gestures for people he cares for	Has learned to deconstruct complicated problems and understand them as parts

Table 4 continued

Chloe	Makes for others and uses tools such as "meditation" to understand her users' needs via "vibes"	Feels comfortable not knowing the solution to a problem immediately and has started thinking of Making now as an entrepreneurial venture
Gerardo	His experiences so far have not included Making for others beyond a few times but sees value in the practice for the future	Him and his fellow Makers have learned how to Make better, in the physical sense of the word
Kandra	Considers feedback and input from people she Makes for important	Understanding of Making and her practice has now evolved to her being comfortable with the uncertainty often associated with Making
Mario	Makes to realize his interest in working with Materials and considers the implications of his Making for others after having Made his artifacts	Has started seeing the purpose behind Making, beyond what he calls "making for the sake of making"
Layla	Makes for others and several things she Makes are artifacts she Makes for other Makers	Has become more comfortable using Maker equipment, which Makes her feel more confident about her skills involving tools and machines
Shaan	Finds engaging with his users imperative while Making and believes that users have the best ideas for how the products could be used in real life	Has learned both the emotional and financial value of hand-crafted objects
Saaj	Makes to realize his interest in working with Materials talks with others for gathering new knowledge, but primarily Makes by himself	Has learned new techniques of paper quilling over time
Tanya	Distinguishes between Making and design by conceiving of Making as something she does for herself and design as something she does for others	Now documents her progress better and thinks of Making in more entrepreneurial ways

Making meaning

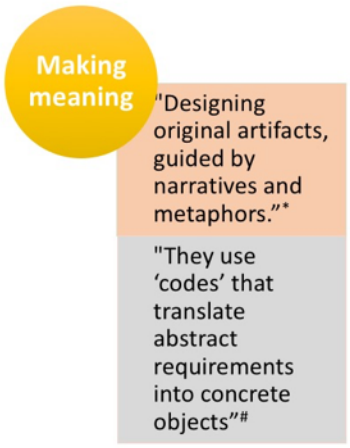


Figure 8: The Making Meaning aspect of the conceptual framework represented in Figure 5.

Designing original artifacts guided by narratives and metaphors

To understand how my participants practice Making using narratives or metaphors, I asked them to tell me the story behind one of their favorite artifacts. When needed I probed further by asking what the artifact signified for them. The following responses inform my understanding of how Makers Make guided by narratives and metaphors.

When asked about his favorite artifact, Aaron narrates the story of one of his students who Made a robotic garden. His student Made this robotic garden after a conversation she had with him about how she thought that she was terrible at gardening and could kill any plant that she tried growing. They together brainstormed ideas for the different things she could Make, after which she decided to Make a robotic garden. To procure the supplies she secured funding from a grant and Made the garden with a basil plant and a lamp,

> She applied for a grant and earned the funding necessary to get all of the materials and the tools that she needed to build this robotic … She tested it with a basil plant and she set it in the window at our school and monitored the amount of light that was coming in from outside and if the intensity of the light did not exist for a number of hours a day, then it would turn on a glow lamp and then she put two

> nails in the soil and if the moisture level of the soil got too low, then the conductivity between the nails would decrease, and so she had a pump that would turn on and automatically water the plant. Then she'd 3D printed a sprinkler head because she noticed that the water was focused too much on one specific area of the plant so the sprinkler would allow it to spray throughout.

Aaron tells me that he likes this story for a couple of different reasons. The first is that his student built the prototype with several different types of tools and materials and progressed from a prototype made of cardboard and batteries to one that was 3 D printed and programmed an Arduino board. The other reason is that his student always received very high grades in all course she took and had become used to receiving a grade signifying completion after putting little effort. This project challenged her in ways that she hadn't been challenged before. For Aaron, this Maker project of his student was a way of her challenging her assumptions and facilitating her holistic development as an individual who had had little previous experience with failing or not achieving a perfect grade.

> One is that it combines so many of the tools and materials of making. Her first prototype of this design was made out of connected cardboard and a battery, essentially. Then she used that prototype to help her understand the idea to apply for the grant, which then let her get all of the materials that she needed … In the later iterations, the fact that she's using Arduino, 3D printing, all of the programming associated with getting the thing working is amazing.
>
> The other reason I like it is because [name] was an all-star student. She had never really been challenged in this way, but she was so moved by-- because this is a long project and she felt frustrated and then overcame that frustration and just accomplished so much and could see the progress of her learning. Unlike other school projects where she would submit and click turn in and get her grade, here she could see

Baden shares the story of a pencil and pen organizer he made for a friend who likes to keep her things organized. When he first came up with the idea, he was unaware of similar products available in the market, though even after he found out, he went ahead and Made an organizer which had a special meaning for both him and his friend,

> One of my friends was very particular about organizing her things. They shouldn't be here and there and everything should have its place. So that was an insight for me and then I made this. I didn't have an idea that, that sort of thing existed before that, but that was insight for me. But I didn't know it already existed in the market.

He decided to Make this pencil and pen organizer with leather, which is one of the materials he prefers working with, as he had shared with me while answering a different question.

> So it's basically something you might have seen in many places. I just have piece of leather and inside there's one nylon strap going up and down, up and down. There are stitches in the middle so you can put your pens and your brushes and things in that. So, it's nicely organized.

He mentions that instead of doing the final stitches on a machine, he stitched it up with his hands as he was running late to catch a flight and was in an auto (3 wheeled Indian taxi cab). He goes on to talk about the personal connection that the artifact signified, holding immense meaning for him and his friend. For Baden, his Made artifact embodied a personal connection between him and his friend and also a gesture of care and friendship.

> I didn't stitch it on a machine because I was running late for my flight and I was in the auto. And then I had to do something because I had to give the thing to my friend. So I did the last stitches with my hand. Those are things that my friend loves the most, because of the connection and the story behind it. It is something that I remember and I think that matters a lot more than just the product and the tangible things. Those intangible things are very meaningful. That was one of the things that happened and it was very interesting and worth remembering.

Chloe talks to me about her living room as an artifact which is also one of the Makerspaces she Makes at. She did not buy new furniture ever since she moved into her new house and has Made her living room morph in response to what she has needed at different times. She Made her living room in response to her needs by moving around pieces of furniture and using already existing things in her house resourcefully. She designated a meditation and prayer corner where she placed a mattress she no longer wanted to be sleeping on, a desk space which she built using shipping containers, and a painting area which again she made with different boxes she already had at home.

I think my favorite artifact is my makerspace because my living room is technically just a living room but since I have been here it has become a space for painting, there is also like a desk space but I have never bought any furniture. I just had the stuff in the living room and kept moving the stuff around. I had this mattress bed in my room that I was noticing was giving me too deep asleep. So I'd take it off my bed and I made it into a stretch space in the corner, and then around that, I just set up stuff that I use when I am meditating, so there is a prayer corner, candles, and stuff. And then I noticed I didn't have a place to sit and do work in my house, and I still don't really sit and do work there, but at least I have a set up for it now. So I built this high desk, a little bit shorter than this, that matched the chairs I already had. I had some high chairs that I was using to paint on but I was not really sitting to paint, kind of made out of shipping containers, that I brought my stuff in, stacked up and then one of my paintings is the table on top of it. And then painting area itself is another version of that table but I used old boxes and stuff to hold the paint and material. I really wish I had a camera in my living room so you could see how I am left and how things move around in that space. Because anytime someone comes over, they say, ""Oh, it seems like you have been here forever"", but really the current set up has not been like that for that long. It has just been really evolving.

The space now carries special meaning for her. Overtime as she redefined her needs, the space changed too. The story that she thinks the space tells is one of her identities pushing against the different constraints she has in life, which the walls represent. She tells me that she knows that the space carries the meaning she wanted it to embody as she has been inspired to paint several paintings in the space.

So every time I go home I am proud of that, just that space as an artifact because it kind of speaks to me, redefining my own needs and the fact that I have not bought anything new in that space since I have -- maybe that chair, but I have not spent money on making that space comfortable, I just kind of moved around in it a lot. I think the story would be: engineering graduate student trying to make space for her other identities in her living room. So, I think the story would be my other identities fighting against the walls of constraint and boundaries that I have. I think it very much speaks to the person I have developed since I have been here. Though I

> painted before I got here, most of those -- I have done since I've been here; in that space, in that room. That's … what I expected from that space when I got there.

Gerardo thinks back to the time he brought a 3D printer from the US to Brazil. After which him and his fellow Makers were inspired to Make their own 3D printer. For them building what might have been the first ever 3D printer built in Brazil, represented their empowerment. He tells me that he shared with his team that everyone has the tools to Make great things, but one only achieves something truly transformatory if we realize concrete ideas by using these tools. The 3D printer they built was representative of this philosophy.

> First, it was like a proof that we were able to do the same in Brazil. It was one of the first, I'm sure in Brazil. There were not too many companies doing, it was only MakerBot, and that was it. We can. It was a good message for my team that we can do, because I have a philosophy. I want to say in Brazil that the technology is spread. You can find the technology, wherever you are. What makes the difference between the Americans and successful, like MakerBot and the Brazilian, is not the technology or the knowledge. It's just the mindset. We need to believe that we can and we do. One example I use is to build things, the tool that Mark Zuckerberg used to develop Facebook is here. You can download PHP and you can start to design whatever. It's free. He did, and we didn't. We need to start doing. That was a kind of help.

Kandra's favorite artifact is the programming that she and the other Makers at her Makerspace had been Making for students from low-resource backgrounds.

> I think my favorite artifact is some of the programming that we've been able to come up with for students. ... The program that's dearest to my heart is our programming around students building or making solutions for homeless-- How to stop homelessness in the city of Indianapolis

Kandra's experiences from volunteering in classrooms informed this programming. She learned that the students realized the disparities between their backgrounds and wanted to help each other out.

> I think, for me, that one really came out of a volunteer experience that I had. What triggered that, between that experience and then dealing with students, was that students were recognizing that their classmates were experiencing this.
>
> It was like these students in kindergarten through sixth grade were already recognizing the disparities in what home life meant for each of them. That really triggered me to start this initiative to allow students not only-- Who are going through it, a voice to contribute to solving the problem, but also students that were recognizing it a voice in that as well.

Listening to the students' narratives of how they understood their classmates' problems, Kandra was prompted to Make this programming which empowered students to help others with whom they went to school. Her programming was representative of empowering the students to have a voice and do something to help others they cared for and learned with.

Layla tells the story of a cassette case with solar panels that she had Made at the charity she works for in Glasgow. The solar panels of the artifact come from broken panels from a factory which they epoxied on to a cassette case. After they made it for the first time, she facilitated an activity to Make them again at another workshop organized by the same charity.

> One of the first things that I thought of was something that I had made at Skill Share, the charity that I was involved with. That's a little solar panel and a cassette case. So it's made using broken solar panels from the factory and it's all epoxied and boxed into a cassette case. It's very cute, and I made it at another workshop that someone was taking at skill share and we made them.

The artifact had special meaning for Layla. Firstly, she talks about the past life of the different materials she used. Secondly, since she used the solar panels to charge rechargeable batteries, the artifact signified self-sufficiency for those Making and using it. Both of which are important elements of Layla's motivations behind Making.

> And I think it's a really interesting object because you know it had a past life and now it's something different for one. And two, it stands for self-sufficiency that comes from an object. So it's a solar charger to charge AA batteries. So in theory it would make you a more self-sufficient person by using it. So that's really nice.

Mario's favorite artifact embodies his childhood fascination for shapes and balloons, and his current draw to Making, which is playing with materials. He first started thinking about how multiple layers of paper put together could be much stronger than a single sheet by itself when he saw someone stick layers of paper on top of balloons to make the structure stronger. He experimented with the idea by Making a stool supported by balloons that were shaped like tubes, which he covered with layers of newspaper. Mario's Making practice is guided by his interest in working with paper and surprising people with artifacts that are physically different than what they appear to be.

> [T]he guy used to have balloons filled with air and then he used to put layers of paper and glue over and over again till it becomes really hard. I was really fascinated by this idea because it has lots of possibilities, as long as you have any shape of balloon, you can create any shape of object out of that. I decided to explore this, to make a stool and then I used a balloon which come in this form of a tube, like a cucumber. Surprisingly, while the individual strand of that newspaper yarn is not that strong, but when I wove it and then gave a coating of glue, it was really strong. The look of the final seating was also very intriguing and very surprising. Entirely it's made of newspaper, nothing else. The body and then the top woven part, everything is newspaper. That's something; a very personally, personal favorite project for me.

Saaj tells me the story of the first paper quilling project he was introduced to. He is emotionally connected to this project as it initiated him into paper crafts. The project was a phoenix made by a Russian artist, which Saaj tells me was later adapted to be a theme for Google Chrome. For Saaj, this artifact represented his initiation into being a Maker and realizing his fascination for working with materials such as paper.

> It's a quilling by a Russian artist, it's a phoenix actually. She had made it with paper quilling technique and that bird was converted into Google Chrome's theme. I think that's where I got introduced to this technique, paper quilling. I had replicated that quilling twice. I think that is one of my very favorite paper quilling[s] ... It is not as [complicated as] the ones later on but I have that emotional attachment to that

> quilling … it was actually my first quilling project also, which also inspired me. It got me into paper craft so that's why I have that attachment to it.

Tanya tells me the story of a Ukulele she Made. She played the guitar but wanted to Make something which was small enough to take home with her. For her first attempt she used cheap wood and other found materials, which she did not like much. Even though she wasn't completely pleased with her attempt, the Ukulele worked which made her want to Make it better. For the second attempt, she incorporated some electronics, and she liked what it ended up as. One of her Maker friends helped her with the electronics to mount them onto the Ukulele.

> So my favorite project that I really liked working on was that I really wanted my own ukulele so it's just that the guitar was an extremely cumbersome instrument to kind of take home with me. So I decided let's make a ukulele. It kind of worked out for me. So, I made one which was kind of a completely meh attempt which was made out of cheap wood and stuff like that was literally just lying around. Cost me nothing other than the tuning attempts and it kind of worked too so I was like yeah maybe I should up my game. Then I decided to make another one with a relative more complicated form it was an electric one and that functioned relatively better than the previous one. It was definitely a plus. I still have it so it's kind of pretty interesting … hopefully some day when I have a good makerspace at my disposal and if I have the time I might want to go for a version Ukulele 3.0. [Her friend, who doesn't play any musical instruments himself] knew about electronics, so he was the one who told me about how we could integrate some of these things. So for example what I wanted to make for my next version drew heavily from what [he] was working on.

The Ukulele tells the story of her merging her interests in music and Making, how she worked through different prototypes by catering to needs like being able to travel with it and adding features like electronics. It also signifies her Making with her friend, combining their knowledge of music and electronics.

Shaan narrates the story of anti-theft bags he and his fellow Makers made with prisoners. This was a compelling project for him to work on as the prisoners possessed knowledge of how people steal, which helped them come up with creative ways to protect the bags they were Making.

> In that we were co-creating anti-theft bag for the prisoners. The prisoners came with the insights like how people steal stuff. At the end of a day, prisoners or the people who commit crime are really creative people. They're really smart to figure out the loopholes. The bag which I did with them was something which I really liked.

Making these bags is representative of Shaan and his companions working with the prisoners to Make something which made the prisoners feel better about themselves and also think through their ideas to Make something productive.

> Entire idea behind the workshop was rather than us going there and telling them what to do, those guys came up with the idea. We were facilitating them and we were helping them in different ways. By the end, we were able to create somewhere around five bags. In the entire process, one good thing which happened was, a lot of the prisoners started looking at things in a different way. They were really happy that you could do things in a very systematic way and still come up with things which are not typical. Every time we'll make a change, they understood that, okay this is why we made the change and this is what it solves. They were really able to understand the iterative process and the prototyping phase. It was something which I felt made sense to me and also made sense to them. They also gained a lot from the entire experience and we also. The bags ended up going to London Design Festival and people really appreciated the entire program which was done.

This story for Shaan is representative of him working with the prisoners, Making a shared common artifact, and facilitating the prisoners learning about different design practices like iteration and prototyping.

In the above narratives, my participants share how narratives and metaphors guide their Making. Aaron mentoring his student to Making in order to develop holistically as an individual who is prepared to face failure and uncertain challenges. Baden's organizer conveyed the connection he shares with his friend and a gesture for their friendship.

Chloe's living room is representative of her several identities and her journey of pushing on constraints as she owns her several identities. Gerardo and his team's 3D printer represents their empowerment and institutional transformation. For Kandra the educational programming for solving homelessness represented the students caring about others they went to school with, and Kandra caring for them. Layla's cassette player with a solar panel is representative of the past life of its parts and her workshop participants' self-sufficiency. Mario's paper furniture is representative of his childhood fascination with balloons and shapes and his interest in working with paper to surprise people's senses. Saaj's first paper quilling of the phoenix initiated him into the craft, which now is the focus of his Making. Tanya's Ukulele is representative of her interests in both Making and music, and something she could carry home with her. The anti-theft bags Shaan Made with prisoners help them realize their productivity and special knowledge.

To answer the question of how Makers realize narratives and metaphors in their Maker practice, above I present the several diverse and unique ways in which they do so. They are able to abstract from a group of experiences and identify the salient aspects of their Making, which is similar to previous work that studies developing expertise as designers (Ho, 2001; Kavakli & Gero, 2002). Ho studied the differences between expert and novice designers' abilities to decompose ill-structured design problems into well-structured problems, which is similar to the Makers making sense of stories and narratives to Make a physical artifact in response. To operationalize this phenomenon further, Kavakli & Gero observed that the concurrent cognitive actions of expert designers are ordered and structured, and those of novice designers are not. Novice designers often take cognitive actions which are difficult to understand and categorize. The Makers' ability to recollect their thoughts and actions, and present them in an organized manner point at their ability for structured thought. I believe that this particular theme of using narratives and metaphors serves as a good place in this paper to begin noticing how all my participants Make and yet have very unique motivations and stories behind their practices. I provide more detail and evidence for this idea in the next section of the paper when I answer what is unique about Making.

They use 'codes' that translate abstract requirements into concrete objects

I asked my participants what means they use to explain to others what they are Making. Their responses to this question were similar to their responses to, what means they consider most helpful when others explain to them what they are Making, which is the question I ask them to analyze the theme *they use to 'read' and 'write' in 'object languages'*.

Thus, I present my analysis of narratives for this theme and the theme, *they use these codes to both 'read' and 'write' in 'object languages'* in the Connections aspect of the framework, which is the following section.

Table 5: Summary of the participants' narratives related to the Making Meaning aspect of the conceptual framework.

Participant Name	**Making Meaning**	
	Designing original artifacts, guided by narratives and metaphors	**They use 'codes' that translate abstract requirements into concrete objects**
Aaron	Mentors his student to Make in order to develop holistically as an individual who is prepared to face failure and uncertain challenges	My participants' responses to this question were similar to their responses to, what means they consider most helpful when others explain to them what they are Making, which is the question I ask them to analyze the theme they use to 'read' and 'write' in 'object languages'. Thus, I present my analysis of narratives for this theme and the theme, they use these codes to both 'read' and 'write' in 'object languages' in the Connections aspect of the framework, which is the following section.
Baden	The organizer he Made conveyed the connection he shares with his friend and a gesture for their friendship	
Chloe	Her living room is representative of her several identities and her journey of pushing on constraints as she owns her several identities	
Gerardo	Him and his team's 3D printer represents their empowerment and institutional transformation	

Table 5 continued

Kandra	The educational programming for solving homelessness represented the students caring about others they went to school with and her caring for them	
Mario	The paper furniture is representative of his childhood fascination with balloons and shapes and his interest in working with paper to surprise people's senses	
Layla	The cassette player with a solar panel is representative of the past life of its parts and her workshop participants' self-sufficiency	
Shaan	The anti-theft bags that he Made with prisoners help them realize their productivity and special knowledge	
Saaj	His first paper quilling of the phoenix initiated him into the craft, which now is the focus of his Making	
Tanya	Her Ukulele is representative of her interests in both Making and music, and something she could carry home with her	

Connections

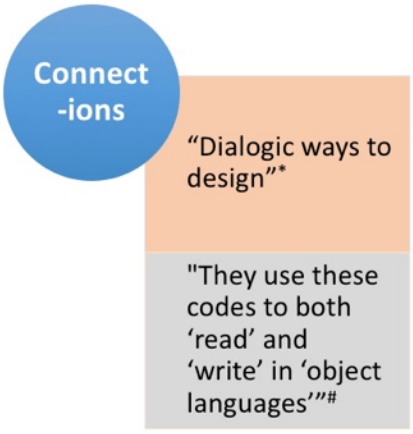


Figure 9: The Connections aspect of the conceptual framework represented in Figure 5.

Dialogic ways to design

I asked my participants if they always know what they will be Making when they start Making and what role their conversations with others, including the users, play in their Making. The following is how they responded. This theme also draws from the human-centered design strategies theme in the aspect on adopted process.

Chloe tells me that she engages with her favorite kind of Making when what she is Making is not defined at the beginning but is something that evolves over time informed by her conversations with people she Makes for and other fellow Makers and designers.

> Yes, sometimes. I think when it is something that's contracted by another person, you have a general idea, but my favorite projects are people who just have ideas, just general needs, not necessarily solutions. Because when I already know what I feel like, I'm more of a technician in the sense of, I'm just putting things together for this cause.

For Shaan, talking to others is an essential part of his Making practice. He sees this as a way to discover and incorporate others' perspectives into what he is Making. He tells me how a majority of the times people he speaks with point out things about his artifact that

he hadn't considered. His Maker practice begins with involving others and continues to involve others throughout the process.

> Sometimes it just totally comes down to a point of critiquing the work, or just giving inputs … It all comes down to how do you incorporate others' ideas, or how do they also see the entire thing. Most of the time it comes down to, they might suggest something which I might not have looked into. It begins with that and most of the time I include the other people in the entire process.

For Baden, being a part of the Maker community means putting aside egos and talking with one another to critique each other's work and offer new ideas. He says that Makers are empathetic towards one another and openly discuss their struggles and give advice. As per him, these kinds of discussions are a part of being a Maker.

> [I]n [the] maker community, I feel that ego is slightly gone and you're more open to critique. You're more open to discussions. Other people also come and then they're empathetic, and they have that empathy towards you that, "You are also struggling so let's struggle together and figure out things together." Which I feel is really a good thing about the maker culture. People are more open and they are willing to help and they're willing too. They straight away will say, "Okay this will work. I know electronics and this will work and this won't work." Which has helped me a lot of times. I'm working on a project and then somebody came up, "I think this will work, this won't work. What is your design like?" These kinds of discussions open between makers

Gerardo explains how he and his fellow Makers Make artifacts together and change them by talking to each other as a group. Below he gives an example of how as a group they started with an idea, and people added to the idea by making suggestions and recommendations. He tells me about the time when they were working on Making test rigs for three different fluid mechanics problems, and upon someone's suggestion they ended up Making a common test rig for all three problems. They had not expected to end up with one common test rig, but it was an idea that they were all open to and ended up fabricating and finalizing.

> Sometimes we start with one idea and we build that idea, but then in the group someone says, "We can do that, we can change a little, we can move, we can-- " Then we can start to change. One example was the fluid mechanics [rig] that we've made. We used to have three different points, then one colleague said, "Why not put all of them together?" Then, "Okay, I'll probably do that." We built some prototypes and CADs and then changed a little bit.

Mario tells me that he benefits from conversations with other who Make with similar materials as him. They share their projects and progress with each other and also receive suggestions and feedback from each other. Some of the suggestions that Mario has received in the past include how certain things could have been done better, and how he could source a particular kind of material. He finds these conversations helpful and beneficial, often altering how he proceeds Making the artifact.

> I talk to people who are working in a similar domain usually, who are dealing with material like natural fibers or concrete and glass. I talk to them and then I ask what they are doing, then I share what I've been doing or I'm wanting to do and sometimes I get really good directions. They'll tell me how I can get things done better, how I can source the particular material just to see how I can use it in my project. It definitely helps.

Layla shares several experiences where conversations with others have not just aided her Making, but also supported her in forming her conception of Making and what it means to her personally. She mentions that the people at "Skill Share" inspired her to be Making and repairing. In particular, she mentions how the director of another Makerspace environment she worked at, "Maklab" in Glasgow, supported her in seeing the connections between Making and social impact. Even beyond that, at College the people around her inspired her to Make and also supported and assisted her in learning to use new tools and technologies.

> So Skill Share as I said really inspired me to do lots of making and repairing and stuff. That was through all the people there, and so that was quite important. However, they are small-scale and so they were just a charity. Then I started working with Maklab in Glasgow. So I used to work there, they have shut down

> now but they were a really interesting makerspace. Their director was really good at sharing the social impact of making with other people. So that inspired me a lot, cause suddenly he tied a lot of knots together. So I was really interested in social impact but I hadn't thought about how making can be important in that and how people like the government are really interested in getting people making for the social impact like that. So that was very valuable and again it was these individuals who were tying these knots for me and making it very valuable. In terms of the actual making, being at the place like Maklab actually having all the facilities and staff there who could teach me how to use the tools was very empowering. And in particular in the University with their facilities I found myself way more likely to actually make stuff because they had the tools and materials that I needed at my fingertips, and they had the expertise. I really like having the confidence by having the tools and people there who can support me. It makes it much more enjoyable the whole process, I don't like making by myself as such.

Saaj's conversation with his community range from others sharing internet links to artifacts he could find interesting, collaborating with friends, and sharing his work on social media. Posting on social media has also made people approach him to collaborate with him on his Maker projects, this Making more.

> When I start making this paper cut a day project, a lot of people did send me a lot of links. This could be an inspiration to you or one of my friend who is an architecture student, he wanted to collaborate with me to convert few paintings into, say an abstract-geometric painting, like painting with paper. Lot of those things happened when I started sharing it on some platforms like post it on Instagram and Facebook as well. That was one when he wanted to collaborate.

Kandra shares a story of the time she was Making a device which people could wear on their wrists, which could perform different health-related functions. Talking with the potential users of the device made her change her idea entirely from what she had originally conceived. The users did not think her initial idea would work so well, and so she changed her prototype on their advice.

> I was like … "Okay at the end, I should have something that fits on my wrist, is going to be roughly this size." … Honestly, the idea that I had going into it, of what I thought it looked like, turned out to be not what it looked like at all. Mostly because the users were like, "That doesn't work for me."

She further talks about how in addition to the people she is Making for, her Making practice is impacted positively by other Makers in the space. She comments on the camaraderie that the larger community of Makers in her space share. She believes that these relationships have helped her form friendships with fellow Makers and they ask each other for support whenever needed.

> In that scenario, there was three other people working in the makerspace. Even I was working on this project on my own. I'm not an electronics person, that's just not really my thing. One of the guys is super electronics savvy and so he actually ended up helping me a lot with how to put together. What the circuit board was going to look like and what the outputs were going to look like.
>
> … Just being able to do it with somebody else made me feel, "Okay, we can accomplish this thing together." I feel in the space, it was always a give or take. People that you saw regularly you became close to. You guys formed a friendship, an unsaid friendship of whenever you need something, you ask. You knew what each person's competencies were, then you can ask around the room. There was always that feeling of, you weren't really [alone]. Even if you were making on your own projects, you weren't making it alone.

On being asked if conversations with the people she Makes for or others around her inform her Making, Tanya narrates a story of how one of her friends helped and inspired her to Make her Ukulele electric by making a new iteration with in-built speakers. Even beyond the Ukulele, she mentions that several of her Maker projects are an outcome of conversations with friends and fellow Makers.

> [He] knew about electronics so he was the one who told me about how we could integrate some of these things. So for example what I want to make for my next version drew heavily from what [he] was working on … So my idea was to make a ukulele with in-built speakers in it, so I did not have to connect it to anything. So

> this ukulele maybe not so much, but there were other projects like binding my own books, I learned a lot from them. So the three of us were like always exchanging ideas and making books ... and things like that. So, definitely.

Aaron describes how the teachers at his school are looked at as coaches who coach the students through the coursework, including Making. He narrates how when he walked into the classroom for the first time, he was struck by all the teachers being addressed as "Coach." After which he realized that this vocabulary which is particular to the school was meant to imply the relationships between the students and the teachers, where the teachers motivate the students to Make and support them through the process. Aaron's story of working with one of his students to brainstorm ideas and finalize a prototype, which I share in the previous theme of narratives and metaphors, is also an example of them Making in dialogic ways.

> On my first day I walked in and I saw posted everywhere the names of the teachers and it said "Coach". I thought, "Wow. I don't coach any sport." All the teachers, you know, Coach Mendel, Coach Crawford, Coach Lacey. I thought, "Wow. There are a lot of athletically minded teachers here, I hope I'm not expected to coach a sport." I realized, "Oh. Wow. That's just what we call the teachers here."

The above narratives show instances of how my participants Make in dialogic ways by connecting with others and being open to unpredictable outcomes. For Chloe, working with others on artifacts that evolve over the process of Making, is her favorite aspect of Making. Shaan too looks to his users to not just provide feedback on the finished product but looks to them as he Makes. He shares how other people often share ideas with him that he hadn't thought of, which affects how he goes on Making. For Baden, open and free communication is an important characteristic of Makers and communities of Makers. He has valued from the critiques and insight his fellow Makers have offered to him in the past. Gerardo and his team of Makers always work together. He shares instances of how inputs from someone else completely changed how a Maker project ended up. Mario connects

with others to learn new techniques and has also benefitted from others' advice on how to do a certain thing better and leads on procuring materials to Make with. Layla has been impacted by her community of Makers in both, her conception of making broadly, and the use of tools and technologies. Saaj uses social media to learn new techniques, be inspired, share his work, and also collaborate with people. Kandra benefits from both, the users of her artifacts and her community of Makers. She has changed her final prototypes based on her user's feedback and has been helped by one of the other Makers in her community on the electronics aspects of one of her projects. Tanya has been inspired by others who Make around her and has also received support from them in finalizing prototypes. Aaron "coaches" his students through Making, which he does by engaging with his students via conversation.

These narratives provide an answer for how Makers Make in dialogic ways, which is a theme of human-centered practice as per my conceptual framework, and has been previously observed in design settings (McDonnell, 2009). McDonnell examined conversations between architects and their clients who are building users and noticed that the boundaries of the conversations were blurred. Both parties offer information from their domain-expertise, particularly when prompted to in conversation or after being provoked to give an expert response when the other party feigned knowledge of their expertise area. Conversations and negotiating with each other's expertise to work together are elements of the dialogic practice Makers engage with. My participants engage in dialogic ways and remain open to unpredictable outcomes by soliciting feedback from their users, Making their users and other Makers a part of their Making, seeking support from Makers who might be more skilled at some tool or technology, mentoring others, receiving feedback and collaborating over social media, being inspired, and finding community.

They use codes to both 'read' and 'write' in 'object languages'; and
they use 'codes' that translate abstract requirements into concrete objects

The narratives I present in this section also inform the theme, they use 'codes' that translate abstract requirements into concrete objects from the previous aspect of Making meaning.

I asked my participants what means they consider most helpful when others explain to them what they are Making, to understand the codes they use to 'read' and 'write' in 'object languages'. Their responses to this question were similar to their responses to what means they use to explain to others what they're Making, which also relates to the theme of designers using 'codes' to translate abstract requirements to concrete objects, a theme from the aspect of making meaning. Thus, in this subsection I address both themes. My participants' responses are as follows.

Baden works with other Makers at the Craft Development Institute (CDI) and uses sketches to communicate with them. He tells me how when sometimes while speaking to each other they are unable to communicate exactly how they are envisioning the problem or the artifact; he sketches on the basis of what they tell him. They are then able to talk around the sketch and reach the same understanding.

> [S]uppose they are a student at Craft Development Institute (CDI) who … find it hard to communicate to us what they want to do. At that time it is through my ability to understand and visualize. What I do usually is, they tell me a sort of thing that they're trying to do, but they don't know how it's going to turn out. So what I do is, I sketch for them. "Is this what you're looking for or is this what you're trying to do?" That works at that time. I can quickly sketch and I visualize "This is maybe what you're thinking of." At then they point out and then, "No, this is not like this. I want it like this. This should be more rounded off or this should be like this." So that's how I communicate to people.

Gerardo and his team use computer simulations to have conversations about the artifacts they are Making. Some of this software is expensive to procure and so his team exports designs from CATIA that are viewable without access to CATIA. He says that sometimes physically viewing the problem and the area is also fruitful but using computer simulations are the easiest. He gives an example of a time when one of their team members was not on the same page as them, and computer simulations helped.

> It's always the CAD system, SolidWorks and, they really call it e-drawings. It's a tool from SolidWorks and CATIA, too. You can export your design and the customer can look and manipulate in their space. You can export, then you can see all the views and the perspective. If you have mail/fax simulation like Finite Elements you can export, too, so the person can see all the-- this makes it really easy. Sometimes they go to the space and look, and they can see all your stuff, but I'm sure that the CAD system is the easiest in the way to show it. I really like to be together. For example, we created a booth where they explain what they are doing, but sometimes it's really difficult. Then, I really like to go close and say, "Okay, show me what you are doing," and then I start to ask questions. I love to ask questions a lot, so I say. "What about those?" When they are doing showing, I can see if they are really aware of what they are doing or not. [Someone] was making different piece. I could identify the problem and ask him to go and find a different technology to do what he wanted to do. It took some time, but now he's doing the right stuff.

For Layla, engaging with the physical prototype or model is best to understand what others are Making and to explain to others what she is Making. For her this prototype could be a rough attempt or a more detailed attempt Made with the intended materials and of the intended size. She says that when she can hold the artifact in her hands and look at it from different angles, it is much easier for her to understand the artifact.

> So I would definitely like to have a very rough prototype to show, that would be ideal. Maybe if it’s just the right size or the right material, but maybe not all the other things not working yet. Then I like to have use-drawings to supplement that and then maybe photos of existing products that might be the same. I like to see prototypes and iterations of what they are doing, and yeah I mean it’s quite diverse with different mediums but I’d say like something that’s already been prototypes physically is much easier to understand. I also think that if you can pick it up and pass it between your hands and kind of look at it from different angles it’s just so much easier for you to understand.

Chloe finds sketching to be her preferred means for expressing what she is Making, to others. While speaking with me, she also realized and shared that she often uses her hands to explain what she is working on.

> I think that sketching is normally the solution, an idea about the solution and how it might work. Sometimes it's the problem space and the sense of scope. So, a friend of mine would be like, "Yes, you're talking about all these things but this is a piece that you're actually interested in." So, then, most of the stuff happens in the air; you don't have to draw everything. When you started talking I realized how another media -- form of media is like talking with your hands, so there's a lot of break yourself down in terms of like, you show this thing and it does this thing and you move it over here and it does this thing. Or this stops here, you can get it -- That's what makes the in-person conversation so useful because you go off from ideas in your head to idea-spaces that you can combine and relate to other spaces.

Similar to the others, to talk about her artifacts with others Kandra too prefers something that can be visualized or observed in the form of sketches or prototypes. To make the connection between thoughts and understanding, she relies on the physically interacting with the artifact in question over verbal communication. When asked about how others and her converse over artifact in the space, she responds

> For me, usually it's showing me. Either in pictures or diagrams or even the-- A prototype or a model or-- Of the artifact usually works well for me. Because as they're explaining it, I can actually physically touch and feel and see exactly what they're talking about. There's so many projects going on in the makerspace, though, that you're not always well versed in what someone else is doing.

Tanya too relies on either 2D sketches or 3D models using software to have conversations about her artifacts. For her, the distinction between 2D and 3D is the type of artifact she is working on. Previously, she worked on 3D models which were to be prototypes that one could physically interact with. Now, her artifacts are screen design projects, and so she has conversations with 2D sketches she generates using relevant software.

> So currently the team that I am working with, we work heavily on sketch – sketch as in it's a Bohemian coding app, so UI design. So now you kind of realize your verbal communication needs to be strong as well, because these ideas are 2 D – we are designing for the screen – so there is a difference in. As in all my previous sketches used to be in 3 D because I was designing tangible things which could be held in your hand, so you need to have a very good understanding a spatial – like drawing skills and all of that. This isn't necessary now in screen design – you can make mocks – ideas are translated into digital screens very rapidly.

Shaan responds to the question by telling me the different modes of communication people he interacts with in Making environments use. People he Makes with and Makes around use visual and physical representations such as sketches, 3D models, and a mix of both.

> Most of the time it's because the people are interested, sometimes they majorly come down to visuals. Sometimes people are good with sketches, we have sketches. Sometimes people are good with 3D model, so they have 3D models. Generally, the people I've come across will mix up, they have visual references or they have the object.

When asked about how he and his students converse amongst themselves while Making and in the Makerspace setting, Aaron shares how being a part of the community involves using specific vocabulary. The example vocabulary he shares might not come across as design vocabulary or object language, however, it is suited for and situated in the learning setting of the school.

> Part of our community involves a very specific vocabulary … You would see a word like, focus areas and PLC, personal learning coach, PLT, personal learning time … Let's see, PMP, project management plan. I know everything I'm saying is an acronym. Cycle, which means our project, our six-week cycle, where we work through design thinking.

For Mario, the medium of conversation does not matter as much as physical proximity to the Maker he is talking to. He tells me that he would instead talk to or sketch for a person

who is around him than try to explain something that he is Making virtually over the internet. However, for him to understand something that someone else is working on he requires the opposite, i.e., video or presentation or even a detailed report on what they are Making.

> If I have a pen and paper, I can explain it through sketches; which I think I can do manageably well. Visuals through sketching, I can manage, but if you ask-- If I want to explain to someone else who is not around through a presentation, then something like that is very challenging because I don't know, it's very difficult for me to put, try to explain someone who is not around. I can't make a very nice presentation where the other person is able to get things exactly what I'm trying to do. It's very difficult for me to articulate sometimes. It's better if the other person is around and I can talk and then I can show through sketches. I find if they have videos or they have a well-articulated report or document, then it becomes easy for me to understand.

Saaj would rather have a one-on-one conversation with an individual using some platform. He does not feel the need to have a finished prototype to have conversations but sees the value in receiving feedback from people as he is Making, and hence sees the need for a platform to facilitate the same between people.

> I think a common platform where a lot of people come, not necessarily with the finished [product] whatever they are making but just to get them feedback like say how the community is responding to whatever they are making. It could be a little platform but I think it should need people one-on-one thing. In person I think they'll be more chances or a [bigger] stage for conversation.

Most of my participants use similar ‘codes’ to ‘read’ and ‘write’ in ‘object languages’; they rely on 2D sketches and 3D models. They also use similar tools to translate what are often abstract requirements into concrete objects. Baden uses sketches to understand and explain what he is Making to others at the Craft Development Institute. He also uses sketches and actually experimenting with the materials by prototyping to generate concrete objects from abstract ideas. Gerardo and his team use sketches from CAD software to communicate.

Being physically present at sites and physically interacting with objects helps him understand the abstract problems they address with their concrete solutions. Layla prefers interacting with physical models, irrespective of how advanced a stage the prototype is at. For her holding the objects in her hands and observing them from different angles helps her understand their form and function better. Chloe both communicates and conceptualizes using sketches. She also uses her hands to convey ideas to others. Similar to the others, Kandra too prefers sketches and prototypes to communicate. She sees value in physically interacting with artifacts being Made to concretely understand abstract ideas. Tanya too relies on either 2D sketches or 3D models using software to have conversations about her artifacts. She heavily uses 2D software currently to conceptualize and share her ideas. Shaan ends up using both 2D sketches and 3D models or a mix of both. Aaron and his students, owing to the curriculum the school uses, end up using a lot of design vocabulary and techniques such as sketching and prototyping. They also use vocabulary particular to the school, which everyone at the school in encultured into. For Mario and Saaj, the conversation between two individuals is more important than the medium and language they use. Given their Making practice, they rely on experimenting with the materials they work with to realize the final physical artifacts they Make.

For most of my participants, 2D sketching and 3D modeling are the preferred modes of communication which constitute their ‘object' language, and which they use to bring abstract ideas to physical form or its representation. Aaron and his students also use vocabulary specific to their school to communicate with each other. Mario and Saaj, similar to prior themes, talk via their materials, but first to themselves. Designers too have conversations with and through their materials (Schon & Wiggins, 1992). Also, they develop an understanding of the scheme using artifacts, which is similar to designers Luck (2007) observed in a real-world situation of designing a building who used drawings, models, and other prototypes to mediate their conversations. The narratives from these two themes of object languages and translating abstract requirements to concrete objects also align with my participants being true to their reasons and motivations to Make and then adopting techniques from design and other fields to meet their needs.

Table 6: Summary of the participants' narratives related to the Connections aspect of the conceptual framework.

Participant Name	**Connections**	
	Dialogic ways to design	**They use these codes to both 'read' and 'write' in 'object languages'**
Aaron	"Coaches" his students through Making by engaging with his students via conversation	Uses design vocabulary and techniques such as sketching and prototyping
Baden	For him open and free communication is an important characteristic of Makers and communities of Makers	Uses sketches to understand and explain what he is Making to others at the Craft Development Institute
Chloe	Working with others on artifacts that evolve over the process of Making is her favorite aspect of Making	Communicates and conceptualizes using sketches
Gerardo	Him and his team of Makers always work together	Him and his team use sketches from CAD software to communicate
Kandra	Benefits from both, the users of her artifacts and her community of Makers	Prefers sketches and prototypes to communicate
Mario	Connects with others to learn new techniques and has also benefitted from others' advice on how to do a certain thing better and leads on procuring materials to Make with	The conversation between two individuals is more important than the medium and language he uses
Layla	Has been impacted by her community of Makers in both, her conception of making broadly, and the use of tools and technologies	Prefers interacting with physical models, irrespective of how advanced a stage the prototype is at
Shaan	Looks to his users to provide feedback on the finished product and also looks to them as he Makes	Uses both 2D sketches and 3D models or a mix of both

Table 6 continued

Saaj	Uses social media to learn new techniques, be inspired, share his work, and also collaborate with people	The conversation between two individuals is more important than the medium and language he uses
Tanya	Has been inspired by others who Make around her and has also received support from them in finalizing prototypes	Relies on either 2D sketches or 3D models using software to have conversations about her artifacts

Goal of the practice

Figure 10: The Goal of the Practice aspect of the conceptual framework represented in Figure 5.

Designing artifacts that are informative (expressive) of their working

I asked my participants if upon interacting with their artifacts I would be able to tell their use or function to understand if their artifacts are informative/expressive of their working, thus meeting the goal of the practice. The following is how they responded.

On being asked if the prototypes him and his students Make are expressive of their working, Aaron laughed and responded that his students are in 9th Grade and like most things 9th Graders work on, the prototypes are not very expressive of their function. However, he

goes on to say that it is one of their priorities and actively strive towards their artifacts to stand for themselves and be user-friendly.

> All of my students are ninth graders right now, would you be able to look at their product in general and know what they're for? Not yet. We're working on that. One of the ways by which we evaluate our prototypes are, if they stand for themselves, we really want our designs to be user friendly. If you're looking at something and you have no idea what it is, then that's likely not user friendly… Our students are definitely improving in that realm. The quality of prototypes this time around was far and above what we had last time. I would say, in general not yet, but we're getting closer.

Shaan mentions that when he is Making artifacts, he is intentional about Making them expressive of their use. He takes an example of handcrafted wooden speakers that he Makes and says that he enjoys that the users of the speakers do not need to use a manual to use the speaker. It is important for him to Make things that are simple, even though he is aware that people will use the artifacts in the ways they choose.

> When I make anything I put in that much effort to make it look like it's in control, I'm just taking example, let's say if I'm making a speaker. I make sure that they are done in such a way that you don't require use of manual. Because I personally feel if you need a user manual for a thing then it's not simple. I generally make things which are really simple and also to an extent I know people are going to use it the way they want to.

For Tanya, whether her artifacts are expressive of their working or not depends upon the artifact itself. Her Ukulele is expressive of its function, most of her artwork isn't, and some of her other artifacts are expressive or inexpressive by intention. Where it is easy to assume that good design practices mandate the artifact to be expressive of its use, Tanya shares an example of UI design in which she had purposefully made online forms for Bank transactions to require users to pay more attention.

For Baden, the artifact is expressive of its use depending on the stage of its production and the medium he uses for communicating about the artifact or the materials with which he is Making. He tells me that if people were to look at his sketches of the final prototype he intends on Making, they would understand its use. However, if he is working with a material, leather, for example, it's difficult to tell its function until it is either used or gains more structure.

> If I'm making proper sketches of things that I'm going to finally make, then it's more or less clear for people. But other than that, when I'm prototyping the sketch is not there and I'm working on a material, initially because you can't figure out what it's meant for unless you put things in it, or if you sat over the piece of cloth and some leather, it could be a bag, it could be like a pen holder, it could be anything. So, until it gets some structure, then people start slowly figuring out what it is.

A part of Gerardo and his fellow Makers' practice involves Making equipment for engineering experiments. When I ask him the question about his artifacts being expressive about their function, he responds by saying that it depends on who the people are. Since the equipment they Make is meant for engineering experiments, engineers can usually look at the artifacts and tell their function.

> If we are talking about engineers going to the space, they would look and say, "Oh, this Is for-- that is for--". They can recognize easily when they look, but if it's a lay person, maybe they would ask, "What is that for?"

Layla tells me that one can tell the use of her artifacts depending on how aware one is in the process of Making them. She gives examples of a jig she Made to extrude clay and a radio. She once asked some students she was working with to guess the function of the radio. They took a long time to identify the correct use. Layla thinks that the students took time to determine the use as it was not usual for them to see a radio without an amplifier.

> I don't know it, depends on how much you know about the processes. So I have like a little jig that I used to extrude clay. And the radio that I mentioned earlier. So you'd never be able to tell that it's a radio if you didn't know that it was one.

> That maybe is a good example. I played a game with some school children last week and I kept giving them hints about what it was. They got there eventually but it took long, mainly because they did not think that you could listen to radio without an amplifier.

On being asked if I would be able to tell the function of an artifact she Made by interacting with it, Chloe responds, "I think you'll be able to make up uses." She takes the example of her living room which she had described to me earlier when I asked her to tell me the story behind her favorite artifact. She says that we would be able to guess how the room is supposed to be used which might not be completely coherent with how she uses it but could be close to it.

> I'm thinking about the artifact of like my living room, I think you can go around there and kind of see: "Okay, this is probably where she sits; this is probably where she paints." But in reality, I spend a lot of times on couch doing things that I could be doing, or at the desk and I made. That usually just becomes a placeholder for stuff I want to get back to because I think you could make your own meaning of the space. And I don't think that those meanings will be far from my reality.

Kandra responds by saying that one could probably come up with a use for most things. She takes an example of a wearable health device that looks like a wristwatch. She says that if someone were to pick up the device, they would probably think that it is just a wristwatch and not be able to tell that it has several other health-related functions. So, one could possibly be able to suggest a use which would be applicable but miss out on the nuances.

> You could go make up something for everything. Yes, you could probably make up a use for it. For example, there's a wearable device, it probably looks like a watch. Not being, maybe, from the space or knowing the background of the project, if you were just to pick it up, you'd be like, "This is just a watch." You would miss all these other features of health tracking and-- In that process. Which I think goes through a lot of projects in our space, of-- Looking at it, you can get a really good

> idea of where it falls, but then you miss the nuances of talking to that person or seeing some other

When asked if I could tell the function of his artifacts by just looking at them, Mario responded, “so far I think you can tell just by looking at it, or even a picture of that”. Which shows the certainty in his belief of his artifacts being expressive of their working. However interestingly, when talking about furniture pieces he Makes using newspapers, he mentions how people might not realize how strong the artifacts are until they physically interact with them. Which again, is not the use, but a hidden nuance of the final product.

Since Saaj’s Maker practice is related to him Making crafts with paper, when asked if I would be able to tell the use of artifacts he Makes, he responds, “No, I don't think my making is solving any purpose it's more of me enjoying the making part like making process.”

In the above narratives my participants shared how the artifacts they Make are expressive of their working. Aaron’s students are not always able to Make artifacts that are expressive of their working, but he and the other instructors support their students’ development to be able to Make such artifacts in the future. Shaan aims to Make artifacts that are expressive of their functioning and easy to use, such that the users do not have to consult a manual. Though having said that he also conveys that he is aware of users using the artifacts in ways he did not intent for them to be used. Tanya’s artifacts are expressive of their functioning if she intends for them to be. For example, her Ukulele is expressive of its functioning, but her artwork is not. There are also other times when her artifacts are not expressive of their function on purpose, as that meets their intended use better. Baden’s sketches and prototypes are expressive of their use, but when he is conceptualizing and fabricating ideas using materials like leather, they are not. Gerardo’s artifacts are expressive of their functioning to the population they are meant for. The equipment that he Makes for engineering laboratories, are expressive of their functioning to engineers or engineering students. People who are aware of Layla’s process of Making, can tell what

she is Making. However, several artifacts that she Makes are not easily comprehendible of their true use. Chloe and Kandra's reposes are similar. They tell me that people will be able to devise uses for their artifacts, but those uses might not always be what they intended or be missing nuances. Mario's artifacts offer a surface level understanding of their function since he Makes furniture made of newspapers. People can tell that his artifacts look like furniture, but they often miss that they are actually strong enough to be used. Saaj's artifacts are not expressive of their functioning and he tells me that that is not the aim of his practice. The aim of his practice is for him to experience and engage with the process of Making.

In understanding my participants' human-centered design practices and particularly if their artifacts are expressive of their functioning, I learn that their practices vary depending on the purpose behind their practice. Their responses vary from the artifacts being expressive of their functioning being paramount to their practice, it being dependent on their intent behind Making the artifact, believing that users will use the artifacts in ways that they did not intend for them to be used, and thinking that users might not be able to understand all the nuances of the function. One of my participants, Saaj, also shares that his artifacts are not expressive of their functioning as he does not Make them for others to use, but for him to Make.

Unlike the previous themes, most of my participants do not respond in affirmative to my question. Whether their artifacts are expressive of their functioning or not, depends upon the purpose behind their Making. These purposes range from being deceptive of the artifact's purpose, invoking surprise in the users by the artifacts being more that what they appear to be, Making with a use in mind, expecting the users to end up using them in different ways, and Making for themselves and not users. This observation of the Makers' purposes informing what they Make, begins to uncover a finding which I detail in the next research questions. My participants stray away from the conceptual framework of unintended design when it does not align with their personal motivations and purposes. I will detail this in the next research questions where I discuss differences between design and Making, and the uniqueness of Making.

Their mode of problem solving is 'solution-focused'

To understand if my participants' mode of thinking is 'solution-focused' I asked them what according to them is of highest priority when Making and followed-up by asking how important it was for them to be solving the problem at hand. They responded as follows.

For Gerardo, when he first started Making it "was like the enjoyment," which was his highest priority. Now for him where the process is still enjoyable, finding a good solution to the problem is required for the process to be complete.

> It should be like a big challenge. The process is really amazing, but for me, if we go through the process, enjoy. If we don't reach a good solution, it's not a complete process. I really like to get a good result.

For Aaron, when Making with his students in the Makerspace solving the problem is secondary to the students going through and learning the process of Making. However, he also adds that the way the process is structured the students should be reaching solutions via iterative steps.

> I would say, solving the problem is of secondary importance to internalizing the process. However, the process is structured such that the solution should be iterated until it solves the problem. Technically if the student is truly internalizing the process and is equipped with the tools and materials necessary to solve the problem, then the problem will be solved every time.

Saaj acknowledges that solving a problem and seeing the result makes him happy, however, the process is of utmost importance to him in his Making practice. His primary way of Making is by paper quilling, and he shares how sometimes while quilling he gets engrossed in Making to such an extent that he continues quilling for several hours.

> I think the process is more important. For me I think the process of paper cutting is more important. I think I enjoyed the most like the end result does give me a sense of happiness that I completed and that's good but I think I enjoyed the process more. Even the quilling, it's very time intensive and it requires a lot of patience. I think I

> enjoy that part most. I spent like entire Saturdays and Sundays just sitting at one place to finish the paper quilling artwork. For me I think it's the process of doing it.

For Baden, where the problem to be solved is central to his Making practice, he also tells me that the gestures he Makes by solving problems for others is very important to him, perhaps more important than anything as things can eventually break. He believes that even if the solution he finds to the problem is not perfect, the memories he gathers and the learning he experiences while Making carry meaning for him.

> For me it's, it is primarily about the problem, but it's also about the gesture that you are trying to make, while making for them. I mean the time and effort we put into it, I think that matters more than the thing itself. Even if the thing breaks, there is still the effort that counts I guess. So, I make sure that I put in my 100% whenever I do. Even if the thing is not perfect, there's still a lot of memories that go into it and you will eventually get better at things and then you'll learn and you get better and you finally accomplish what it's meant for.

For Mario, his priority while Making is to affect someone who sees his artifact by invoking surprise and fascination. He is aware that his approach to Making is not focused on solving problems, but he says he is aware and comfortable with that. For him, being inspired by an object, transforming them into artifacts and invoking emotion in people looking at his artifact is more important.

> The first and foremost thing which I would like to create is an affect in someone who sees it. I want to surprise them and I want to fascinate them with whatever they're seeing or whatever they're interacting, the things that I have created … I am comfortable with this approach where I'm inspired by object and then I translate and create artifact. I accept that for now that I'm not good at projects which are very heavily problem solving based, and I think that there will be someone else who will be good at and he'll do that and that's how I see it; that someone else will be good at that and he'll take care of that, I will take care of creating stories and creating objects out of inspiration.

For Shaan, the list of priorities for his Made artifacts include, the function of the artifact, the uses it induces, the openness, accessibility, and replicability. However, as he mentions in the quote below, the function and the uses it induces are the highest on the list. Showing the solution-focused approach of his practice, and also his practice of being open to and prepared for however people end up using the artifacts he Makes.

> Yes, for me the function and the induction part are first on the list then the second thing is how open they could be, if I have to make them available to people how easy they could be for people to replicate. And then this part is kind of aesthetics. For me, I won't put things in -- like I wouldn't put confidence in objects which I'm having this and the concept. That's something which I really do like doing.

For Chloe, the people affected by the problem and the problem's reach are of the highest priority. Knowing who all are affected and the breadth of the impact of the problem Chloe decides how much time she would dedicate to solving the problem.

> I think I'm usually focused on who else is affected by the problem, and how wide the problem reaches because I think that's how I prioritize -- what I'm gonna do is like, what is the potential impact, who else is affected by this, and how else can I change? And if it's just me, that's fine, but I think that kind of affects how much time I give.

On being asked if she has an end in sight when solving the problem, she says that it is not something which carries much importance for her. She knows that she has to progress out of the problem, but what the "virtual" solution space looks like is not something she would be thinking about.

> I think normally I'm so focused on the problem that anything that's not the current state is fine with me. So it's like I don't really think about what the virtual space could be; I just know I need to get out of this space in some way.

For Kandra, the Making is not always about solving a particular problem. Where sometimes she goes into the Makerspace knowing precisely what problem she wants to address, other times she goes in to de-stress by drawing and using her hands to Make something.

> It so depends. Sometimes I go in, I make just to destress. As my space of use my hands, get out of the normal flow of life and just be in my own element. Other times, I go in because I want to make something that I might want to turn into a real product. Then, other times, I do make on real projects that I'm working on. It just depends on what the mode is. I would say my favorite time is just making to stress relieve because it could be anything. You never know. I always relate back to drawing.

For Layla too, it depends on what she is Making and why she is Making. If she's Making for herself for fun, solving the problem does not matter much, though solving the problem and the sense of achievement makes her feel good sometimes. She adds that she often is not Making to solve a problem, but to go through the process of Making. She carries this understanding into workshops she runs on Making in which she encourages people to have fun more than solving a problem. She also gives an example of the Maker activities she helps with at the space in Glasgow where people with histories of addiction Make things. There they teach woodworking, which is not about solving a particular problem but going through the process and feeling proud of what they Make.

> [I]t depends on what I'm making. So if I'm making for fun for myself it does not matter that much to solve the problem, even though it feels good when I achieve something. But often you're not making to solve a problem, you're making for the process of making. So when I run workshops I try more for people to enjoy themselves rather than to certainly get to an endpoint.
>
> [Y]es so there're lots of such examples. one such example is that Glasgow where they teach woodworking. The men are learning joinery, but obviously the joint that you have in the end is not that useful because it is just a join click a cross of wood. It doesn't actually have any function, but they're doing it to learn one how to make a joint and then also the other part of that which is they feel proud of what they're making, because they made something beautiful.

For Tanya, it is about striking the right balance between the effort she puts into her Making and finding a solution to the problem at hand. She tells me that she keeps trying, however

at some point, if the problem isn't solved, she gives up, as she doesn't see the purpose of going on indefinitely.

> Depending on, it again depends on how much effort you are putting in and what reward you are getting back. It's a pretty delicate balance. So for example as a kid I made Cryp-text, so it's like a puzzle box that you make, so it was like I made a lot of attempts and it didn't work so I was giving up and suddenly it clicked and I kind of knew the answer to it after a few days. You kind of get back on track, so it's something like, I think it depends on how much effort you can pump into it – at some point you give up ... You try to solve it, but you wouldn't go on indefinitely.

Similar to the prior theme in the goal of practice aspect, in the current theme of their problem solving being 'solution-focused' a majority of my participants do not reply in affirmative. This is unlike the other aspects of the framework, namely, need, adopted practice, making meaning, and connection . When it comes to the aspect of the goal of the practice, my participants' purposes inform their Making practices.

For Gerardo, when he first started Making, the process and having fun was of the highest priority. However, now that he has transformed his practice into a profit-making enterprise solving the problem at hand has become more important. This shows how his goal of the practice has transformed too. For Aaron, it is important for his students to find solutions to the problems they are solving, but the learning and practicing the process of Making still holds the highest value. Similar to Aaron, Saaj acknowledges that solving a problem and seeing the result makes him happy, however, the process is of utmost importance to him while Making. For Baden, it is important to Make a final product, however, the gestures that his artifacts signify for people hold the most importance. Mario's purpose behind Making is to invoke surprise in the user by novel use of materials. He is well aware of this not being a solution-focused approach, and he is comfortable with that as his approach better aligns with the purpose behind his Making practice. Shaan looks to invoke the function and uses of his artifacts from his users through the artifact he Makes. If we understand his use as the solution, this could be understood as a solution-focused approach.

For Chloe, the people for whom she Makes are most important and so the importance of the solution depends upon how important the solution is for the people she is Making for. Kandra and Layla Make for others and themselves. When they Makes for others, it is important for them to solve the problem, but when they Make for themselves it is not. For Tanya solving the problem is important, but it is also important for her to understand when the efforts she is putting into solving the problem are not worth the solution. At which point she stops.

Table 7: Summary of the participants' narratives related to the Goal of the Practice aspect of the conceptual framework.

Participant Name	**Goal of the Practice**	
	Designing artifacts that are informative (expressive) of their working	**Their mode of problem-solving is 'solution-focused'**
Aaron	His students are not always able to Make artifacts that are expressive of their working, but he and the other instructors support their students' development to be able to Make such artifacts in the future	It is important for his students to find solutions to the problems they are solving, but the learning and practicing the process of Making still holds the highest value
Baden	His sketches and prototypes are expressive of their use, but when he is conceptualizing and fabricating ideas using materials like leather, they are not	For him it is important to Make a final product, however, the gestures that his artifacts signify for people hold the most importance
Chloe	People will be able to devise uses for her artifacts, but those uses might not always be what she intended	The people for whom she Makes are most important and so the importance of the solution depends upon how important the solution is for the people she is Making for
Gerardo	His artifacts are expressive of their functioning to the population they are meant for	When he first started Making, the process and having fun was of the highest priority. Now solving the problem at hand has become more important

Table 7 continued

Kandra	People will be able to devise uses for her artifacts, but those uses might be missing nuances	She Makes for others and herself. When she Makes for others, it is important for her to solve the problem, but when she Makes for herself it is not
Mario	His artifacts offer a surface level understanding of their function since he Makes furniture made of newspapers	His purpose behind Making is to invoke surprise in the user by novel use of materials
Layla	People who are aware of her process of Making, can tell what she is Making	She Makes for others and herself. When she Makes for others, it is important for her to solve the problem, but when she Makes for herself it is not
Shaan	Aims to Make artifacts that are expressive of their functioning and easy to use, such that the users do not have to consult a manual	He looks to invoke the function and uses of his artifacts from his users through the artifact he Makes
Saaj	His artifacts are not expressive of their functioning as that is not the aim of his practice	He acknowledges that solving a problem and seeing the result makes him happy, however, the process is of utmost importance to him while Making
Tanya	Her artifacts are expressive of their functioning if she intends for them to be	For her solving the problem is important, but it is also important for her to understand when the efforts she is putting into solving the problem are not worth the solution. At which point she stops

RQ 1 Summary: Making as Unintended Design

In this section, I analyzed and discussed my participants' narratives to answer the research question

RQ1: How do Makers practice human-centered design and designerly ways of knowing?

I analyzed their narratives following lines of inquiry detailed in the conceptual framework to understand how they practice human-centered design and designerly ways of knowing. A majority of my participants provide rich descriptions of how they practice each of the aspects of the conceptual framework, namely: need, adopted practice, making meaning, connections, and goal of the practice.

For the need aspect, my participants (re)design the characters of their artifacts and tackle 'ill-defined problems.' They practice (re)designing the characters of their artifacts by mentoring and coaching their students in doing so, by choosing the materials they Make with and aligning their practice with their personal ethics of prioritizing quality over other criteria. Two of my participants address this theme by connecting it to their broader journey as Makers, and one does not believe that he has done so in the past but envisions himself doing so in the future. They tackle ill-defined problems by mentoring their students and workshop participants through ill-defined problems, by solving such problems successfully which in turn contribute to their confidence as Makers, by scoping problems and probing to find the hidden assumptions in the way they understand their problems, and by responding to ill-defined requirements and needs. Two of my participants do not solve ill-defined problems as doing so does not align with the purpose behind their Maker practices, which are encouraged by the process of Making and the use of materials in ways that are personally interesting to them.

For the adopted process aspect, my participants design human-centered design strategies and their modes of thinking are 'constructive.' They design human-centered design strategies by soliciting and addressing feedback from their users, and by enacting human-centered techniques, some of which exist in design literature and others that they adopt from other fields such as signals, vibes, and mindfulness. My participants who do not explicitly claim to Make for or with people, Make for themselves as that aligns better with their purposes to Make. Their mode of thinking about their Maker practices is 'constructive.' In their narratives, they do not always address how they have learned new skills involving tools and materials, but several of them explain how their understanding of Making and how they engage with it has evolved. For Aaron and Mario, Making now is

a practice with a purpose behind it. Kandra and Chloe have learned that they do not need to leap to a solution the moment they encounter a problem but can instead work through it. Chloe, Gerardo, and Tanya have now started thinking about Making in entrepreneurial ways. Saaj has learned new techniques for paper quilling, and Tanya has learned the importance of documenting what she Makes. Baden and Layla have learned how to approach problems by deconstructing them and using new equipment, respectively. Shaan has learned why custom-made artifacts are expensive and now he is more conscious about repairing products and salvaging them for parts.

For the making meaning aspect, my participants design original artifacts guided by narratives and metaphors and use ‘codes’ that translate abstract requirements into concrete objects

They realize narratives and metaphors in their Maker practice, and in the discussions above I present several diverse and unique ways in which they do so. They are able to abstract from a group of experiences and identify the salient aspects of their Making. These unique stories also start bringing our attention to how all my participants Make and yet have unique motivations and stories behind their practices. I address them using ‘codes’ that translate abstract requirements into concrete objects in the next aspect of connections.

For the connections aspect, my participants provide evidence for designing in dialogic ways and using codes to both ‘read’ and ‘write’ in ‘object languages.’ They engage in dialogic ways and remain open to unpredictable outcomes by soliciting feedback from their users, Making their users and other Makers a part of their Making, seeking support from Makers who might be more skilled at some tool or technology, mentoring others, receiving feedback and collaborating over social media, being inspired, and finding community. They also use codes to ‘read’ and ‘write’ in ‘object languages’ and translate abstract requirements into concrete objects. For most of them, 2D sketching and 3D modeling are the preferred modes of communication which constitute their ‘object' language, and which they use to bring abstract ideas to physical form or its representation. Aaron and his students also use vocabulary specific to their school to communicate with each other. Mario and Saaj, similar to previously observed themes, talk via their materials, but first to

themselves. They have conversations with and through their materials, which is also characteristic of designers. The narratives from these two themes of object languages and translating abstract requirements to concrete objects also align with my participants being true to their reasons and motivations to Make and then adopting techniques from design and other fields to meet their needs.

To understand the goal of practice aspect I discussed if my participants design artifacts that are informative (expressive) of their working and if their problem solving is 'solution-focused.' In understanding, if their artifacts are expressive of their functioning, I learned that their practices vary depending on the purpose of their practice. Their responses vary from the artifacts being expressive of their functioning being paramount to their practice, it being dependent on their intent behind Making the artifact, believing that users will use the artifacts in ways that they did not intend for them to be used, and thinking that users might not be able to understand all the nuances of the function. One of my participants, Saaj, also shares that his artifacts are not expressive of their functioning as he does not Make them for others to use, but for him to Make. Unlike the previous aspects, most of my participants do not respond in affirmative to their problem solving being 'solution-focused.' Whether their artifacts are expressive of their functioning or not, depends upon the purpose behind their Making. These purposes range from being deceptive of the artifact's purpose, invoking surprise in the users by the artifacts being more than what they appear to be, Making with a use in mind, expecting the users to end up using them in different ways, and Making for themselves and not users.

Whether or not my participants' ways of knowing and thinking are solution-focused or not depend upon the purpose they seek to meet with their Maker practices. If they are Making for others to solve a problem for them, finding a solution is important. Though at the same time, someone like Mario seeks to invoke surprise in his users, and not necessarily functionality. My participants do not always Make to find a solution. They sometimes Make for themselves, and also Make for the process of Making, which they sometimes consider more important than finding a solution. On principle, my participants realize that finding a solution is important, but explain how their purposes behind Making do not

always align with finding a solution. It is interesting to notice here that the people, means, and activities framework from Paper 1 can be used to situate each of the participants' purposes. Some see the purpose informing their Making as the activities, others as the people (themselves and others), and others as the means and skills they and their students learn.

Making and Design

In my pilot interviews for this study I observed that my participants attempted to make distinctions between Making and designing. This observation made me curious about how my participants understood and distinguished Making and design, and also if they were more inclined towards owning one identity over the other. It also made me realize that conversation aimed at understanding the distinctions between the two could help me make a case for Making as an educationally meaningful activity beyond proving its similarities with design, which I do in answering the previous research question.
In the next two sections, I ask the research questions:

> RQ2: How do the Makers in my study distinguish between design and Making?
> RQ3: What does Making mean to my participants?

These two questions help me understand how my participants navigate the differences between the two, and also understand if and how Making is unique in comparison to design. Design throughout this paper, is always characterized by the conceptual framework informed by Krippendorff (2006) and Cross' (1982) work. Since these research questions are aimed at understanding my participants' experiences, I employ narrative construction with direct quotes to answer the above questions from my participants' perspectives.

Differences between Making and Design

In the previous sections, I analyzed how my participants' Making practices compare against human-centered design practices (Krippendorff, 2006) and designerly ways of knowing

(Cross, 1982). In this section, I present narratives from my participants to understand if my participants identify themselves as designers in addition to being Makers, and how they think Making and designing are different and similar. I have constructed a majority of the narratives from the participants' responses. To situate the responses better and for making reading more coherent, I have added some text, which is italicized.

The following narratives and synthesis, answer the question:

RQ2: How do my participants distinguish between design and Making?

As I state in the methods section, these narratives are of the narrative analysis type which is constructed majorly by direct quotes from participants. The primary aim of this method is to not separate the participants from their narratives. The synthesis following the narratives, help situate the narratives in the context of this research study to answer the above-stated question.

Aaron

Definitely yes, I would *Identify as a designer*. I really love the Stanford design school's thinking model.

To me, the making comes in the prototyping, the rest is the design. When I think, "I'm going to enter the maker space" that's because I'm in the prototyping mindset.

Making and Design can't stand alone. They need to be in there. The way I'll phrase this is, if you have a solution, a white paper is not an adequate message to convey that solution. You need something to show versus just telling, and you have to have the making to support the realization of the solution that is generated from the design process.

Baden

Perhaps, *I also identify as a designer.* Let me explain how.

I'm connected to the craft world. *Some* craftsmen take craft as a sort of revenue generating thing. Even if you're talking about makers, and the music the maker creates and making as an art form, you still feel hungry at the end of the day. You have to somehow look at how to monetize it. That's how it interferes with design. You have to plan in a way that you are

able to sustain your form of expression, so that you continue making the music that you're making. There's sort of *a* design of that.

Discussions *are* open between makers, *but* not necessarily designers. I guess designers do critique *things,* but there's some sort of ego in there. I've felt that, I don't know if it's true or not, but I've felt that it's like that. But between makers it's more empathetic and they want to help you, which is really helpful, and which is a positive thing about this whole maker culture.

Chloe

Yes, *I identify as a designer*. I would probably identify as a designer first, just because a lot of the things that I make are not tangible. I think the designer's a little bit more inclusive of the wider spectrum of the stuff I make.

Sometimes I think the making piece is a part of the doing, because as a designer, a lot of the designing happens on my head. Just kind of visualizing and deciding what I like to see and then the doing of it is when the making happens but there's still designing happening in the making that's not just doing because usually whatever I saw in my head is incomplete in some way. There's still some means to which I have to make decisions about how to go about making the things in my head real that are not just doing.

Well, I think the design identity comes with a lifestyle in terms of what you see and what you act on and what you think about. If you have the space, time, and money, you make things *in* that space. Because I remember being younger having ideas and thoughts about things but not really the space even nobody to talk about it. Even then, I think I considered myself a designer. But if you were ever to ask me and if I was given my space to show *my Maker* identity, it would have come through.

Gerardo

I would say that I'm not the guy who is all the time doing CAD. I'm the guy who likes to define the requirements, define the problems, and sit together with the designer and then specify what they should do, how they should do. In that sense, I'm a designer.

In a Makerspace, I know people who likes to receive a design project, and they'd love to build that, to go to the milling machine, to go to the lathe, to put all *things* together, *and*

put *them* to work. This guy is a maker. Then, there are others that like to design their own stuff, and then go to the 3D printer, and others just like to stay on the conceptual stage, where it gets designed.

If the guy is both, he's a big maker, but if he is from the side of building the stuff, *he* is a maker. The guy who likes the design space, for me, he's not a maker, because he lacks the making

Kandra

Do I identify as a designer? Yes and no.

When I think of a designer, and I think this is probably why I said no, I think of all the things that we do as a maker, but I also think of it with an increased focus on the-- Not just aesthetics but more the human-center component. Like, "How does it fit? Can it be washed 85 times versus once?" those kinds of things. I can completely do those as a maker, I just don't.

A lot of the time that I don't is because I'm not at a stage where those things are important yet. Because a lot of the things that I'm doing in my making is very front end. Either trying to garner support around an idea or funding around an idea or just, like I said, *playing around*.

I think *my Making and design identities* intersect. I think, for me, I see them as different overlapping identities that I move in and out of, depending on what I'm doing. I feel maybe, within the maker space, I always feel like a maker, but I don't always feel like a designer.

Layla

Yes, I call myself a designer, but I also do a lot of research and a lot of facilitation and that kind of a thing and I wish I was doing more making for making's sake.

I guess you can't make without constantly seeing problems. Even if they are small problems like should it be this big or this big, like should I file it smooth or should I leave it rougher, so you're obviously always designing even if you only call yourself a maker. But I do know a lot of people who would call themselves makers and not designers necessarily. Like I work in a boat building workshop and so every day they work on other people's boats, but they don't realize that they are solving problems everyday by deciding

the tools they use and how exactly day shape the piece of wood so that kind of thing, but they would call themselves more makers. I think design is a very broad term, you can be the designer but not the product designer like you say design research and all that kind of thing. That's quite hard to define.

Mario

I am more of a maker and less of a designer. But yes, I call myself a designer. I'm more of a Maker because I've been practicing the process of making more than practicing the process of designing. Both of these projects, which I have mentioned, are still limited to creating artifacts. I have a plan to make designs out of *them*, but I haven't done it *yet*. That's why I can't confidently say that I am a designer, but I'm confident about calling myself a maker.

To keep it simple, w*hen* people are using *my objects* and finding them useful, *they* are beautiful, they are affordable, and they are sustainable. Once all these qualities are met, then I can say that I've designed something and that's when I would see myself a designer. Making is more about personal satisfaction and designing is more about satisfying the person or the context you are designing for. *When* I'm trying to convert my artifact into design, but there I'll have to consider the price and then the effort that goes into making the material; like what a person in a business would consider. Things like these won't be a concern in the first half of the project, where I'm trying to just make stuff, the translate the inspiration into object. Yes, they will definitely be important in the later years when I'm trying to make the designs out of that.

Saaj

I think that *a Maker and a designer* should be the same person. A designer would imagine and a maker would help him do *the* building work. I think the maker would help him to bring it to the real one. I think one is incomplete without the other.

I think making is more *about* experiencing and learning through it. If you are say solving some problem design I think it's more of connecting, bringing all the pieces together, and making would be part of the process.

Tanya

Yes, sure *I identify as a designer*. So right now, I work as a designer with [big tech company] so I'm completely into a non-hands-on field like I do UX design. So, I'm definitely kind of missing the action happening in the workshop.

I would say that when you are making for yourself you're not accountable and so the process gets slowed down. Like for example the ukulele I took my own sweet time. But when there is a user on the other and demanding something from you then you are under a little bit of stress and you are accountable. But when you're making for yourself it takes some more motivation, like "I really want that ukulele", that kind of thing. So, it is true that it kind of flows more freely than when you are designing for a client. Because with a client there's a lot of back-and-forth and communication lag between both the parties.

Shaan

For me *my Maker and designer identity* support each other.

For me these two things are a way of life. So, it's not something which comes external to me. Making is something which is really ingrained in me and also design. So, it's a bigger picture for me, a bigger picture in the sense it's more inclusive and more open than the two of them taken in isolation. So, when you join these things, like the sum of part is greater than the whole. So, for me the maker and the designer is something which is far better than the two of them. I've seen both the sides like the hardcore making as in like being involved into really hands-on approach and also seen the sight in which you actually create systems or create an entire ecosystem. Both the approaches combine together work well for me. If I've to do them in isolation I think it won't work, or it won't be as satisfying, or being as content as practicing both of them at the same time.

But, there's a huge difference when it comes to the scale of objects, or the scale of things. Because when we talk about making, we actually think about making a physical object, and we don't think about systems. So, when you talk about design it comes to a point that you are creating a system. It's not just an object, you are looking at the entire picture from a very big holistic point. For me right now the two worlds have merged.

As we see from the above narratives, several of my participants identify both as designers and Makers to varying degrees. Baden, Kandra, Mario think of themselves more as Makers than designers. Aaron, Gerardo, Saaj, and Shaan consider themselves to be an equal blend of Makers and designers. Layla and Tanya, though identify more with being designers currently, wish they were Making more. Chloe recognizes herself as more of a designer as she has lived that identity for a longer time than that of a Maker.

For Chloe and Layla, Making is the physical and tangible act of making something, and Chloe goes on to add that it is related to being in a space. For Aaron and Saaj Making supports and complements design. Aaron calls it realizing design and Saaj calls it a part of the process of designing. For Kandra, Mario, and Tanya, Making is about them, and design is about the users. Kandra calls her Making "front end" and in an earlier narrative explained that she could be Making for leisure or some other person, and it depends on what she wants. When Mario's Maker objects cater to users, he says he becomes a designer. Tanya too believes that Making is for herself and design is for others. Another interesting and contradictory difference is brought up by Gerardo and Shaan. Where for Gerardo, Making is about bringing together several moving parts and ensuring they work together and design is related to CAD or sketching, Shaan believes that Making is about the object, and design on the other hand is about the systems around the object. Finally, Baden, whose conception of design is similar to Shaan's, talks about design as a way to sustain Making, to which he adds that Makers are open, critical, and empathetic., highlighting values which he believes distinguish Makers from designers.

These distinctions show that my participants do not understand Making and design similarly, and consequently consider them as separate but often related identities. After asking my participants to differentiate between design and Making, I asked them what Making meant to them. Their responses help us understand the uniqueness of Making in comparison to design and engineering. It is interesting that the thread of realizing a purpose via Making, which explains the deviations from design practices and ways of knowing from the first research question, emerges again in their responses to what Making means to them.

What does Making mean

After understanding how my participants distinguish between design and Making, in this section, I focus on understanding what Making means to them. Similar to the previous section, here I employ narrative analysis to present my participants' narratives comprising primarily of direct quotes from their narrative interviews. I have italicized the additional text that I have added.

The following narratives and synthesis, answer the question:

RQ3: What does Making mean to my participants?

Given everyone's conception is their own, it is particularly important to present my participants' narratives as their own, and hence this type of narrative construction is best suited to answer the above-stated question.

Aaron

I think really from a maker's standpoint, I've been a maker all of my life.

I was a high school chemistry teacher and I was teaching at a school that did not have access to laptops and so MasterCard donated 30 laptops to my classroom. They were missing operating systems and needed some parts replaced so I started a club called, Tech Army. Tech Army was established to get the laptops back in better repair for use within my chemistry classes because there are a wide variety of digital lab, note-booking and contents online. Thankfully my students were able to get the laptops working very quickly. We had this standing club of students who were interested in technology and engineering and making with fun things to explore. We started to dive into robotics and Arduino micro-controller programming, 3D printing, modeling. That led to the idea of what would it look like if school was like this. We pitched the concept of a makerspace to a nearby school, grade 6 through 12, and I became a full-time makerspace teacher there, starting five years ago.

The school that I started the makerspace is in St. Louis. Since then, I have moved to Indianapolis where I am teaching at *Another* High School. It is a fantastic fit for me because it's essentially a makerspace blown up to the whole school. In St. Louis, I was doing design thinking with students and using the makerspace tools and materials to support the design thinking and building of prototypes and testing those. Here, makerspace and design thinking is the entire curriculum.

Baden

Making for me is meditation. When I'm working, I am just focusing on what I'm doing. It's like what dancers do when they dance or it's like what painters do when they paint, that they're lost in their world and it's sort of nirvana. It's like you are free. It sounds like you are working or you're dancing. It's just that even if your legs are going numb you're still going. It's a meditated escape for me, making. But if it's commercial then some of it is also very nice, but there's still that commercial mentality, "Okay. It's getting late, you've to finish it, you've to finish the job, somebody has to use it." When they're under constraints, although it's still interesting and challenging but it's not the same when you're making personally like an art form. So, making for me is different. It's an art also and then there is another making in which you're looking at it commercially for selling for people for other purposes.

I was making a gift for a friend and I didn't stitch it on a machine because I was running late for my flight and I was in the auto (3 wheeled Indian taxi cab). And then I had to do something because I had to give the thing to my friend. So, I did the last stitches with my hand. Those are things that my friend loves the most, because of the connection and the story behind it. It is something that I remember, and I think that matters a lot more than just the product and the tangible things. Those intangible things are very meaningful. That was one of the things that happened, and it was very interesting and worth remembering.

Chloe

I think I only started to feel like a maker when I had a space of my own. Then it was like, "This is something that I do, and therefore, I am making." Before that, it was just like, "I like to paint, I like to do design, but I like --" I would paint in my dad's basement and it

wasn't really my space though it's my dad's; he makes other stuff down there. I think in my head, I was in his makerspace as a designer. Once I got here, and kind of had my own space to control how the space works, to control how I interact with the space. Then it felt like, "Okay, now I'm a maker." Also, because I started working in the makerspace.

Gerardo

I consider the heart of progress, is making. We can design an iPhone but if I don't have an iPhone, I cannot call. I cannot sell. We need to make, that's my philosophy. We need to make. In my opinion, it's like *this*. We can design, but if this design is only in the conceptual side, or theoretical within a computer, we cannot transform the world. We can only transform the world when we have the product, and we can sell what we can use to do whatever we want. My philosophy is that we need to make. We need a physical-- Even a software, but we need an artifact. That's the only way.

Kandra

Being not only a maker within this makerspace but also *being* on the leadership team of *the pop-up Makerspaces, I really like* how this makerspace works for other people. At this point, the program that's dearest to my heart is our programming around students building or making solutions for homeless-- How to stop homelessness in the city of Indianapolis. I think, for me, that one really came out of a volunteer experience that I had. What triggered that, between that experience and then dealing with students, was that students were recognizing that their classmates were experiencing this. I volunteered at a family shelter a while back. One of the things that came out of that family shelter as I was dealing with students from kindergarten through sixth grade, for the most part, was that they didn't feel like everybody else. They didn't feel normal because they were like, “Well, I don't get to go to a house. This is where I come every day.” For them, that wasn't home because they shared that home with a lot of people. Even though they had their own apartment inside of a big building, it just wasn't. It wasn't their idea of home or their idea of what their peers had as home. In combination with that experience, and then dealing with kids that I worked with at the Boys and Girls Club, whom were in very different situations as far as what home meant to them, often you would hear them say, “Well, there's a kid in my class who

doesn't have a home." It was like these students in kindergarten through sixth grade were already recognizing the disparities in what home life meant for each of them. That really triggered me to start this initiative to allow students not only-- Who are going through it, a voice to contribute to solving the problem, but also students that were recognizing it a voice in that as well.

Layla

I started becoming involved in a charity in Dundee where I studied, and we were teaching people lots of different making skills which got me passionate about teaching people making for all the reasons like how people can be more resourceful, can make things out of waste, can see an object not as a broken thing but actually as a series of components which can be taken apart and either replace the broken component or you use the broken components to make something new. But then thanks to my involvement I kind of started seeing a broader impact of teaching people making, and that people feel more like problem solvers and they feel empowered therefore more likely to solve problems in their community. I might actually end up solving my physical problems but also social problems, I kind of take ownership of them, because then to think like "oh I fixed that thing that was broken, maybe I can help fix the problem that person has maybe I can help fix the problem that this person has our community has as well." That's really important to me, and so since then I have volunteered with the charity at Glasgow where they take people from any age group and people who have long time history of unemployment and addiction and they teach them carpentry and woodworking. They could take this skill, these people who have had horrible lives, they too could achieve something and that's what inspires me now. And so, I really like this idea of democratizing making.

Mario

Thinking back to my experience with designing, there was something which was not satisfying me. While I'm looking to satisfy the user, it was something which was not satisfied within me. Upon reflection and then upon talking to people, I found out that the objects which I create are nowhere close to the things which I usually find interesting

around me, which are usually either through unfamiliar use of material or through storytelling. My user was getting satisfied, but I was not getting satisfied. Making is more about personal satisfaction and designing is more about satisfying the person or the context you are designing for. *To step back,* in the bigger picture, my objects are serving not just the end user that will be using the furniture, but also the makers who are involve in making of the furniture. That's the meaning I would like to give through my objects. That's it.

Saaj

When I started thinking with the paper, the inspiration came from the paper. If I just see a pattern, immediately my brain starts imagining how this could be a good option to explore. I would come home, I would try it immediately on paper with initial draft cuts and see how it looks and then I can go ahead with it.

One of the artifacts that comes to mind is a quilling by a Russian artist. It's a phoenix actually. She had made it with paper quilling technique and that bird was converted into Google Chrome's theme. I think that's where I got introduced to this technique, paper quilling. I had replicated that quilling twice. I think that is one of my very favorite paper quilling. It is not as complicated as the ones later on, but I have that emotional attachment to that quilling. Yes, it was actually my first quilling project also, which also inspired me. It got me into paper craft so that's why I have that attachment to it.

Tanya

I've thought about *what making is* in a way that what I'm doing for a living, this designing, what is it really, does it translate into the impact I would want to have in the community and is it really the creative freedom that I want, because when you're working for a corporate , a big corporate like [big corporate name] where your brand guidelines and your style guideline are set in stone – they are there and so there's kind of – at the end of the day you are just pushing pixels around. So, when I think about it in context, like in the evening when I come back from work, there is an urge that I need to do something on my own. So that's where this maker really gets into action. Yeah, it kind of does play an important role – that is why I am working on my own illustrations and things which are not related to my work exactly just to keep that creative beat and the creative juices kind of flowing. Are the

maker and designer the same people, I would say no. They are two – at least in my case, the designer is a bit professional kind of financially a little sounder. The maker is the kid who relies on this designer to *say* like "give me some money Mom" kind of thing. The maker survives because this professional designer is taking care of her. That's what I feel at this point of time. I could be wrong, hopefully the tables will turn some day and I will be like a full-fledged maker, making a living out of it.

Shaan

Making to me is a very conscious effort in a very simple word, conscious effort of making the quality of life better, whether it's for me or for anyone else. It all comes down to how do you, how does anything lead to contentment and happiness. So, for me maybe money might not be the very big thing but seeing a kid smile making an airplane is far more important to me. So, it comes down to increasing the quality of life of people by being part of their life, or by being associated with them. That's making to me. I don't want it to be done in isolation. If it doesn't include other people then it's worthless or it's not, it's useless yes. ... Yes, so for me tinkering is more of a frugal approach. It's more of a way, you see the world and you want to change it and design is still a very glossy word, like not for me but for how it appears on the outside. So, design is still a very glossy word in which we see, we imagine these people who are sitting in these nice rooms and doing things and all, but that's not always the real case.

In the above narratives we see the several different meanings that Making carries for my participants. As they explain what Making means to them, some of them compare and contrast it against design. For Aaron, who has been a Maker his entire life and is a teacher, Making and Makerspaces help him bring together both these passions. Baden considers Making to be a meditative experience in which he is lost in his own world and he Makes to make heartfelt gestures to people. For Chloe, Making is about having a space to Make things. Gerardo believes that it is only through Making that we can transform the world. For Kandra, educational Making is a way to support underserved communities. Layla fights against consumerism and helps people with histories of unemployment and addiction via Making. Mario, a professional designer, realized that by designing he was satisfying others,

but needed to Make to satisfy himself. Saaj's Making is inspired by his inspiration from the medium of paper. Tanya, also a professional designer, believes that where design is a profession, she Makes for herself. Finally, for Shaan, Making is a conscious effort to make life better for himself and others, and Making is frugal whereas design as a word comes across as more glossy at times. These narratives are evidence for all my participants seeing different but rich personal meanings in Making. It is also evidence for Making being a practice via which individuals realize purposes that are personal to them.

The answer to the research question I discuss in this section, "What does Making mean to my participants" serves as culmination to a thread of evidences that we have now seen through the several narratives I present in this study. The deviation of certain narratives from substantiating Making as unintended design, particularly those in response to the goal of practice aspect, in answering RQ1, my participants understanding Making and design differently in RQ2, and their rich and compelling accounts of what Making means to them in RQ3, all point toward my participants Making to realize purposes that are personally meaningful to them.

Beyond answering the research questions and proving significant similarities between design and Making to make a case for the epistemological significance of Making, this unintended but very important theme of realizing purpose via Making forms the crux of this paper. Making provides the participants venues to realize purposes that are personally meaningful to them. In the previous paper, we had learned that the purpose behind a Makerspaces defines how people, means, or activities focused it is. In this study we learn that people use Making to meet several different types of purposes that are personally meaningful to them. Such as Aaron and Layla's teaching and workshops being activities-focused, Mario and Saaj's Making being focused on the materials and tools, and Baden and Tanya's practice being focused on the people they Maker for or themselves. This finding aligns with Schrock's (2014) claim of Making being an activity that challenges scientific rationality and aligns better with a felt experience that represents the Makers' emergent and fluid identities, informed by their lived experiences. In a recent study by Barton, Tan, & Greenberg (2017) they too found that Makers give meaning to their Maker

practices depending on their contexts, and figure out their identities from within the experiences they find themselves in. Within my dissertation, in the previous paper I propose that Makerspaces serve as sites to meet purposes that can be characterized as situated between people, means, and activities. In this paper, I conclude that in addition to the similarities between design and Making, as a practice Making provides people a venue to realize their personal purposes.

Conclusion

This research study uses narrative inquiry as a method to understand how Makers practice human-centered design and designerly ways of Knowing by analyzing narratives of ten people who identify themselves as Makers. The similarities between the practice and ways of knowing of Makers and designers make a case for the epistemological legitimacy of Making. In addition to the similarities, the thread of realizing purpose and personal meaning across the participants' narratives, call for further exploring them as constructs in educational Makerspaces and other similar spaces.

The conceptual framework for unintended design in Makerspaces, the compelling narratives of individual Makers making sense of their practice and differentiating it from design, and the thread of realizing purpose which runs through each of the participants' narratives, are some of the contributions of this study. The framework for unintended design in educational Makerspaces and the associated interview-protocol prove to be promising tools to understand the unintended design practices and knowledge of people who identify as Makers. The framework and protocol can be used to understand knowledge and practice in Makerspaces and similar informal educational settings. The insights gathered about the practice of Making and the ways of knowing of Makers from the first research question, as human-centered design and designerly ways of knowing, help situate learning and development in Makerspaces within the epistemology of design. The narratives of the participants and their analysis prove the congruencies between Making and design education, thus making a case for the epistemological legitimacy of Making

akin to design. Further, the narratives of the participants depict rich examples of Makers practicing design and knowing designerly ways, in alignment with their purposes to Make.

Where the first research question, helps understand the similarities between design and Making, the second and third research questions which evolved while conducting the research study, shed light on how even though similar, how design and Making are different, and also on a characteristic that sets Making apart, which is realizing individual purposes. Makers Make and continue Making because they see Making as a way to realize their purposes. This not only challenges the status quo where Makerspaces are being used as venues for design education, but also suggests how the constructs of purposes and personal meaning which are known to accentuate learning, are prevalent in the practice of Making. In the next paper, I utilize this relationship between Making, purpose and personal meaning, to understand how Maker identities can be developed using reflective practice.

PAPER 3: THE ROLE OF REFLECTION IN STUDENTS' CONCEPTION AND DEVELOPMENT OF MAKER IDENTITIES

Introduction

The educational potential of Makerspaces has led to investments and resources being directed to schools and libraries (Abram, 2013; Delaney, 2015; Dougherty, 2012; Maker Media, 2012, 2013; The British Council), educational research (Bilkstein & Krannich, 2013; Dale Dougherty, 2012; Halverson & Sheridan, 2014; Meehan et al., 2014; K. Peppler et al., 2015; Sheridan et al., 2014), and community spaces (Dougherty, 2012; Gunby, 2015; Makerspace North, 2014; Makespace Madrid; Mathilde, 2015). The evidence for the efficacy of such spaces for learning has yet to be substantiated. Thus, this study aims to understand how reflective practice can be used as both a tool for researchers to understand a Maker's identity development, as well as a pedagogical approach to help student Makers construct personally meaningful connections in support of their learning. Insights from this research could provide evidence for the benefits of Making in formal and informal learning environments, and also elucidate ways to individualize learning in Makerspaces and similar environments. This empirical work is informed by Ibarra's theory of "provisional selves" (1999), which proposes a model for identity development via a process of provisionally experimenting with the identity that is to be developed. The implications for this study support the pursuit of Makerspaces as learning environments where students engage in personally meaningful projects for learning and development.

This study follows the excitement of the Maker revolution and its movement into educational settings. Until recently, Makerspaces had been confined to communities of "makers," "hackers" and other communities interested in the Do-It-Yourself (DIY) culture (Dougherty, 2012). The idea, however, has transcended into the space of education and has created a gap between the exciting potential of these informal spaces and actual learning outcomes (Blikstein & Krannich, 2013). Further, there has been particular interest in the educational potential of Makerspaces from the field of engineering and engineering

education (Bevan et al., 2015; Bilkstein & Krannich, 2013; Bowler, 2014; Halverson & Sheridan, 2014; K. Peppler et al., 2015; Vossoughi et al., 2016). Some of this potential relates to how project-based (Solomon, 2003) and experiential learning (Kolb, 2014) approaches present themselves in Makerspace environments. Both these forms of learning can be seen in Makerspaces as Makers work on different projects, which invokes rich personal and communal experiences in them. Makerspace projects also tap into the powerful role interests play in learning and development (Renninger, Hidi, & Krapp, 1992).

Papers 1 and 2 of this dissertation, demonstrated that Making activities are context-dependent, and personal engagement and meaning play a vital role in drawing people to engage with Making. This knowledge in addition to prior opinion pieces about the contextual (Barniskis, 2014) and individually motivated (Durham, 2015; D. L. Rendina, 2015) nature of learning in Makerspaces, present Makerspaces as environments that can be used to make education personally meaningful and communally relevant. This paper explores how Makerspaces, which are all contextually different and driven by human agency, can be used as sites for learning and development. An important element of professional learning, especially engineering, is professional formation (National Science Foundation) which is closely tied to engineers' identity development (K. L. Meyers, Ohland, Pawley, Silliman, & Smith, 2012; K. Meyers, Ohland, Pawley, & Christopherson, 2010). With this study, I explore the individualized nature of Making and the role of reflection in the development of Maker identities.

The Maker movement can now be seen at venues such as schools, community spaces, exhibits at museums, libraries, and other spaces espousing the DIY culture. Depending on the purpose of such settings, they can be considered people-focused, means-focused, or activities-focused, as I detail in the previous chapter. The individual-defined nature of activities in Makerspaces make them opportune spaces for enacting practices for individualized learning. Maker initiatives though educational, currently rely on their implicit educational value. In Paper 1, I reviewed other pertinent literature related to

Makerspaces and education. I also explained the presence of the Maker movement by characterizing it into the three unifying themes of people, means, and activities.

Literature Review

The role of reflective practice in learning has been studied in engineering education settings. Adams, Turns and Atman (2003) investigated the role of reflective practice in educating engineering designers. They measured reflective behavior by both, the breadth of the problem area and the number of design criteria considered and observed. They found that seniors do better than freshmen in these areas and also transition between the tasks more effectively through the timeline of working on the project. Reflective activities in similar project-based engineering learning settings have also shown to support students in being able to understand key principles that lead to effective teamwork by Hirsch and McKenna (2008). They report that when reflecting, students are able to abstract principles of effective teamwork from their work, and these principles are similar to those reported by successful teams in the engineering industry. Though they often do not use the same language, they "understand the value of having a shared goal and high-performance standards, communicating effectively and drawing on team members' diverse strengths" (p. 377). Turns, Sattler, Yasuhara, & Borgford-Parnell (2014) propose a framing to think about the elements of reflection. This framing comprises the elements of experience, lens, meaning, action, intentional, and dialectical. The curricular framework I adopt in this study has several similarities with their framework. However, one of the differentiating factors is that the students in my study have greater autonomy as they redefine the skills they reflect on and pick their own problems to solve, which affords a more democratic learning setting. This will become clearer when I explain the instructional design of the research settings. Thus, reflective practice has been adopted in several other engineering and design education settings.

Reflective practice coaxes the learner to be at the center of their education, which aids them in building upon their prior experiences in alignment with their interests, hopes, and aspirations.

> Students have different levels of motivation, different attitudes about teaching and learning, and different responses to specific classroom environments and instructional practices. The more thoroughly instructors understand the differences, the better chance they have of meeting the diverse learning needs of all of their students. (Felder & Brent, 2005, p. 57)

The above quote from Felder & Brent further makes a case for the need for individualized educational practices as the students in our classrooms are not the same. For instructors to meet their students where they are at, reflective practice has proved to be helpful. As I highlight in Paper 1, the theory of situated cognition can be used to understand how authentic learning settings and projects like the one often undertaken in Makerspaces and in this study, have a positive effect on students' engagement. This connection between authentic learning and the central role that contexts play in learning, Johri & Olds (2011) suggest, is one of the areas that can subsequently act as a bridge between engineering education and work in the learning sciences. Another model of education similar to Makerspaces is the model of cooperative education. Haddara & Skanes (2007) traced the development of cooperative education in North America and recommended reinventing cooperative education to demonstrate its experiential learning and value, going beyond reporting on accrued benefits to students, employers, and institutions. Their recommendations for this reinventing include the adoption of reflective practice for students to make meaning of their experiences beyond the classrooms. They recommend mechanisms to allow students to utilize their experiences from their work terms as experiences to reflect upon in order to learn from their experiences. This invoking of experiences from outside of the classroom is similar to the instructional design I developed for this study which uses reflective practice.

A unifying thread through reflective practice and individualized learning experiences is the need to promote the autonomy of students in their learning. Traditional pedagogies that adopt the "Chalk and talk" or lecture-based models do not factor in this importance of student autonomy in learning (Mills & Treagust, 2003). Problem-based learning as a pedagogical practice is being looked at as an answer to the traditional "Chalk and talk"

pedagogy. It is looked at as a way to satisfy industry needs and at the same time ensure engineering content to be delivered and learned in learning setting. Mills & Treagust suggests that implementation of such pedagogies in undergraduate engineering curriculums should include the adoption of the pedagogy in traditional courses and increase the complexity and student autonomy in problem-based setting into the senior years. Amongst other tools, in engineering education portfolios are being considered as tools to track, understand and map students' learning to educational outcomes (Matt Eliot & Turns, 2011; Williams, 2002). A similar approach has also made its way to online-models for formative assessment. Bull, Quigley, & Mabbott (2006) developed and tested a computer-based model for formative assessment and promoting reflection and autonomy of the learners. They designed the computer model with the aim of students to be able to identify their knowledge, the difficulties, and misconception they become aware of and engage with the course, their peers, and the instructor. They found that the students did in fact frequently use the model and compared their levels of knowledge with their peers and the expectations of their instructors. Promoting and harnessing student autonomy in the learning process via reflective practice also form the basis of several of the strategies suggested by Woods, Felder, Rugarcia, & Stice (2000) to develop critical skills amongst engineering students. Some of these include, "Identify the skills you wish your students to develop and communicate their importance to the students; make explicit the implicit behavior associated with the successful application of the skills; provide prompt constructive feedback on the students' efforts; encourage reflection; and grade the process, not just the product" (p. 4). The instructional design I developed for this study is also aligned with these strategies.

In the context of Makerspaces, there is need for work to understand how people truly learn in the spaces and how their learning can be accentuated. Morocz et al. (2015) conducted a study to characterize the different user and non-users in a Makerspace on the bases of their engineering design self-efficacy. They found that students with higher participation exhibit more motivation to participate in design tasks. They concluded with the crucial role that institutions and introductory design courses can play in developing students' design self-efficacies by promoting Makerspaces. This study further strengthens the claim to

understand and benefit from educational Makerspaces. The richness of self-reported data of Maker-related educational initiatives in a study by the Maker Ed Open Portfolio Project (K. Peppler et al., 2015) strengthens the promise of employing self-regulated learning practices such as reflection in educational Makerspaces.

Conceptual Framework

The central framework adopted for this study is the theory of provisional selves (Ibarra, 1999). As per Ibarra, people develop identities via a three-step model: 1) understanding and identifying different characteristics of the identity in focus; 2) experimenting with this identity by taking on the role of a provisional self; 3) evaluating steps 1 and 2 and developing an identity if they are in commensuration. Figure 11 is a representation of this model. For this theory to be realized in a research setting, participants need first to be made aware of characteristics of the identity that they seek to develop, then have an opportunity to practice their provisional identities, and finally have a space to evaluate the connections between their conceptions of the identity from step 1 and the identity they lived provisionally in step 2.

Ibarra's theory of provisional sells has been previously used in engineering education research. Cech, Rubineau, Silbey, & Seron (2011) found that a major contributor to more men staying in engineering careers as compared to women is the lack of confidence amongst women as compared to men to foresee themselves in engineering roles. This foreseeing and lack of alignment between understanding what engineers do and what they see themselves do is an application of Ibarra's model. Similarly, Dehing, Jochems, & Baartman (2013) studied the mechanisms of engineering identity development during workplace learning. They tested two models of identity development, namely the mentoring or alignment model (Sheppard, Macatangay, Colby, & Sullivan, 2008; Sullivan, 2004), and Ibarra's theory of provisional selves (1999). They found that the students developing in accordance with Ibarra's theory showed significantly more growth of their professional identities. The participants of this study were 216 third-year bachelor student engineers. Dehing et al. (2013) analyzed how engineering students' professional identities are developed during workplace learning. They reported that students' capabilities to

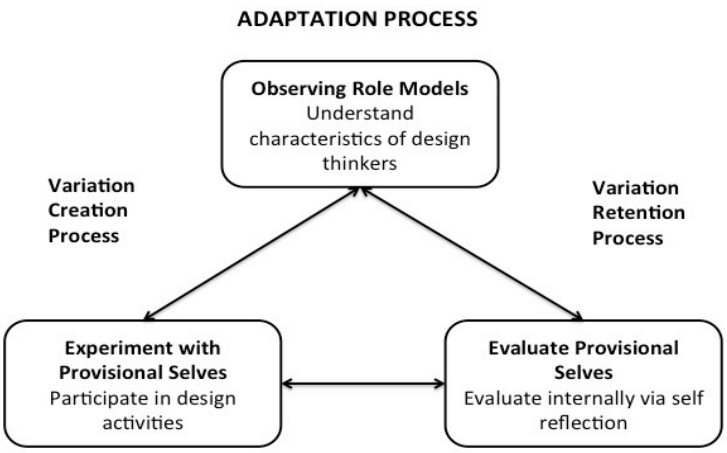
clearly identify their future professional roles play a positive role in professional identity development. They recommend "that students professional identity development should be acknowledged and explicated in the course design, so it gets greater and explicate attention during the preparation, during workplace learning, and in the final year. For this purpose, a system of career conversations could be used" (p. 42). Thus, a model which enables students to envision their future selves and particularly Ibarra's theory has shown great promise in students developing and realizing their professional identities.

I use Hatch's Maker manifesto (2014) to define characteristics of a Maker identity. As per Hatch's framework Making comprises of different aspects: make, share, give, learn, tool-up, play, participate, support, and change. At the time of conducting this study, Hatch's manifesto was the only document with contributions similar to engineering habits of mind, that provided a framework with skills/attributes for learners to reflect on.

I use Hatch's characterization of these aspects as a framework to understand and further explore what it means to Make. Students reflect upon each of these aspects after their Maker experiences and present how they connect with the aspects and what they mean to them. This characterization and introducing students to aspects of being a Maker serve as the basis and the first step of Ibarra's model. The instructional design of the course and the engineering workshop in the next chapter provide students opportunities to experiment with the identities, which is step 2 of Ibarra's model.

To ground the third step of Ibarra's model, which is evaluating steps 1 and 2 and developing an identity if they are in commensuration, I draw from Schön's theory of reflection in and on action (Schön, 1983). His theory of reflection on action can be used to understand the practice of thinking back to a critical moment to make meaning of it. He writes, "[w]e reflect on action, thinking back on what we have done in order to discover how our knowing-in-action may have contributed to an unexpected outcome" (Schön, 1983, p. 26). Following Ibarra's framework, if the students are able to evaluate the connection positively, it leads to positive identity formation. Thus, this framework is realized by individuals first acquainting themselves with role models, skills and attributes of the identity they seek to

develop, then living that identity as provisional selves, and finally assessing if what they learned about the identity in step 1 and what they experienced in step 2 align with each other. To assess this alignment between steps 1 and 2, they reflect on their experiences and actions. By this process, individuals learn and develop the skills and attributes that constitute the identity they aspire to develop.



Adapted from: Ibarra, H. (1999). Provisional selves: Experimenting with image and identity in professional adaptation. *Administrative Science Quarterly*, *44*(4), 764–791.

Figure 11: Adaptation of Ibarra's theory of provisional selves (Hira & Hynes, 2016).

Research Methodology

Methodology

For this study, I employ the methodology of narrative inquiry. Narrative inquiry as a methodology is understood as an umbrella methodology to understand the human experience (B. Smith, 2007). As a methodology posed to understand the human condition which is continually emergent as humans actively make meaning of their experiences (McAdams, 2006; McLeod, 2006; Polkinghorne, 1995; Riessman, 1993; C. Smith, 2000), the methodology accommodates methods and techniques which support understanding these experiences. Another perspective offered on the meaning-making by humans which

is inherent to the methodology is of narrative inquiry eliciting the back stories that inform the narratives recorded for research. From Bourdieu's (Bourdieu, 1977) perspective of habitus, these narratives being studied are understood as embodiments of the participants' habitus. The change and resistance to change of the habitus which informs the participants' predispositions can be studied to understand how people change as they make new meanings for themselves (B. Smith, 2007).

Narrative inquiry has been intimately connected with education. It is claimed (Case & Light, 2011) to have a basis in Dewey's (Dewey, 1938) work relating experience and education, which has led to its widespread adoption in educational research. Additionally, Bruner, also an educational theorist, wrote about (1986) "narrative cognition" as a fundamental human activity via which humans make sense of and represent their lives to others. This conception of narratives presenting the truth of individuals is the traditional cognitive approach to understanding the meaning behind narratives (Gergen, 1994). This conception, however, has evolved and now also takes into consideration the culture or the plot in which the narratives are situated as an important aspect of the nature of knowledge being studied (Kellam et al., 2015; Polkinghorne, 1995). As Polkinghorne writes, "*narrative* refers to a discourse form in which events and happenings are configured into a temporal unity by means of a plot" (p. 5). In my study, I seek to understand both, the truth of the individuals and the culture and the plot of their educational experiences which they uncover by their realities.

I choose this methodology as it is in line with the core inquiry question of narrative inquiry as articulated by Patton (2014) "how can this narrative (story) be interpreted to understand and illuminate the life and culture that created it? What does this narrative or story reveal about the person and world from which it came?" I seek to understand the experiences of the participants as they go through the experience developing their Maker identities. For this inquiry, I conduct analysis of narratives as described by Polkinghome (1995), in which the analysis includes identifying common themes from different narratives as they relate to the inquiry. Hinchman & Hinchman (1997) define narratives as "discourses with a clear sequential order that connect events in a meaningful way for a definite audience, and thus

offer insights about the world and/or people's experiences of it". For this study, I seek to connect experiences of students in Makerspaces, to offer insight for designing future educational Makerspace interventions. In the previous study, I employ narrative analysis in addition to analysis of narratives, which is another type of narrative inquiry, and synthesizes events and presents a story that explains the experiences being studied.

Previously, Winberg (2008) has employed narrative inquiry to study professionals' academic identities as they completed a Master's degree in Engineering Education. An interesting and relevant finding from this study is that even identities within the same discipline of engineering are flexible, have multiple layers, and are susceptible to change at varying degrees. Jorgenson (2002) conducted a study aimed at understanding how women engineers negotiate their professional identities. In this study, Jorgenson observed that the participants employed different and at times contradictory positions to negotiate their identities in their narratives. Further, Case & Light (2011) cited methodologically similar work being conducted in the field of engineering education situated around engineering identity. The similarity of this prior work to the aims of my study make narrative inquiry a worthy choice for my methodological approach.

Method

Within the methodology of narrative inquiry, three methods are commonly used, namely, thematic, structural, and constructed narrative analysis. Thematic and structural narrative analysis are well suited for analysis of narratives, and constructed narrative analysis is well suited for narrative analysis (Polkinghorne, 1995; Riessman, 1993). For thematic analysis, prior theories and frameworks inform the analysis of the narratives. The analysis aims to identify themes within particular cases, which answer the research questions. In this paper, to understand how students develop their Maker identities and the role of reflective practice in realizing their Maker identities, I conduct a thematic analysis of the participants' narratives using the conceptual framework informed by Ibarra's theory of provisional selves (1999) and reflection on action (Schön, 1983).

Positionality

In most qualitative research projects, the positionality of the researcher plays an important role in the motivation behind the research. The motivation behind the research, the way the study is conducted, the relationship between the participants and the researchers, and the implications of the work, all are impacted by the researcher's positionality. A close relationship between the researcher and the participants is an important characteristic of narrative inquiry work (Clandinin, 2006), and writing of the research is often understood as not as much as retelling of their participants' stories, but restory-ing them from their positionality.

In the spring of 2016, I was a co-instructor for a study abroad course, "Makers in cross-cultural perspective: Geeks, Artisans and Inventors in Spain and Morocco." The reflective exercises that comprise the data of this research were a part of the course deliverables. Through the process of data collection, I maneuvered the multiple roles of an instructor, researcher, and Maker myself. Given these various roles, I elaborate on each one to declare my positionality for this study.

Instructor

I was a part of designing the curriculum of the course. This included deciding the outcomes, content, and assessment for the class. With this being a very new area for teaching and learning, I found myself and my co-instructors creating learning outcomes not necessarily informed by prior existing educational outcomes or assessment. Legitimizing what we taught the students, to the students, and also to my co-instructors required high levels of openness and authenticity from us.

Researcher

The most prominent challenge I faced under this role was to not bias the instruction of the course from what I wanted to research. Keeping a journal where I documented all my

decisions and going over it periodically helped with this challenge. I also exercised a high level of honesty and intentionality within my research analysis and took particular care to not influence the students' conceptions with ours.

Maker

I have designed and facilitated summer engineering camp activities for middle school and high school students, and faculty development workshops focused on Makerspaces and education. My positionality and agenda are defined by my belief in the power of Makerspace like environments to broaden the reach of education, particularly engineering education in informal environments.

Context and participants.

The participants were undergraduate students enrolled in a semester-long course called "Makers in cross-cultural perspective: Geeks, Artisans and Inventors in Spain and Morocco." They met once a week in a Makerspace throughout the Spring semester and traveled through Spain and Morocco for ten days during Spring break. We designed the course to provide the students with experiences to expand their understanding of Making. As part of the course project, the students were asked to Make something representative of their culture to take with them on the study abroad experience. The students worked in teams of four that we assisted in randomly choosing, and they decided, as a team, the culture they wanted to represent via their artifact. The total class strength was 20 students. Of the ten consenting participants, all were freshmen engineering students, of which six were female, and four were male.

They had access to the Makerspace on campus to work on their artifacts and were permitted to buy $75 worth of supplies from the course-funds. When in Spain and Morocco, they used their artifact to mediate conversations with primary school students (English speaking students of the American School of Tangier, and Arabic speaking students of a local

primary school in Ifrane), and Makers in a University Makerspace at the FabLab in the College of Architecture in Seville.

Alignment between instructional design and the conceptual framework

We designed the course on the basis of Ibarra's theory, which translates into 1) students understanding the different aspects of Making (via case studies and discussions), 2) participating in Maker projects to experiment with their provisional selves, and 3) evaluating by reflecting on their provisional selves against their initial understanding of Makers. The students got opportunities to exercise their provisional selves as part of the course in which this study is situated. After being their provisional selves, the students reflect on the connections between who they thought Makers were and if they were Makers while being their provisional selves. Figure 12 is a representation of the alignment between the instructional design and conceptual framework. Students observe and understand the Maker identity through curricular activities such as class discussions, watching videos, reading the Maker Manifesto, and meeting other Makers. They then experiment with their provisional Maker identities as they Make in the Makerspace and travel owning their identities as Makers. In these two steps, the students reflect both in and on action. Finally, they work on the final deliverable for the course and reflect on their past actions and experiences to evaluate if they developed a Maker identity.

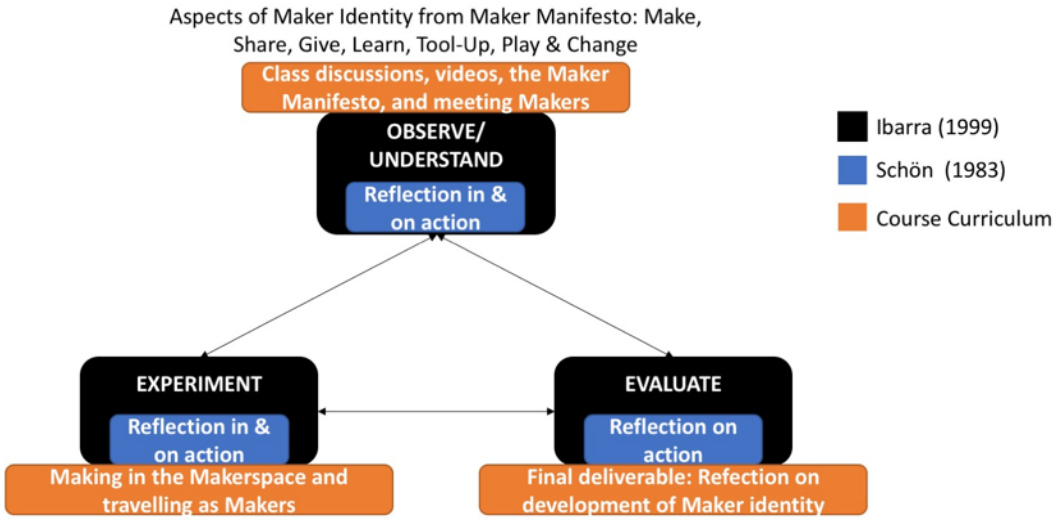


Figure 12: Representation of the alignment between the instructional design and conceptual framework.

Research questions

The research questions were:

RQ1: Do students' conceptions of the different aspects of Making: "make, share, give, learn, tool-up, play, participate, support, and change" differ?

RQ2: How do students conceive their maker identities following Ibarra's theory of provisional selves?

RQ3: What are some of the common themes that play a role in students' realization of their Maker identities as they reflect on their experiences?

Systematically, these three research questions help us (1) understand the individualized nature of students' conceptions of Making; (2) understand the mechanisms students adopt to realize Ibarra's framework for positive Maker identity development; and (3) explore the themes that are prominent in students' recollection of and reflection on their experiences during the Maker course.

Data Sources and analysis

The students were asked to reflect on their experiences through the course, and think about how they developed their Maker (Hatch, 2014) identities. This was informed by Ibarra's theory of "provisional selves" (1999), as students experimented with their provisional selves as Makers through the course, and then reflected on the development of their Maker identity, as the last step of Ibarra's theory. The students were instructed to reflect on the development of their Maker identities in writing. Some students also submitted videos of their reflections. Before this, students also documented their conceptions of the different aspects of Making (make, share, give, learn, tool-up, play, participate, support, and change), and co-constructed meanings for each of the aspects. The reflection prompt that was communicated to the students is appended to this chapter as Appendix B.

In the following section on findings and discussions, I will explain the methods used to answer the research questions in detail. However, concisely, I conducted a thematic analysis of the collected narratives to answer each of the research questions. To conduct the thematic analysis I read through the data several times and developed codes using Nvivo. The codes were informed by the framework to answer each of the research questions. After multiple passes of the data, I consolidated the codes into major themes, which I report in the discussions to follow. I report the themes in the following sections along with narratives and other supporting contextual data. I include direct quotes, where applicable, to ensure goodness and trustworthiness of the analysis. I also report on the goodness and trustworthiness of all three studies in detail in the summary chapter of the dissertation.

Findings and Discussions

The three research questions were:

> RQ1: Do students' conceptions of the different aspects of Making: "make, share, give, learn, tool-up, play, participate, support, and change" (Hatch, 2014) differ?

RQ2: How do students conceive their maker identities following Ibarra's theory of provisional selves (Ibarra, 1999)?

RQ3: What are some of the common themes that play a role in students' realization of their Maker identities as they reflect on their experiences?

I answer these questions in the following text in subsections titled, *multiplicity of meaning*, *from provisional selves to identity formation*, and *other themes for the development of Maker identity*, respectively.

For RQ1 in the section on *multiplicity of meaning*, my data comprises primarily of pictures from a class discussion in which students shared their conceptions of the different aspects of the Maker identity (Hatch, 2014). For RQ 2 in the section titled *from provisional selves to identity formation*, and to answer RQ3 in the section of *other themes for the development of Maker identity*, I use the students' written reflections which were the final deliverable for the class as data. In this 5-page long written reflection students provided evidence from their experiences during the course to substantiate on how they had developed different aspects of the Maker identity, and also their Maker identities as a whole. This final reflective writing can be considered as a written narrative in response to an open-ended prompt, on which I conduct an analysis of narratives.

RQ1: Multiplicity of meaning

In this section, I focus my discussions on answering the first research question:

RQ1: Do students' conceptions of the different aspects of Making differ?

To answer this question, I analyzed the students' responses to a class activity in which they shared their conceptions of the different aspects of the Maker identity (Hatch, 2014) multiple times and consulted their written end-of-course reflections when relevant. Instead of themes emerging from the data, I realized that the data presented itself in a theme which represented the *multiplicity of meaning*s of the different aspects of Making among the students. These aspects being make, share, learn, give, tool-up, play, participate, support

and change. The students' conception of the different aspects of Making differed considerably, even though the consenting students were all enrolled in the Freshmen year of their engineering degrees at the same university and had self-selected themselves into enrolling in this Maker course. The students' differing conceptions of these aspects of Making illuminates the need for individualizing educational practices for students with different starting points.

When I introduced the different aspects of Making from Hatch's work, the students in the class read a brief description of each of the aspects from the manifesto. The students were then asked to populate posters with their conception of each of the aspects. Figure 13 shows the pictures of these posters and Table 8 shows the transcriptions of the text from the posters. The students' responses on the posters exhibit that even after reading the same preliminary text describing each of the aspects, the students have multiple conceptions of their meanings.

Figure 13: Students' conceptions of different aspects of Making. Pictures of the posters from the class activity.

Table 8: Students' conceptions of different aspects of Making. Transcriptions from the pictures of the posters.

Make	**Share**
Physically crating something Just do it Encompasses all aspects of design, creativity engineering, craft, art, and ingenuity Anything you want Doesn't have to start big	When you get to show off See others' ideas Teaching others how to make something Defend your turf We make to share The pixels matter – all pixels matter Sharing = caring
Give	**Learn**
We are given making-talent to better the lives of those around us Provide what we make to satisfy the need Other will appreciate your effort Helping others Engineers without borders Making things that give back to the community Making the world a better place Giving others to opportunity to create	Learning new skills to make and create new things Learning about maker cultures in other countries So you can make more useful things New idea Active learning More resources Learning and teaching Variety Learn what you want to learn Using others to help your learning Actively seeking new knowledge and acquiring new knowledge through making

Table 8 continued

Tool-up	**Play**
Creating things with the tools you have Purdue provides a lot of tools for Making Duck tape! [drawing of a hammer] Power tools Ingenuity Accessibility Without the tools you can still make something Person behind the tools – necessary skill important Sophisticated tools and well equipped Makerspace attracts diverse group of Makers Participate We are participating in the Maker movement in this class Going to "Make"athons (do they exist?) Getting involved Encouraging others Passion! Online communication Helping others Make	Have fun with the making that you do Doing what you love Don't be afraid to challenge yourself Fun Enjoy Playground More fun/laughter = More Productivity Think outside the Box Building is a form of play Support We got the funding from Purdue ^We want more $$ Please ☹ Do it for the fun Appreciating everyone else's ideas Make resources more available Helping others and receiving help Opening up lab spaces so everyone has access to them
Change	
Doing by myself and do adjustment Doing something new Changing our ideas and perspectives of making and of other cultures Go OUT of the box Let your ideas escape yourself	

The breadth of responses to their conceptions of aspects of a Maker represents how students understand these aspects in a variety of ways. It is also worth mentioning that the aspects are words used in common parlance and are not part of any specialized vocabulary. Where some students understand the aspect of share as teaching others to make something, others think of it as sharing their finished products. On the aspect of give, some students acknowledged the talents they were given, and others assume the responsibility of giving to others. For some students, the aspect of learn is curtailed to new skills, and others mention learning about new cultures. On tool-up, some of the students write about how it is important to have sophisticated tools, and others write about how the person working the

tools and ingenuity are more important. Some understand participate as participating themselves, and others consider making others participate as an important component of participating. For change, some students write about doing something new, and others write about changing their perspectives.

This diversity of meanings that students associate to each of the aspects forwards the case of the importance of acknowledging students' different conceptions while learning in Maker environments. This also aligns with the widely-stated need for instructors to understand the differences between their students, which in the past has been attributed to "different levels of motivation, different attitudes about teaching and learning, and different responses to specific classroom environments and instructional practices" (Felder & Brent, 2005, p. 57). Opportunely, Making can cater to several interest and motivations, rendering Makerspaces as promising sites for learning while catering to differences across students. Pedagogically, facilitating learning in open-ended problem-based learning environments like Makerspaces presents itself as a healthy alternative to the age-old "chalk and talk" models (Mills & Treagust, 2003). In the next sections, I elucidate on how my participants developed their individual Maker identities, informed by their interests and motivations, as they engage with the course activities developed in alignment with Ibarra's theory.

RQ2: From provisional selves to identity formation

In this section I focus on answering my second research question:

RQ2: How do students conceive their maker identities following Ibarra's theory of provisional selves?

To answer this research question, I analyzed the students' end of course reflections multiple times and my field notes from our trip to Spain and Morocco and other classroom activities. I used the qualitative coding software Nvivo to keep track of the students' narratives, identify, compare and merge themes. Upon analyzing their narratives in conjunction with their individual stories and backgrounds, three themes for how the students develop their

Maker identities emerged: (1) from foreign to personal; (2) I'm a Maker, I just never noticed; and (3) my Maker identity will remain evolving. All three themes provide evidence for how this course designed on Ibarra's theory of provisional selves resulted in all the participants developing their Maker identities.

From foreign to personal

This theme explores narratives of students for whom Making and/or a Maker identity was a foreign concept that they could not relate with prior to the course, but form conceptions of their own Maker identities after the course.

As someone who knew little about Making before the course, Sofia writes,

> Over the course of this past semester, I was able to see what the nine aspects of the Maker identity were and what they mean to me. During the second class period when I talked about the Maker Manifesto, I had never thought about what a maker was or what makes up a 'maker', now after about ten weeks of learning about making and makers, it is easy for me to read the Maker Manifesto and understand why each of the nine aspects are important.

Further conceptualizing her own Maker identity, she writes,

> I am a maker because I am passionate about making the world a better place to live. I am a maker because I love giving and sharing the things that I bake, design, and create with others. I am a maker because I am a lifelong learner. I am a maker because I want to change the world.

Before the course, Mary did not relate to the stereotypical characteristics of Making. She writes,

> When I came upon the idea of a "Maker Identity" it seemed to add to that list of expectations that already burdened my shoulders. I had never been the person to "make" things, certainly not in terms of the trinkets, machines and 3D-printed designs I had pictured in my head to define who a "Maker" was. Trying to find my

> maker identity was a foreign concept- especially when I didn't identify as a "Maker" to begin with."

Towards the end of her reflection, she writes about how she identifies as a Maker now,

> I am a Maker when I cook. I am a Maker when I craft or knit. I am a Maker when I engineer. I am a Maker when I help people. My Maker Identity continues to form from success and failure, from setbacks and progress and it will continue to Change, but only from Change will it become the best it can be.

For Kaitlyn, the activities of the course helped her embrace her cultural identity under the purview of a Maker identity. She writes,

> For me, this trip acted as one of the milestones of my life in terms of change. This change is very personal to me. Prior to this trip, as a Chinese girl who has spent the majority of her life in an English speaking world, I never tried to embrace my own culture … Through the entire duration of my maker trip, I was making something big. I was making a video, a memory, an artifact—my recordings on my GoPro will eventually be compiled into something I plan to make."

She ended up using Making as mechanism to initiate and experience this change in her identity.

Sofia knew little about Making, Mary didn't associate with Making, and Kaitlyn began to make more sense of her cultural identity via her Maker identity. The common rhetoric through these narratives is of the re-conceptualization of the foreign concept of Making and connecting with it personally. Sofia relates to Making as a way of changing the world, Mary sees herself Making in other activities, and Kaitlyn situates her cultural identity in Making. These narratives show how curriculum and instruction informed by Ibarra's theory supported these students in understanding a concept which they considered foreign, and also develop their conceptions of their Maker identities. The course supported them in being able to understand Makers beyond a stereotypical type, experiencing being Makers themselves, and finally realizing how they too had been Making and situating being a Maker within their individual identities.

I'm a Maker, I just never noticed

The next theme is of positive Maker identity formation when participants realize that they had been Making since much before their enrollment in the course.

Emma writes,

> All in all, the course taught me a lot about making, my maker identity, and myself as a person. I've learned to look deeper into the little things that I do each day, as I'm probably making a lot more that I've ever thought about … I can now say that I am a Maker. But I believe that I always have been one, I just didn't understand what it was previous to this course.

On similar lines, Joanne makes connections with some of her favorite childhood activities. She comments, "[s]ome of my favorite memories are from helping my family make and create things. I have been making since I was a kid I just haven't realized it until now."

Olive too sees herself Making in many everyday activities as she reflects after the course.

> Making is both familiar and strange to me at the same time and I didn't notice it until this course. For me, making is such a common activity that people do everyday—my mom preparing dinner for the whole family; the light pink scarf my grandma knitted for my sixth birthday." She shares her understanding of Making as, "It is about the beauty of transforming an idea into an innovation, into something you can benefit from, into something that you feel really passionate about.

In all three of these narratives after going through the course activities, the participants start identifying the Makers in them which results in positive Maker identity formation. It is claimed that Making is inherent to human nature (Dale Dougherty, 2012; Hatch, 2014), and this theme further consolidates on this construct of Making. The participants realized that they had always been Making. However, their engagement in the course activities made them cognizant of their Maker identities. These narratives too, like the previous theme, show evidence of positive identity development following Ibarra's framework which informed the curricular experiences that made them aware of their Maker identities.

They had been engaged with Maker activities even prior to the course, but it was understanding who Makers are, living their Maker identities, and then reflecting on how they had been Makers during and before the course, that led to realizing their Maker identities.

My Maker identity will remain evolving

Another prevalent theme of Maker identity development amongst the participants is of the evolving nature of their Maker identities. Many of the participants embarked upon the path of realizing their Maker identities through this course and voice how they believe the construction of this to be an evolving process.

Larry writes about his prime learning from the course as "[e]veryone in the [world] makes items, and I can learn something new from each person. Because of that, I will always be learning and changing as a maker to hopefully be able to create something that is uniquely me."

On the different aspects of Making from the Maker Manifesto, Ron writes, "[a]s I experience more of life and I try and to increase these areas in my life, I will learn more about what they really mean. Being a maker feels less like an instruction set and more of a way of how to view life."

Mary, who I quoted earlier regarding the re-conceptualization of making from a foreign to a personal idea, writes,

> My maker identity shifts, like colors inside a kaleidoscope, changing depending how you look at it. It Change[s] when I travel, such as to Spain and Morocco, and it will continue to do so with each new experience I have. It will take a long time to find exactly where my making identity lies, perhaps its best that it will never be defined it will retain this freedom.

Jeff too attributes his understanding of the different aspect of the Maker manifesto to experience, which is always evolving. He writes, "I have my own interpretation along with experiences of the development I've had in each aspect through this study abroad class experience[,] and my life in general."

All of the narratives above elucidate how the participants conceptualized their Maker identities while writing their reflections. However, they believed that future experiences in life would make their Maker identities evolve. Larry's idea of creating something uniquely him, Ron understanding Making as a way of life, Mary embracing the changing nature of her Maker identity, and Jeff attributing the development of different aspects of Making to experience, all make for evolving Maker identities. This points to the importance of communicating to students about the evolving nature of their identities. They should not expect the end of a course or a degree to mark the finality of their identities but realize that their experiences over time will keep informing their identities as they evolve.

The above quotes of development of Maker identities represent 9 out of the ten consenting students from the course. The last of my consenting students had the following to say:

> Based on the definition of maker, I would say I can be identified as a maker. But I value privacy way too much that it would be nearly impossible for me to share my ideas with other people at an open area like maker space … Well, part of being creative is to make your own rules so I guess eventually I can count as a maker.

A budding roller-coaster designer, he further writes about the kind of roller-coaster he wants to design: "[t]his is the kind of thing I want to make. Something that a whole family enjoys together, share their experience together and laugh about it together whenever they mention about it. This is my maker identity." For him Making might not be what his classmates talked about. Though he has his own conception of Making, and what it means to him.

In this section I answer the research question, how do students conceive their maker identities following Ibarra's theory of provisional selves? Upon taking the course, which I designed to model after Ibarra's theory of provisional selves, three themes for how the

students develop their Maker identities emerged: (1) from foreign to personal; (2) I'm a Maker, I just never noticed; and (3) my Maker identity will remain evolving. All three themes provide evidence for how this course designed around Ibarra's theory resulted in the participants developing their Maker identities, by making connection between what they understood Makers do and their practices during and outside of the course activities. The first two themes of owning an identity that they earlier considered foreign and realizing how they had been Makers even before they realized so align with findings from Eliot & Turns (2011). They had learned while studying undergraduate engineering students that students' internal frame of reference, which comprises their emerging realizations and their personal interests and values, accounted for twice as many responses as the external frame of reference when constructing their engineering professional identities through portfolios. The third theme of them realizing that their Maker identities will keep evolving is similar to an ongoing process of self-discovery (Pintrich, 2004), and points towards the need of instructional support to help students embrace this evolving nature of their professional identities in similar environments. These three themes emerge after studying how my participants in this study develop their Maker identities. If this study was to be scaled up, with a greater number of participants, perhaps newer mechanisms of developing identities following Ibarra's framework would emerge.

RQ3: Other themes for the development of Maker identity

My discussions in this section will focus on answering the third research question:

RQ3: What are some of the common themes that play a role in students' realization of their Maker identities?

To answer this research question, similar to the previous research question, I read the students' end of course reflections multiple times and my field notes from our trip to Spain and Morocco and other classroom activities. I used the qualitative coding software Nvivo to keep track of the students' narratives, identify, compare and merge themes. Upon analyzing their narratives in conjunction with their individual stories and backgrounds,

three themes for how the students develop their Maker identities emerged: (1) from the old to the new – narratives of change; (2) agency; and (3) more than self – doing good for others. The answer to RQ 3 in these three themes provides insight into the incidents that are prominent in students' recollection of and reflection on their experiences during the engineering camp. These can potentially be helpful in the design of future curriculum and instruction following the Ibarra's framework and reflective practice in Makerspaces and similar open-ended problem-solving and engineering design learning environments.

From the old to the new – narratives of change

One of the themes of the participants' narratives was that of change – letting go of old beliefs and values for new ones. Joanne writes, "I guess all in all my perspective of what a "maker" is changed a lot over this trip and I am really happy about that. I am happy that I got to experience a different culture and how they view their tradition and the culture of "makers"." Larry acknowledges his change in perception of Makerspaces, from "a space where mechanical engineers and electrical engineers build robots," to "everything from making wine, to making guitars, to building cathedrals." Sofia while explaining her conception of the aspect of Share from the Maker Manifesto writes:

> At first, I didn't really understand why you would want to share your processes and your designs with other people, that seems to be the opposite of what I do in engineering. But after being in fab labs and seeing people using open source equipment like the Arduino, it is easy for me to see why sharing is important.

The above narratives show the important role that embracing change plays in students developing their Maker identities. Joanne changing her perspective of who a Maker is, Larry changing his understanding of what Making is, and Sofia realizing the importance of sharing ideas and artifacts with others, show how they changed their perspective and ideas which helped them understand Making better, and thus developing their Maker identities. This phenomenon of embracing change to learn and develop could also be equated to students developing their schemas as they experience disequilibrium with what they already know (Piaget, 1970).

Agency

Another theme from the narratives is that of agency, i.e., the participants motivating themselves to achieve something. This agency is observable in Olive's reflection on how she and her team ended up Making a complicated Chinese knot. She writes,

> To be honest, my idea was not to make the fantastic […] knot at first. My initial idea, being the laziest person on Earth, was to fold a fan with paper because it's easy (I know it might not sound this way, but trust me, it is). But after some inner struggling and debating between the devil and the angel within me, I decided to trash this cheap idea … Sure it is much more difficult and time-consuming to tie the knots or to 3D-print a rocket, but it can teach me a lot of things too.

Larry's description of the power of the internet also has a similar tone of taking up challenges by himself. He writes,

> The internet is something that contains information on almost anything. When someone tells me that they can't find something, I always tell them that they have not looked hard enough on the internet. One example using the internet to support my learning is when I tried to learn computer programming in high school.

Ron too writes about how his "entire focus is on how to become better so I can share, and give, and play." He adds, "I also think that the desire for change is what drives us to become better. The more I want to change something, the more effort I put into it when it doesn't happen."

The above narratives represent the students being agentive. Olivia going beyond her idea of Making a paper fan, Larry saying that he can find the answer to anything he wants on the internet, and Ron wanting to become a better person by making efforts and embracing change, similar to the previous theme, all represent the students being agentive as they develop their Maker identities. Students being agentive can be understood by Bandura's (1989) conceptualization of agency in the Social Cognitive theory as making causal contributions to their motivations and actions.

More than self – doing good for others

Another theme that emerged from the participants' reflections is the critical role that doing good for others played in them realizing their Maker identities. Joanne lays stress on the importance of giving back to the community as a Maker. She writes,

> Whether your community is a neighborhood, your country, your continent, or the world "making" is giving back. Part of "making" is satisfying some need in my community. Giving means helping others whether its developing things that make other's lives better or it's creating opportunities for others in your community."

Ron attributes his decision to become a computer engineer to doing good for the world – "[w]e do what I do because I want to change the world. I choose to be a computer engineer because I wanted to change the technology that the world has." Emma writes about how "when you are able to connect to others around you in the community, it gives a sense of belonging." For her, "sharing the maker movement with the students was awesome, and listening to them talk about what they make made me feel connected to them." To sum it up I quote Larry, "I feel as though every person should make something to be [a] better person."

The above narratives show how the students are encouraged to Make in order to do good for others. Joanne's understanding of Making as giving back to the community, Ron looking to Making to change the world via innovative technologies, Emma's joy in sharing the Maker movement with others, and Larry's thought of Making to be a better person, all show how doing good for others plays an important role in their Maker practices. The purpose of doing good for others directs their Maker activities, which is aligned with Dewey's (1938) work on how purpose determines an individual's learning activities.

These three themes of change, agency, and doing good for others, illuminate impactful experiences that the students underwent while developing their Maker identities. The importance of these experiences and the role they played in aiding students to conceptualize their own identities merit intentionally creating experiences as part of curriculum that provides opportunities for students to have such experiences. Greater reliance and practice of reflexivity in classrooms, supporting student autonomy, and implementing service

learning projects, are some examples of curriculum and instruction that bolsters the three themes presented above. As we will see with the next chapter with the younger school students, they too report being impacted by similar incidents as they narrate how they developed their engineering skills.

Summary

The above discussion in response to the research questions have far-reaching implications for the educational potential of Makerspaces. With the first section on the *multiplicity of meaning*, I provide evidence for how Making and its aspects are not understood as one-size-fits-all conceptions. I learn that people relate to Making differently. This has implications for how we understand the experiences and consequent learning in Makerspaces. Formalized learning and assessment practices that teach and access the same knowledge across participants do not do justice to the nature of Making. Following this implication, the section on *from provisional selves to identity formation* proposes an individualized practice of reflection for participants to develop their Maker identities. I learn that my participants develop their Maker identities differently, but they all develop. This instructional design using reflection as a means for development following Ibarra's framework of identity development is unprecedented. My findings make a case for more empirical and instructional work using this instrument. All the participants develop their Maker identities, but for broader implications, it becomes imperative to test this instrument in other settings. The third section on *other themes for the development of Maker identity* initiates asking the question of how, even though participants have different experiences, Makerspace environments facilitate development. The three themes I identify of change, agency, and doing good, are important constructs of fundamental theories for learning and development (Bandura, 1989; Dewey, 1938; Piaget, 1970). From my findings, I further hypothesize that the novelty of learning in a Makerspace rests on these and other well-established mechanisms of learning and development.

Conclusion

With this study, I explore the role of reflective practice in students' conception and development of their Maker identities. Learning from the People, Means, and Activities framework for educational Makerspaces in paper 1, this work directly addresses the activities aspect. It is, however, imperative to mention that the people and means aspects are closely related to the activities, which in this paper is the activity of reflection. This paper also takes advantage of the importance of personal meaning and engagement in Making activities, which we learned from Paper 2. In this paper, I employ a narrative inquiry approach to qualitatively analyze student reflections following a Maker course designed using the conceptual framework of the study which is informed by Ibarra's theory of provisional selves and Schön's reflection on action . The implications of this work include understanding the individualized nature of Making and even engineering to some extent, testing reflective practice as an activity to benefit from the educational potential of Makerspaces, and understanding how in the context of this study students positively construct their Maker identities and develop engineering skills following the model for identity development proposed by Ibarra. This paper contributes to the ongoing dialog of the educational potential of Makerspaces, and also recommends innovative practices for learning and development in informal environments that emphasize individualized learning. In the next chapter, I illustrate how a similar approach can be used to design instruction for younger students and compare their reflective responses with the older undergraduate students from this study.

PAPER 3 B: THE ROLE OF REFLECTION IN STUDENTS' CONCEPTION AND DEVELOPMENT OF ENGINEERING SKILLS

In this chapter, I present a case of an engineering workshop for school students between the ages of 9 and 14. My primary aim for this case with the younger school students in engineering camp is for it to serve as a corollary to the previous chapter with the case of the older student enrolled in the Maker course. After observing the successful role of Ibarra's framework in students developing their Maker identities, with this case, I seek to understand younger students' capabilities to reflect in a similar setting, which is essential for Ibarra's (1999) framework and directly related to Schön's (1983) theory of reflection on action. The aims of this chapter are:

- To illustrate how instructional design informed by Ibarra's theory of provisional selves (1999) and reflective practice (Schön, 1983) can be translated to 9-14-year-old students.
- To understand 9-14-year-old students' capabilities to reflect on their experiences in comparison to college-aged students.

I meet the first aim by describing the participants, the context in which the engineering workshop is set up, and the instructional design of the workshop in alignment with the conceptual framework from the previous chapter. I meet the second aim by analyzing the students' responses to understand their capabilities to reflect and the common themes that emerge in their reflections, in the sections *not too young to reflect*, and *themes for developing engineering skills*, respectively.
In both section I make comparisons with the college students from the previous chapter.

Context and Participants

The participants comprising this second case of the study were 9-14-year-old students who attended the engineering station at a month-long summer camp. Along with my colleagues, I conducted this study after the previous chapter and made changes to the research protocol

to suit the research practices better to younger students. The engineering station saw a total of 425 students of whom 138 consented to participate in the study. All participants were between the ages of 9-14 and belonged to low socioeconomic backgrounds as they all qualified for free or reduced lunch. Unlike the older participants, these students were not self-selected as participants already interested in Making. The presence of the students at camp was predicated on their parents/guardians signing them up for the camp.

Similar to the older undergraduate students from the previous Chapter, we introduced these students to five engineering and maker skills instead of the nine for the older students. We informed them that they were in a Makerspace environment. However, we called the skills we introduced engineering and not Making skills, and the names of the skills were edited to make them accessible to younger students. We introduced all skills at the beginning of the camp and assigned each skill to one day of the camp. The skills were imagine, create, learn/ask, change and okay to fail. The instructors focused on explaining the skills to the students at the beginning of each daily session, and the students completed a brief reflection of how they practiced that skill at the end of each session.

Alignment of instructional design with the conceptual framework

Similar to the design of the curriculum for the undergraduate students, I use Ibarra's theory of provisional selves to define the instructional design for this case. I use a synthesis of engineering habits of mind (Katehi et al., 2009) and engineering design skills (Dym, Agogino, Eris, Frey, & Leifer, 2005) to define engineering skills for the first step of the model illustrated in figure 1, which is observing and understanding the identity to be developed. I rename the skills such that they are accessible for students of ages 9-14 years: imagine, create, learn/ask, change, and OK to fail. This characterization and introducing students to engineering skills serve as the basis and the first step of Ibarra's model. The students then solved engineering problems in a Makerspace environment to experiment with the provisional identity to be developed, fulfilling the second step of Ibarra's model. At the end of five days of the camp the students shared how they operationalized the engineering skills during the workshop. They were prompted to share this information in

writing using prompts such as, “How did you imagine today?” A complete list of the prompts can be found in Appendix B. For the younger school students, I seek to understand their capabilities of being able to reflect on experiences they have had, which is necessary for the third step of evaluating the commensuration between the first and second steps of the model.

Figure 12 is a representation of the alignment between the instructional design and conceptual framework. Students observe and understand who an engineer is through information on who engineers are, what they do, and the skills they use. They then experiment with their provisional engineering skills as they solve engineering problems. Finally, at the end of each day they evaluate their experiences by reflecting on their actions and report how they practiced the engineering skill of the day.

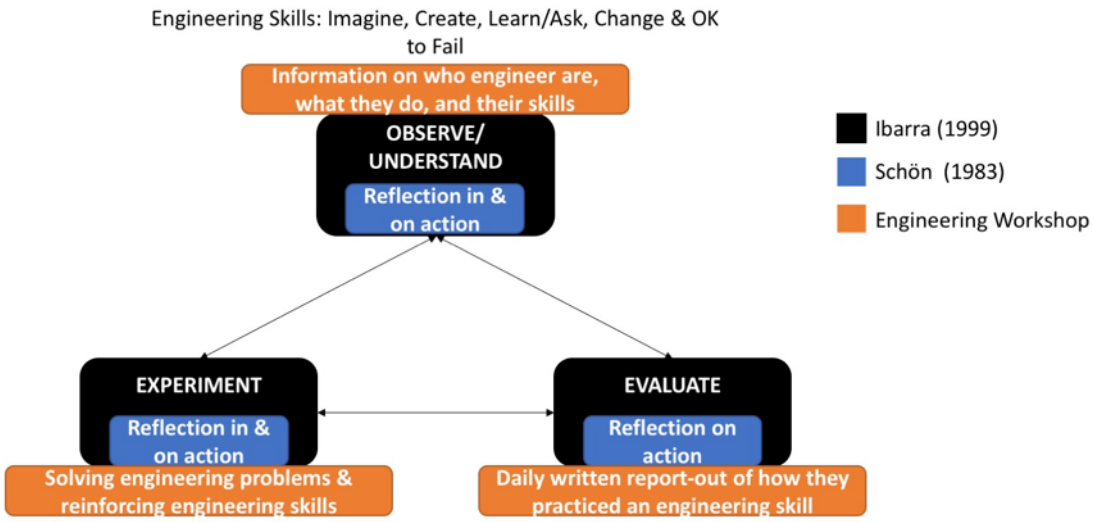


Figure 14: Representation of the alignment between the instructional design and conceptual framework.

Data Sources and Analysis

The students were asked to fill out brief reflection prompts at the end of each day we introduced a skill to them. The prompts for the end of the day reflections can also be found in Appendix B. In addition to written reflections by individual participants, participants were video and audio recorded as they worked in teams during the camp, and some of them were interviewed at the end of the camp and asked which of the skills they thought they developed most. Similar to the older students, I coded the transcriptions of the interviews using Nvivo. For the following discussion in which I address the students' capabilities to reflect on their experiences, I coded their responses as meaningful engagement, not meaningful engagement, and negative responses to the written reflection prompts. In the discussion to follow I report the themes that emerged in the participants' spoken reflections, which I consolidate from the codes I developed after multiple passes of the data.

Not too young to reflect

In this section I analyze the students' responses to understand their capabilities to reflect on their experiences. Table 9 captures a summary of students' reflective responses. A total of 138 students from the 425 attending the camp consented to participate in the study. Every day, a certain number of students did not participate in the activity as they were either absent or were attending band practice instead. I report these numbers in the column titled "Did not participate." The students who "participated" were 138 less of those who did not participate. I count the students who started filling out the reflection sheets but wrote illegibly as "Incomplete." I count the students who did fill out the sheets, but their responses were not related to the prompts as N/A (Not applicable). Finally, students who reflected on the prompt, but said that they did nothing related to the skill of the day are in the "No" column, and those that reflected on how they practiced the skill are the "Yes." I count both, "Yes" and "No" as active reflection by the students as they engaged with the prompt, even if some believed that they did not practice the particular skill on that day.

The "Percentage of Yes & No" column depicts the percentage of students who actively engaged with the reflection prompt out of the total students present and participating in the study on that day. I calculate the percentage of students who positively responded, that is engaged with the prompt and reported practicing the skill in question, in the column of "Percentage of yes."

The percentage of engagement with the prompt is very high for the first four skills: Imagine, create, learn/ask and change, ranging between 84% and 96%. The percentage of engagement with the skills of OK to fail is lower than the other four, but still 61.3% of the students which represents a majority of them, engaged with the prompt. This presentation of engagement with the reflection prompts shows how a large majority of the students were able to meaningfully engage and practice reflection-on-action (Schön, 1983), albeit shorter and drawing from fewer experiences as compared to the older students. This ability to be able to reflect on their actions meaningfully is required to complete the first step of Ibarra's three-step model.

Table 9: Summary of school students' reflective responses.

	Did not participate	**Participated**	**In-complete**	**N/A**	**Yes**	**No**	**%age of yes**	**%age of yes & no**
Imagine	25	113	5	12	91	5	80.53	84.96
Create	42	96	2	2	92	0	95.83	95.83
Learn/ Ask	52	86	2	7	76	1	88.37	89.53
Change	49	89	2	7	76	4	85.39	89.89
OK to Fail	76	62	3	21	34	4	54.84	61.29

To gain a qualitative sense of the different ways in which the students meaningfully engaged with the reflection prompts, below in Table 10 I present some of the students' responses, organized by skill. These excerpts are only meant to serve as examples of the responses from students that exhibited positive engagement with the reflection prompts.

Table 10: Examples of students' positive engagement with the reflection prompts.

Imagine
I imagined that the restaurant will come to life I imagined a soccer field and how it looked How I imagined today I just thought of stuff people need I imagined it because homeless people have nowhere to go for a home
Create
I created with straw and wire I created a therapy chair out of pipe cleaners I used the skill "create " to make basketball hoops and goal posts
Learn/Ask
I learned how to design a refrigerator. I asked how they 3D print I learned how to make stairs out of paper I learned to move the object. We asked [researcher] to know how to size object We learned that popsicle sticks can be very useful because they are strong I learned that the couch I made wouldn't stand so I changed it We can ask questions from teachers and learn things that we don't know I asked for help thinking of things to make
Change
I changed the real words to braile for the blind people because blind people can't see We changed the smell so we can tell the person what to smell for I used change when I made changes to our solution that made me feel good and we made devices, stands, and new apps Put lots more fabric on the walls and other furniture so they don't run into stuff and get hurt. I helped change peoples perspective A blindperson's life It is a hard proccess but all you need to do is try and try again
OK to fail
Everybody sometimes fails If you fail you can try and try and try again. Not everything is easy I learned that is okay to fail we fail to make more ways for blind people to know around the house today we kind of failed to all communicate but we tried our best I acknowledged the flaws in our design and improved them

Imagine

Table 10 above shows some of the ways in which students engage with the prompt “How did you imagine today?”. The students' conceptions of the skill imagine, and consequently, their responses to the prompt though relevant, vary widely. Where for some, imagining is fantastical like the restaurant coming to life, for others, it's visual like imagining a soccer field and how it looked, and for some others, it is about thinking about people’s needs and how they might engage with the solutions produced.

Create

The highest percentage (95.8%) of students meaningfully engaged with the engineering skill Create. Table 10 reports examples of some of the students' responses to the prompt, "How did you create today?". All responses either capture what they created, what they created with or both. The participant who wrote "I created a therapy chair out of pipe cleaners," tells us what was created and with what. The response, "I used the skill "create " to make basketball hoops and goal posts" tell us what was created. Whereas, the response "I created with straw and wire" reports what was used to create.

Learn/Ask

Following suite, the students engaged with the skill of Learn/Ask also in a variety of ways, and a considerable percentage (89.5%) of them meaningfully engaged with the skill. Even though they were responding to the prompt in a procedural sense, i.e., I learned this _____, and I asked this _____, they responded with relevant knowledge and skills they learned, questions they asked of others and other realizations they had pertinent to the skill of learn/ask. Where some students learned skills like "design[ing] a refrigerator" and "mak[ing] stairs out of paper," others learned factual information, such as "popsicle sticks can be very useful because they are strong" and "the couch I made wouldn't stand." As per asking, some of the students reported how they asked particular questions of the facilitation team, such as "[w]e asked [researcher] to know how to size object” and “I asked for help

thinking of things to make", others had broader reflections such as "[w]e can ask questions from teachers and learn things that we don't know".

Change

As reported in Table 10, responses to the prompt on the skill Change elicited a broad array of responses, ranging from procedural responses such as "[p]ut lots more fabric on the walls" to eliciting reflections such as "[i]t is a hard process but all you need to do is try and try again." On the procedural end, the responses included, "I changed the real words to brail[l]e for the blind people because blind people can't see" and "[w]e changed the smell so we can tell the person what to smell for." These responses can be attributed to the instructional team asking the teams to make changes to their solutions to make them accessible to people who are blind. Several students' responses aligned with making a change to do good, such as "changing people's life," "change peoples[‘] perspective" and "[changing a] blind person's life." Certain students also reported how the change made them learn things about the world and themselves, such as "I learned change is good" and "when I made changes to our solution that made me feel good."

OK to Fail

Even though, the skill OK to fail engaged the lowest percentage of students with some examples in Table 10, the completed reflections were thoughtful and relevant. Some of the students reported on their and their team's failures in response, such as "we fail[ed] to make more ways for blind people to know [things] around the house", "today we kind of failed to all communicate but we tried our best" and "I acknowledged the flaws in our design and improved them". Others offered deeper decontextualized reflections such as "[e]verybody sometimes fails," "[i]f you fail you can try and try and try again. Not everything is easy" and "I learned that is okay to fail." As alluded to previously, the skill Ok to fail perhaps required the students to engage at a higher level of metacognitive ability that the others skills, that is, they not just had to tell us how they failed, but also tell us how it was ok if they failed. A majority of the students were able to engage with the reflection meaningfully.

Thus, to answer the research question, “To understand students’ (ages 9-14) capabilities to reflect on their actions”, I reported the percentage of meaningful engagement with the reflection prompts for each of the skills and quotes from the some of the student responses to the reflective prompts. Two findings that emerge from these results are that younger students are capable of reflecting meaningfully on being prompted and that students understand and reflect on skills in different ways even when they are introduced to the skills together. The high percentage of students meaningfully engaging with the reflection prompts points towards the students' abilities to reflect meaningfully on prompts given to them. The several ways in which students engage with the same reflection prompts show how even after being introduced to the same skills in the same setting, they understand and consequently reflect on the skills in a variety of different ways. Both these findings show that even students who are younger (aged 9-14 years) than the undergraduate students from the previous chapter are capable of reflecting on their experiences when asked how they lived or experimented a particular skill. Here these skills were imagine, create, learn/ask, change, and OK to fail. This capability of being able to recollect experiences by the process of reflection to provide evidence for how they lived or developed a particular skill or aspect of identity is the bedrock of Ibarra’s theory of provisional selves. The younger students are also capable like the undergraduate students to reflect on their actions and experiences. However, they are not as articulate and require more scaffolding in the form of prompts and exercises to do the same.

Themes for developing engineering skills

In this section I analyze the students’ responses to uncover common themes that emerge in their reflections. On the last day of the camp, we interviewed some of the consenting students about their experiences at camp. They were all asked, "Do you remember the different skills we learned at camp? Which of them do you think you learned most about?" The students' responses to this question spanned the different skills introduced, not skewed towards or against any of the engineering skills we introduced them to. When I analyzed their interviews, certain themes emerged which provide insight into the incidents that are

prominent in students' recollection of and reflection on their experiences during the engineering camp. Similar to RQ3 from the previous chapter (What are some of the common themes that play a role in students' realization of their Maker identities as they reflect on their experiences?), these themes can potentially be helpful in the design of future curriculum and instruction following Ibarra's framework and reflective practice in Makerspaces and similar open-ended problem-solving and engineering design learning environments. Similar to RQs 2 (How do students conceive their maker identities following Ibarra's theory of provisional selves?) and 3 from the previous chapter, I used the qualitative coding software Nvivo to keep track of the students' narratives, identify, compare and merge the themes. The three themes that emerged were: *change*, *working with others*, and *having been practicing Making/engineering* before the camp.

The themes of change and having been a Maker before camp, are in alignment with the themes found in the older students in response to RQs 2 and 3. The theme of working with others is related but different from the theme of doing good for others which I observed in the older students. Where the older students' reflections focused on working for others, the younger students spoke about working with others.

Change

Students embraced the idea of change while developing their engineering skills. Where for some the realization sparked from having to change their ideas to accommodate people who are blind, others narrated prior experiences where they had to change their approach and ideas to solve a problem. One of the student's comments on changing their solution to make it accessible to people who are blind.

> Because I learned that some blind people and um like if I learned that people um that when we did the pretending to be blind thing that um it changed the whole different world because um somebody have to live like that so like their whole entire life with their eyes close so they couldn't see nothing but um for our design we puta braille on it so then and um voice things so if they so it can talk to them and guide them where to go and touch the braille.

Another student told us about how after his brother broke his leg, he had recommended to his mother that they change the setup at home.

> When my brother um had broke his leg um um like we had these stairs that were like really steep and really big and this um wheelchair couldn't go up them so um I um helped my mom and told her like make a ramp so we could push him up and push him down the thing um so he wouldn't uh like have trouble cause if he cause if he didn't do that he would go up the grass and the wheel did get stuck in the mud.

Another student embraced the spirit of change broadly, stating how they learned that when working with others one has to listen to others and be open to changing ideas accordingly.

> Well, like changing your idea and like working with people cause like some people have different ideas with each thing, cause like people said like you need a laptop to applications for jobs, other people said like other things, we all worked together to do one thing.

Similar to the older students, the theme of change appears when students observe a change in how they think of certain things and when they realize that they should be changing something. This theme is in line with both cognitive development and the engineering. Students experience change when they are developing cognitively and understanding new things (Piaget, 1970), and change is an important aspect of engineering work (Koen, 2003). This experience could include the change of a system to make something work better or changing the environment around an engineering artifact.

Working with others

The previous narrative from the student stating that it is important to embrace change when working with others brings us to the theme of working with others. Several students reported working with others as the most fun and challenging part of the camp. One of the students reflects upon how working together helped them come up with solutions,

> I could say that um just kind of kind of working together that you'll find a way or have like experience like walking around see people, and you see how they're managing before giving up.

Another student addressed how even though difficult, working with others helped their team come up with their solutions.

> [T]eamwork, like it was difficult with the teamwork, but we all came down to one idea with the alert watch and then the glasses.

While working with others on the team, students addressed how the final solution was a result of compromising/negotiating within the group,

> Well I wanted to like make a bigger kitchen, and they wanted to make like a bigger living space and stuff, and we just compromised.

Another student reported how they bounced ideas off of each other to come up with their solution.

> Uh well we first of all we had a work as a team to find out what we should do and um what creation we should make and so we made like that remote with the sensor we was I was like wait if there's not like you said like if there's an object we should put like they could trip over it and I was like wait should we have a sensor and they were like yeah cause then the remote would say there's an object in the way and then we could move it like without.

The theme of working with others tells the story of the students' orientations towards others, especially when held against the theme of doing work for others, observed in the older students. Where both, younger and older students are connecting with humanistic aspects of engineering, it appears that the engineering "for" people aspect is more pronounced in older students and the engineering "with" aspect in younger students (Fila et al., 2014).

I've been Making/engineering

When we asked the students to tell us about their experiences at camp with Making and engineering, several of them said that they had done similar activities before. They might not have always realized that what they were working on was engineering, but after attending camp, they were able to make the connection.

A student related it to how his team had been using Legos to Make,

> Cause um at my when I was young I had a lot of legos and I was using them a lot, and I made a bunch of creations, and my mom was very proud of me.

Another said how they help their siblings by fixing the TC and phones,

> Yes, uh, I thought like cause my siblings they would say that the tv's not working, or why uh my phone's not working or something like that and I would kind of come up with a way for uh it to work, and it usually works pretty much. So, they'll come to me and be like I need your help with something.

One of the students who was interested in art realized that engineering was not very different from art and so while practicing art they had been engineering in some way.

> Uh, I thought it was different than art because like it wasn't all that different because like first we had to draw out what we were gonna do, and then we had to paint it, we had, it was, well when we drew it was sort of like our blueprint.

Another student who related art and engineering similarly, told us how they learned how to draw better from the internet.

> I like drawing flowers and then like I just try to draw anything the best I can. I, I don't know how to draw the dog, draw a dog very well, but I like to go on youtube and just let them teach me, and I know how to draw like one of my favorite anime characters.

This third theme of being able to connect engineering with previous practices proves the important role that reflective practice can play in supporting students as they make meaning of their experiences and relate them to learning new knowledge and developing skills. It also shows how even though often purported as a highly specialized field with formalized

education being the only way to access it, these students narratives show how some form of engineering is an everyday practice for them.

Above, I report themes to answer the research question, “What are some of the common themes that play a role in students’ reflections on their experiences?”. The common themes in students' reflections on their experiences are of change, working with others, and having been Making/engineering. Similar to the older students, these themes can be used to bolster the quality of curriculum and instruction. In the case of younger students, scaffolded reflective practice, promoting working with teams, and making available upperclassmen as facilitators and mentors, are some of these practices.

Summary and comparison with older students

In this chapter, I analyzed reflections from students to understand young students' (9-14 years of age) capabilities of reflecting in comparison with the older students from the previous chapter. We did not ask the younger students to provide one cohesive course reflection at the end of the camp but asked them to reflect on the engineering skill of the day at the end of each day. The high percentages of meaningful engagements with the reflection prompts show that students are indeed capable of engaging with reflective prompts, thinking back to activities they did in the day, and provide, although brief, an account of their experiences. The students' reflections also show the multiple ways in which they understand the engineering skills. They were all introduced to the skills at the same time and via the same instruction, and yet they report out engaging with the skills in a variety of ways. This finding is in line with the *multiplicity of meaning* theme from the older students. In the second section on the themes for developing engineering skills, the three themes, change, working with others, I’ve been Making/engineering, are similar but also in some ways unique from the older students. The theme of change is similar to the older students and presents itself as either the change students want to make with their Maker/engineering work or the change they see in themselves. The theme of working with others can be related to the theme of More than self-doing good for others from the older students as it focuses on the people the students are working for (older students) or with

(younger students). Finally, the theme of I've been Making/engineering is similar to the theme of I'm a Maker, I just never noticed which emerged from the older students. Again, similar to the older students, the themes observed from the narratives of the younger students are related to established theories of learning and development such as agency (Bandura, 1982) and communities of practice (Wenger, 1998). This linkage provides grounding for the educational potential of Makerspaces and suggests curricular and instructional interventions using Makerspaces and similar environments.

CONCLUSION

Summary

In this dissertation, I present work from three studies to understand and begin to operationalize the educational potential of Makerspaces. Figure 15, which I borrow from the introduction is a representation of the connections between these three studies.

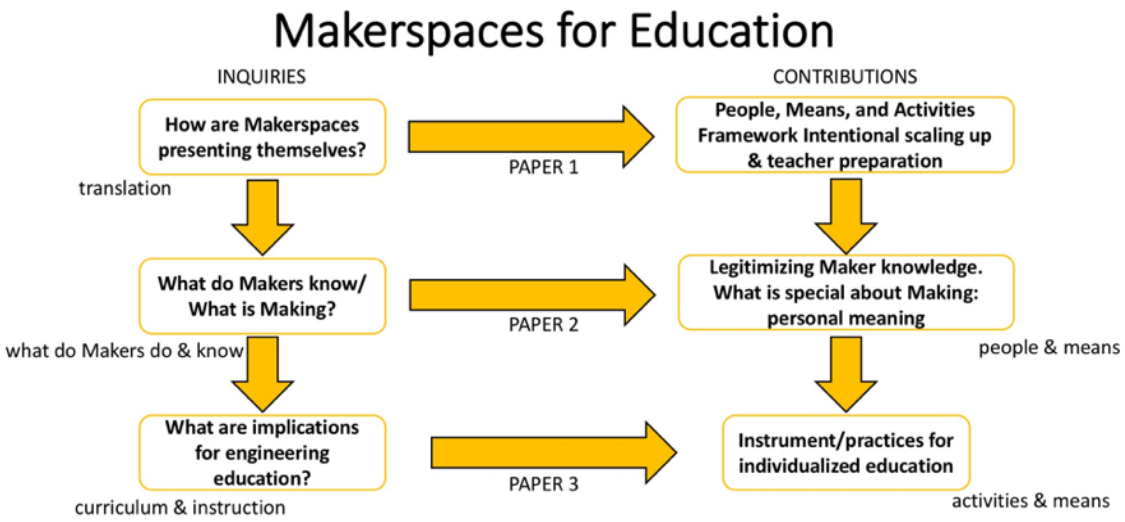


Figure 15: Schematic representing connections between the three studies of this dissertation.

In the first study, I examine how Makerspaces have presented themselves and develop a conceptual framework that describes the relationship between the people, means, and activities of an educational Makerspace and how that can translate to the space's vision or purpose. This framework may serve as a translational tool for people looking to develop a new educational Makerspace or to define their vision and purpose for the space. The primary aspects of the framework—people, means, and activities—represent the people who are part of the space as Makers and facilitators, the technological tools and materials Makers use as means to Make, and the activities they engage in while Making. I argue that the purpose of a Makerspace can be situated within the framework. The variable nature of

Makerspaces is described by its purpose as being people-focused, means-focused, or activities- focused, or some variable combination. The purpose of a Makerspace could be defined when the space is initiated, such as Makerspaces in educational settings, which are set up for meeting educational needs or outcomes. The purpose could also be continually evolving as many spaces redefine their nature depending on the contexts they are situated in. This first study contributes a conceptual framework for understanding Makerspaces for education, determining future areas for research, and situating the following studies.

In the second study, I focus on the people aspect of the framework developed in study 1. As the people are inextricably tied to the tools and material they Make with, discussions about the means aspect of the framework are also part of this study. I examine how the knowledge and practices of Making and design compare to each other. This study addresses the epistemology of Making. In a narrative inquiry approach, I ask how Makers practice human-centered design (Krippendorff, 2006) and possess designerly ways of knowing (Cross, 1982). The encouragement behind this study was to legitimize Making as an area of knowledge akin to design, situated between knowledge of the physical sciences and the social sciences. The practice and knowledge of most of the Makers who participated in the study are similar to designers in that they understand and operationalize the needs behind the artifacts they Make; they adopt processes that are human-centered and constructive; they and others around them see meaning in the artifacts they Make; and with their practices they connect Makers, artifacts, and users. However, where as per the framework, designers Make artifacts that are expressive of their functioning, and their practice is solution-focused, Makers only do so if it aligns with their purposes for Making. A similar theme of realizing individual purposes via Making emerges when I ask the participants to distinguish between design and Making and ask them what Making means to them. All the participants consider Making to be a way to realize purposes that are personally meaningful to them. Some of these purposes include fighting consumerism, invoking reactions in people by the use of materials, having their own space to work, and transforming the world. Thus, in addition to the similarities with design, which makes a case for its epistemological legitimacy, in this paper, I also find what makes Making distinct from design, which in turn, adds to its educational potential. Such personally meaningful practices in education

have known to accentuate learning and development (Dewey, 1938; Renninger et al., 1992).

In the third study, I investigate the implications of Making for engineering education. This paper addresses opportunities for inculcating Making in classrooms from a curriculum and instruction standpoint. The primary data source for this paper is reflective journal entries of students who were enrolled in a semester-long Maker course. The students kept a reflective journal throughout the length of the course and were asked to turn in a reflective journal entry describing how their Maker identity, based on aspects of being a Maker (Make, Share, Give, Learn, Tool-up, Play, and Change) as per Hatch's Maker Manifesto (2014), had developed over the course of the semester. For this entry, they were instructed to use evidence from both, their experiences during and outside of the course activities to narrate how they developed or did not develop aspects of a Maker's identity. Though all students reported a positive identity development, the takeaway from this study is the mechanisms the student employed to build and report on their identities. The students report having known Making as a foreign concept which became personal to them over time. They also stated that they were perhaps always Makers but had not noticed and that their current Maker identity will continue to evolve. For this identity formation, the students drew from several experiences. Common themes of these experiences include embracing change, being agentive, and doing good for others. In this paper, I also conduct a corollary study with younger students aimed at understanding the extent to which younger students are capable of similar reflective practices. The design of this study and its findings have implications for how we educate students in Makerspaces and similar environments, and also for individualizing learning using reflective practice.

Goodness and Trustworthiness

To address the goodness and trustworthiness of the three qualitative studies that constitute my dissertation, I draw upon Tracy's (2010) eight "Big-Tent" criteria for Excellent Qualitative Research. In Table 11 I illustrate how the three studies meet these criteria.

Table 11. Tracy's (2010) eight "Big-Tent" criteria for Excellent Qualitative

<table>
<tr><th>Criterion</th><th>Paper 1</th><th>Paper 2</th><th>Paper 3</th></tr>
<tr><td>Worthy topic</td><td>Timely topic to understand the organically growing Maker movement</td><td>Worthy topic due to connections between Making and design, and personal stories to education</td><td>Relevant topic for realization of educational potential of Makerspaces in learning environments</td></tr>
<tr><td>Richness of rigor</td><td colspan="3">The research followed/constructed a relevant conceptual framework, is methodologically sound, the RQs align with the inquiries and contributions. Validity is proven by these 'big tent' criterion</td></tr>
<tr><td>Sincerity</td><td colspan="3">The research was designed, conducted and analyzed in reflexive ways and it reported the positionality and potential biases/agendas of the researcher</td></tr>
<tr><td rowspan="2">Credibility</td><td rowspan="2">The use of sources that self-report as Maker related initiatives, and by stating explicitly data collection methods</td><td>Reporting narratives from participants and providing a rich description of their backgrounds</td><td>The involvement of other people in carrying out the educational activity and data collection</td></tr>
<tr><td colspan="2">Distinguishing between what the participants say and what the researcher understands from the participants' narratives.</td></tr>
<tr><td>Resonance</td><td>Relevant for Makerspace administrators and those hopeful of setting up educational Makerspaces</td><td>Relevant for pro-Making educators and researchers, the design community, those interested in reflective practice, and using personal stories in education</td><td>Relevant for teachers, curriculum developers, and those interested in developing their own Maker identities and knowledge</td></tr>
<tr><td>Significant Contributions</td><td>Contributes tool for intentional scaling up & teacher preparation for educational Makerspaces</td><td>Legitimizes Maker knowledge & identifies uniqueness in Making</td><td>Proposes and tests instrument & practices for individualized education via Making</td></tr>
<tr><td>Ethics</td><td colspan="3">The reflexivity and transparency of the process guaranteed procedural, situational and culturally specific ethics</td></tr>
</table>

Table 11 continued

Meaningful Coherence	A worthy topic, being grounded in rigorous theoretical constructs, the studies resonating across their readers and making significant contributions. The researcher being reflexive, ethical, and credible through the conduct and reporting of the research. Also, the connections between the three studies make for coherence across the dissertation.

Worthy topic

The first criterion is that of a worthy topic, one that is relevant, timely, significant and interesting. With Maker Ed having been set up in 2012, which was followed by several opinion pieces about the educational potential for Makerspaces, and initiation of research and implementation of educational Makerspaces, the first study is timely to understand the organically growing Maker movement, which is claimed to be educationally meaningful. The second study has a worthy topic within the field of engineering education because it draws from the already established area of design and makes a case for the legitimacy of Making as a new educational practice. The third study is on a relevant topic as it proposes ways to realize the educational potential of Makerspaces using practices that make education more personally meaningful for students.

Richness of rigor

The second criterion is of the richness of rigor in the research. I either followed or constructed a relevant conceptual framework in all three studies. In the first study, I constructed the People, Means, and Activities framework. For the second study, I synthesized the conceptual framework from Krippendorff and Cross' work. For the third study, I used Ibarra's theory of provisional selves and Schön's work on reflection in and on action. The design and implementation of each of the research studies are grounded in suitable methodologies. Since the second and third studies were aimed at understanding the experiences and truths of the participants, I used narrative inquiry as a methodology. The research questions align with the inquiries and their contributions, and the conceptual framework I develop in the first study helps situate the following two research studies

within research work on educational Makerspaces. The second study focuses on the aspects of people and means, and the third study on the activities and means aspects, from the people, means, and activities framework from the first study. Further, I also prove the validity of the studies in this discussion by detailing their adherence to these 'big tent' criteria.

Sincerity

All three studies embody the third criterion of sincerity. I designed, conducted and analyzed the research in reflexive ways by maintaining an audit trail during collecting data and a journal during analyzing data. In the first study, I share my rationale behind constructing a conceptual framework, including the reasoning behind choosing the untraditional sources that inform the framework. In paper two I show sincerity by addressing how the second and third research questions emerged after the initial pilot study, providing detailed descriptions of all my participants and their backgrounds, and explaining my decisions about the research methods I use. I also attribute the emergence of these research questions to the reflexivity I practiced in the process of analyzing and discussing the data. For the third study, I was balancing the multiple roles of being a researcher, instructor, and Maker, and I am explicit of my positionality and how it affects my research in the write-up of the study.

Credibility

The fourth criterion is of credibility. For the first study, establish the credibility of my sources by selecting sites that self-report as Maker related initiatives, and justify the untraditional nature of my data sources. In the second and third study, I do not leave the readers with solely my interpretation of the participants' narratives, but report narratives from participants verbatim along with the analyses. I also provide a rich description of the backgrounds and contexts in which the participants are situated. In doing so, I distinguish between my participants' narratives and my understanding of their narratives.

Resonance

For the fifth criteria of resonance, Tracy (2010) suggests that the research "influences, affects, or moves particular readers." The framework I develop in the first study is relevant for Makerspace administrators and people interested in setting up educational Makerspaces in schools, colleges, libraries, and other settings. The second study is relevant for pro-Making educators and researchers, the design community, those interested in reflective practice, and using personal stories in education. The third study is relevant for teachers, curriculum developers, and those interested in developing their own Maker identities and knowledge.

Significant Contributions

The sixth criterion is that of making significant contributions. The first study contributes a tool for intentional scaling up & teacher preparation for educational Makerspaces. The second study legitimizes Maker knowledge & identifies uniqueness in Making. The third study proposes and tests instrument & practices for individualized education via Making. I also address my dissertation's contributions to research and practice in detail in the next section.

Ethics

The seventh criterion is related to ethics. The transparency of my process guarantees procedural ethics as I report on and explain the procedural decisions I made during the process. My reflexivity guarantees situational ethics as I via my journal and conversations with mentors and colleagues I questioned my decisions thought deeply about ways to handle unexpected situations. Also, my background knowledge, and relationships with Maker communities and individuals in the different countries and social groups my participants hail from, add to my culturally specific ethics. Having said that, I am certain that in conducting and writing up my research I would have crossed certain ethical

boundaries and might not have always been able to represent my participants' narratives in their truest senses. I remain attentive to how I can do better in the future.

Meaningful Coherence

The eight criterion is of the study being meaningfully coherent. As I show in this section, all three studies have a worthy topic, are grounded in rigorous theoretical constructs, the studies resonate across their readers and make significant contributions. Through my conduct and reporting of the research, I am reflexive, ethical, and credible. The studies connect with each other to make contributions to research and practice in the area of Makerspaces for education, within engineering education. Thus, the three studies and the connections between them, all make for the meaningful coherence of my work in this dissertation.

Major Contributions

The contributions of this work are multi-tiered. The first study offers a framework that can serve as a tool to support Makerspace researchers and educators in articulating a purpose and setting up an educational Makerspace aligned with that purpose. The people, means, and activities aspects of the framework are pieces of a jigsaw puzzle that come together to describe the purpose of a Makerspace, which can subsequently guide the development of a Makerspace. The framework provides guidance around whom to invite into the space, the technologies to procure, and the programming to carry forth in the space. From a research perspective, this framework paves the way for studies to understand how different people want or do not want to engage in educational Makerspaces. Further, issues of broadening participation and social justice arise as we consider who has access to such spaces in their schools and communities. In addition to researching questions pertaining to equitable access to Makerspaces, research is needed to understand how Making affects people from different age groups, whether it is better suited for informal environments than formal environments like schools, and what their meaningful implementation in educational settings looks like. Conducting research that addresses each of the aspects of

educational Makerspaces, the people, means, and activities, will also prove to be beneficial for implications of research to practice. With my work and recommendations, I initiate this conversation of meaningful Making.

The novelty of the second study stems from exploring the people, or Makers, of Makerspaces. The participants for this study are people who are aware of the Maker culture and self-identify as Makers. Their narratives are compelling stories of how they Make and how their Making practice is different. These differences emerge as a theme of personal meaning. Each participant Makes because Making is a way for them to realize personal meaning. The contributions of this study relate to the individualized interests and meaning one experiences in education. Personal interests and meaning have been tenets of valuable educational experiences (Voss & Schauble, 1992). Making provides a venue for realizing these tenets which can result in positive educational experiences. This paper also details the different ways in which Makers use the means aspect of the framework, for some, it is central to their Making practices, and others use it as a means to an end. Knowing the roles that the means in a Makerspace play, again support implications for practice, informing which means to provide in educational Makerspaces.

The third study can be considered an addition to previous empirical work on connections between engineering, design, identity and reflective practice. The unique contribution of the work is in it being situated in the context of Makerspaces, with implications for how we teach and assess learning in such spaces, which I characterize as the activities aspect of educational Makerspaces in Paper 1. Reflective practice and positive identity formation have shown merit in similar open-ended problem-solving settings in engineering and design, and from the previous study, we know that the essence of Making is in realizing personal meaning. This study utilizes the potential for Making to invoke and realize personal meaning and an individualized education using reflective practice and identity formation for curriculum and instruction. By combining Making, identity, personal meaning and reflection, I present a case for a successful educational Makerspace.

Through this dissertation, I conduct and report on timely work to investigate the educational potential of Makerspaces. Makerspaces are often purported as sites with immense educational potential. However, it is important to scale up educational Making intentionally, or else as we had predicted in a conference paper (Hira, Joslyn, & Hynes, 2014), "the honeymoon will soon be over." People have started questioning the rapid procurement of tools and technologies to set up Makerspaces, with little to no plans to realize their educational potential in their particular settings. Via this dissertation, I contribute a tool for the intentional translation of educational Makerspaces to varied contexts, forward a case for the legitimacy of Maker knowledge and draw out its uniqueness which aligns with established theories for learning and development, and understand the of role that reflective practice can play in educational Maker settings. It is my hope and firm belief that these studies add to the meaningful conversations on Makerspaces for education.

In addition to Making, this dissertation also serves as an exemplar for using narrative inquiry as a methodology in engineering and Maker settings and explores the connections between people's stories, personal meaning, reflective practice, design, and individualized education. Work has been done exploring the connections between the aforementioned for different age groups and settings of participants. However, this work is the first to bring together this discourse situated in Makerspaces.

Implications for practice

Based on the research I presented in this dissertation and established theories and frameworks for learning and development, in this section, I describe operationalizable practices for Makerspace educators and facilitators. Even though I use the conceptual framework from Paper 1, again represented in Figure 16, to organize these practices, it is important to mention again here that the people, means, and activities do not exist in isolation from one another, but rather are interconnected. Also, as we know from the conceptual framework in Paper 1, and the findings from Papers 2 & 3, the purpose of the space and purposes of those served by the space play an important role in the intentional

setting up and restructuring of Makerspaces. While developing a Makerspace with an educational purpose that would fit into a school environment, the following practices can be considered to address the people, means and activities aspects of the space.

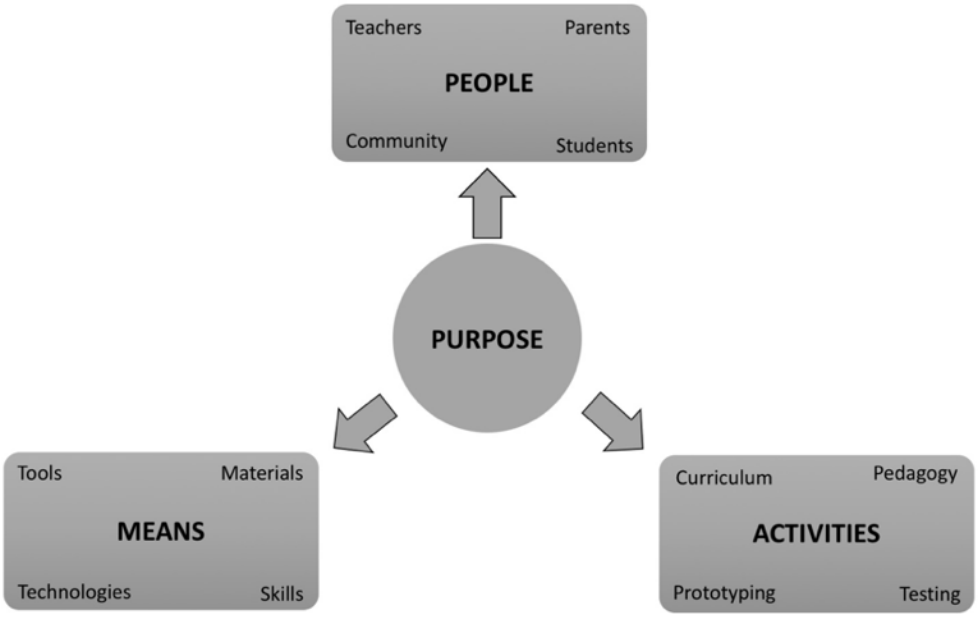


Figure 16: Representation of the people, means, and activities framework for educational Makerspaces.

People

Practices focused on the people in the Makerspace include encouraging students to progress at their own pace, facilitating students engaging with activities that are personally meaningful to them, encouraging students to learn from each other, and developing and utilizing shared resources and skills.

Encourage students to progress at their own pace. Opportunities and resources should be provided for students to think and learn at their own pace, similar to the instructional design of the Maker course from Paper 3 in which the students reflected on their progress at the end of the course. This recommendation is informed by constructivism (Piaget, 1970) which posits that people construct knowledge by building on what they already know and have experienced. Similarly, Makers develop and build on new

knowledge at a Makerspace. In an ideal Makerspace environment, opportunities for development through these processes should be abundant, as the individualized nature and pace of learning support individuals to go through the different stages of developing their cognitive schema at their own pace. Realization of this can include students working on individual projects and teachers/facilitators engaging with students individually and meeting them where they are at in the learning process.

Facilitate students engaging in activities that are personally meaningful. Working on activities that students find personally interesting and meaningful can accentuate their learning and development (Voss & Schauble, 1992). Also, as we saw in the narratives of the Maker participants from Paper 2 and students from Paper 3, realizing their personal purposes and working on problems that they cared about, proved beneficial. Makers bring with them their interests and motivations to the Makerspace. Even though the external environment that they are a part of often alters their beliefs and motivations, students learn better when the new information they receive aligns with what they consider valuable. Papert (1980) noted a focus on projects being personally meaningful as one of the tenets of constructionism. This personal meaning creates a drive for the learner to engage more deeply in the activity and wanting to complete the project when faced with mundane or challenging tasks. A Makerspace learning environment has the unique opportunity to allow students to engage in activities that they see as valuable, in turn accentuating their learning in the space. Hence, activities and practices that are authentic to who the students are and what they like should be facilitated. This can include covering several topical areas that are of interest to the students or designing learning interventions to accommodate students working on problems they bring in themselves.

Encourage students to learn from each other. Similar to other spaces, knowledge in a Makerspace is constructed by the social interaction between people in the space (Vygotsky, 1962). The Maker participants in Paper 2 practiced Making in dialogic ways, and engineering workshop student participants from Paper 3 benefitted from conversing with each other. In a Makerspace different people have different expertise. For learning to be truly social, everyone should have access to others' shareable expertise (Chaiklin, 2003),

and have the opportunity to grow. Hence, students should be encouraged to learn from each other. Fostering a climate of respect for each other's work, and receiving peer-feedback can go a long way in ensuring this. The teachers/facilitators can further encourage learning by creating opportunities where students discuss problems within the community of learners to develop and test solutions.

Develop and utilize shared resources and skills. The community of Makers comprising of the people directly involved in the Makerspace supports learning. Again, the Maker participants from Paper 2 relying on their communities to learn new skills and gather feedback is an example of this practice. Within communities of practice, community members meet because they find value in their interactions. They create artifacts and develop tacit understandings that they share (Wenger, 1998). There also exist shared resources, beliefs, and practices that are shared amongst the people within the community (Wenger et al., 2002). In the purview of Makerspaces, Makers define and understand commonly shared values concerning what they do and their motivations. They also have access to the resources housed within the community. Thus, Makers in a Makerspace and also those in virtual communities, exhibit characteristics of a community of practice. Essential for learning and development within such a community, the community of learners should be encouraged to utilize their shared resources, skills, and develop common beliefs and values within the space. This also aligns with the previous recommendation of encouraging students to learn from each other. All students possess skills and knowledge, and therefore they should be encouraged to identify and utilize their communal skills and knowledge to develop an identity for their community as they see fit.

Means

Practices that use the tools, materials, and technologies that students use in Makerspaces include, encouraging connections between the means and who is Making, facilitating learning in authentic settings, and developing skills that are transferable to other contexts.

Encourage connections between the means and who is Making. Makers construct entities which embody different meanings for them. At least two of the Maker participants from Paper 2 are inspired to Make by the materials they Make with, and others too use narratives and metaphors to describe their practices. Depending on the context and their motivations, Makers can be constructing a myriad of artifacts, from something for their entertainment to something that helps with the needs of their community. As Makers in Makerspaces construct physical artifacts, they learn. This learning can be regarding the context they are building for, the skills they use to build, or something that we have not hypothesized yet. An environment that supports and sustains Making to learn embodies constructionist values (Papert, 1980). Students should be supported to learn in a constructionist paradigm by encouraging them to interact with the tools and materials and develop conceptions of how they matter. They should be encouraged to see meaning in the means beyond just their physical presence, and also all the other values they hold, the solution to a problem, a whim, world-changing innovation, any value that encourages them to create.

Facilitate learning in authentic settings. Individuals learn in authentic contexts (Herrington & Oliver, 2000) and transfer their learning to other contexts (J. Bruner, 1966b). In formalized settings with no real-world applications, students may manipulate algorithms, routines, and definitions and fail to use them in real application tasks. In contrast, active use of these tools in a Makerspace, foster a rich understanding of the tools themselves and of the worlds in which they are used. Hence, students should be free to decide which of the available tools and technologies they consider fit to Make with, and also what it is that they want to be Making, similar to the Maker course and engineering workshops from Paper 3. By doing so, students can learn transferable skills required to operate tools and technologies, and also gain knowledge about the contexts they work in. Being grounded in an authentic context helps learners learn better as compared to learning unrelated skills in isolation. These practices of engaging students in solving authentic problems might also help steer curricular practices away from what might be considered cookie cutter projects in which students follow procedures to solve pre-defined problems.

Develop transferable skills. In addition to learning concepts and skills in authentic activities which are relevant and real-world, it is also essential for learners to be able to transfer their knowledge and skills to other settings. Brown, Collins, and Duguid (1989) posit that when education is decontextualized, one can talk about the purpose and way to use a tool, and yet fail actually to use it. Makerspaces present themselves as an answer to this problem of transfer, by serving as sites where individuals do not learn skills in decontextualized ways. People hone skills such as Computer Aided Design (CAD), computer programming, machining, woodworking, etc. in contexts that are meaningful to them. One of my motivations behind asking participants to reflect on their Maker attributes and engineering skills in Paper 3, was for them to be able to develop these attributes and skills, beyond the contexts they practiced them in. Ideally, Makers have the freedom to acquire the kind of knowledge that they deem important, and be able to transfer it to contexts that matter to them. After learning new skills in contextual environments, students should be encouraged to transfer their skills to newer contexts. Students might need help in seeing how skills from one context are transferable to another. This is where a teacher/facilitator can help students in identifying skills that transcend context and reflect on how they put these skills to practice.

Activities

Some practices aligned with the activities aspect of the framework include constructing and valuing rich and meaningful experiences and encouraging reflective practice.

Construct and value rich and meaningful experiences. When implementing interventions in educational settings, even though educators take it upon themselves to provide a learning environment for their students, they often fail to consider other factors that create experiences for the students (Dewey, 1938). These factors include the powers and purposes of those being taught and other experiences that prompt students to reflect meaningfully. The different critical incidents my participants from Paper 3 report such as Making for others, Making with others, and embracing change are examples of such experiences. Also, participants from both, the Maker course and engineering workshop

picked the problems they were to solve during the educational activities. For Makers as learners, it is important that they understand and experience the power of the new skills and knowledge they are developing, and that they experience it in a way that empowers them. Following this ideal, it is important that Makerspace learning environments are a space where failure is encouraged, diverse solutions are possible, and the curriculum is flexible to the changing needs of the learners. Teachers/facilitators should value the broad experiences of the group, and also respect and nurture stories of individuals. For their experiences to be truly genuine, students need to own and feel a part of their experiences. This includes making room for students' voices and ideas and also feeling consequential to how the learning experience is set up and run.

Encourage reflective practice. As we learn in Paper 3, reflective practice serves as an exemplar activity for the kinds of learning that occurs in Makerspaces. Reflection on both, the Made artifact and experiences of Making can prove to be beneficial for learning and development. Reflecting on experiences has shown promise in similar educational environments where there is no one correct answer expected from the students, but the learning outcomes are related to their personal development. Examples for such interventions include those in health and medicine education (Branch & Paranjape, 2002; Charon, 2001; Mann, Gordon, & MacLeod, 2009) and open-ended problems of engineering design where students reflect on their engineering attributes (Adams, Turns, & Atman, 2003; Turns, Sattler, Yasuhara, Borgford-Parnell, & Atman, 2014). Similarly, one of the ways for students to truly learn from Making is for them to look back and construct meaning of their experiences, how they relate to what they already knew and believed, and how their knowledge and belief structures were augmented. Schön's (1983) work on reflection-on-action can help situate this practice. This practice helps people understand how their previous knowledge and experiences resulted in the situation they are reflecting on and also how something unexpected may have happened in their experiences.

Future work

All three studies pave the way for useful future work. The first study can inform a taxonomy for categorization based on the conceptual framework to construct a repository of existing and potential Makerspaces. The spaces from the repository and those set up using the framework become use-case examples for other spaces. The framework can also be used as a tool for intentionally setting up and changing Makerspaces. The aspects of educational Makerspaces from the framework along with theories of learning and development that align with the three aspects of the framework can provide a foundation for determining best practices for learning and development in a Makerspace, similar to the ones I list in the previous section. These best practices will have important implications for developing educational programming at Makerspaces in schools, colleges, museums, libraries and other educational settings. Also, further empirical evidence can be gathered to understand the people, means, and activities, and their interplay.

The second study with the narratives of Makers, merits future research being conducted for artisans, craftspeople, and others involved in Making activities from under-resourced communities. I would hypothesize similarly toned narratives of design practices and knowledge from these populations as the narratives of Makers I illuminate. This potential work would align with my initially stated encouragement to legitimize knowledge from oppressed communities that do not share the privilege of positionality with professional engineers and designers. My work in this study and the work I propose for the future is not aimed at equating design and these other practices but using the similarities between the two practices to advocate for their legitimacy. On a separate note, a similar study with engineers can serve as a way to understand design practices of engineers beyond mapping them to elements of the design process and serve as an initiation into facilitating engineering students to reflect on and narrate their personal engineering stories. Also, an inquiry to investigate how students in schools, who may not identify as Makers, take on maker identities similarly as they engage in making activities can prove to be useful.

The third of my studies is nearest to being ready for implementation in learning settings like engineering classrooms and engineering workshops. In addition to the programming I

execute in the study, I would scaffold the activities for the learners to choose aspects of their Maker/engineer/designer identity, as I do not believe that the options I gave them in the intervention do justice to the breadth of skills and aspects that could make up their identities. I also believe that this addition would make the learning more democratic and would increase the ownership students take in their learning. Further, I think a similar approach can be used throughout the trajectory of engineering students' undergraduate careers for them to carve their ways through their degrees and be a step closer to individualizing engineering education. Also, the different critical incidents the participants report such as Making for others, Making with others, and embracing change are examples of such experiences, can be further studied and be intentionally be made a part of future curriculum. A similar inquiry can also be undertaken to understand reflective decision making and reflection in action.

Epilogue

Where each of the three studies possess methodological and contextual limitations, I feel imperative to end this dissertation with a few lingering thoughts I have had as I studied Makerspaces and their educational potential.

The first is that although defining concrete and separating boundaries between Making, engineering, design, and art, might seem beneficial on the surface; I believe that doing so will achieve more harm than good. In my opinion, most learning is interdisciplinary, and that we should not attempt to separate it into parts any more than it already has been. Where one can feel the urge to isolate engineering, design, and Making, I recommend resisting the urge. They are related, it is fluid, there is no center, and that is ok. The most productive steps for education would be to learn from the space, the educational outcomes, the individual development, and make alterations to what exists and plan for the future, for more productive educational experiences.

My other closing remark comes from a perspective of "diversity and inclusion." Making as we see it in a majority of places today, is not inclusive. However, the reason I keep getting

drawn back to it is that it can be. Like most phenomena in the world, Making cannot be rid of gender identity, race, socioeconomic status, and sexual orientation, but it is an activity that can provide rich experiences and fruitful sites for people to realize personal meaning, despite their differences. That to me is the beauty of Making and a significant reason behind my work on this dissertation. I believe that critical discourse about Making and relevant actions, similar to engineering, are imperative to realize their educational potential in genuinely democratic ways.

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APPENDIX A. INTERVIEW PROTOCOL FOR PAPER 2

K – Krippendorf (2006) (Human Centered Design)
C – Cross (1982) (Designerly ways of knowing)
What is your name? What are the kinds of things you make? Where do you make? Would you identify yourself as a Maker?

- Do you include the users of your artifact in the process of making? How? (K-designing for and with humans)
    - Would you say you design more for the users, or with them?

- Would you say you Make differently, or think of Making differently since you've started? What new things have you learned? If yes, could you share some of your experiences? (C-mode of thinking is constructive)
    - How would you say you have progressed in your journey of being a Maker?

- Think of one of your favorite artifacts. What is the story behind your favorite artifact? (K- design original artifacts, guided by narratives and metaphors)
    - Does the artifact tell a story?

- How do you go about going from a need/want/ interest (something that is abstract) to actually Making (perhaps physical)? (C- codes to translate abstract requirements to concrete objects)
    - What do you consider the best way for you to explain to someone what you're making?

- Do you always know what your artifact will end up as? Do you talk to others about it, during the process? (K- dialogic ways to design)
    - Beyond those you are designing for/with?

- When someone else in the space explains their work to you or you to them, what means do you consider most helpful? (C- codes to read and write in object languages)
    - Do you think that there are ideas/concepts/phrases that people you Make with understand better than others?

- Interacting with your artifact by itself, would I be able to tell its use? (K- artifacts are informative (expressive) of their working)

    - Let's take an example, an artifact X you have made – if you are not around, will I be able to tell what it's meant for? Will that be its "correct" use, or something else?

- When starting to make something, what would you say is the most important thing you think about? How important is it to solve the problem? (solution focused problem solving)
    - Would you say that you have an end in sight?

- Do you ever find yourself conflicted on needs/design decision? How do you decide the needs your artifact should cater to? (K-detailing and creating contrasting values and reconciling incompatibilities)
    - How do you understand and work with the tensions?

- Would you say you do more than solving text-book word problems when you Make? How do you go about solving real-world problems (as compared to a text-book word problem)? (C- tackle ill-defined problems)

- Do you identify as a Designer?
    - How do your Maker and Designer identity speak to/interact with one another? Is one stronger than the other? Do they support each other? What would others say about you?

- What to you is the difference between Designing and Making?

APPENDIX B. REFLECTION PROMPTS FOR PAPER 3

Reflection prompt from Maker course final deliverable (Case 1)

ENGR 195: "Makers" in Cross-Cultural Perspective: Hackers, Artisans, Tinkerers & Inventors in Spain & Morocco
Upcoming deliverables:
Reflection on Maker Identity
Due: April 1st at 11:59 pm on BlackBoard
Reflect on the different aspects of a Maker identity (Hatch, 2014).
Your reflection should include (1) what each of the aspects means to you, and (2) personal accounts as evidence for the development of each of the aspects.
Hatch, M. (2014). The maker manifesto. Retrieved from http://www.techshop.ws/images/0071821139 Maker Movement Manifesto Sample Chapter.pdf
Aspects: Change, Tool Up, Make, Support, Share, Give, Learn, Participate, and Play
You can find our notes from the class on Maker Identity on BlackBoard.

Reflection prompts for engineering summer camp (Case 2)

We used the following prompts for students' written reflections on each of the skills:

Imagine: "Tell us how you imagined today?"
Create: "Tell us how you created today?"
Learn/Ask: "Tell us how you learned & asked today?"
Change: "Tell us how you changed today?"
OK to fail: "Tell us how you learned that it is OK to fail today?"

VITA

Education

Ph.D., Purdue University, School of Engineering Education
August 2014 - August 2018
Bilsland Fellow
Advisor: Dr. Morgan M. Hynes
Committee Members: Drs. Robin S. Adams, Jennifer J. DeBoer, and Brian E. Gravel
Dissertation Project: Makerspaces for Education: Making as Reflective Practice and Unintended Design

M.S., Purdue University, School of Aeronautics & Astronautics
August 2013 - August 2015
Advisor: Dr. Dengfeng Sun
Major: Aerospace Systems
Minors: Aerodynamics, Mathematics and Engineering Education

B.E., PEC University of Technology, Department of Aeronautical Engineering
Advisors: Drs. T.K. Jindal and Rakesh Sharma
August 2009 - May 2013
Capstone Projects: Surveillance Micro Aerial Vehicle and Tethered Aerostat

Research Experience

Purdue University, School of Engineering Education (January 2014 – August 2017)
Research Assistant at the FACE lab (Advisor: Dr. Morgan M. Hynes)
Worked on an NSF funded project to develop an interest-based framework for engineering design challenges to broaden participation in engineering. Responsibilities included designing, conducting, presenting, and writing results for publication, conceptualizing initiatives for outreach to teachers and students, and conducting outreach workshops. Also managed the tools and technologies in the lab's Makerspace and mentored incoming undergraduate and graduate researchers.

Defense Research and Development Organization, India – Snow and Avalanche Establishment (May - July 2012)
Worked on building a mathematical model for aerodynamic lift and power produced by wind turbines in high altitude cryospheric regions. Findings from this work were used to make alterations in the placement of the turbines, generate more energy during icing, and keep people living near the turbines safer, in the state of Kashmir in India.

Indian Institute of Technology (IIT), Madras (January - May 2012)
Worked on a Lagrangian flow solver to model and understand the lift generation characteristics of flapping-wing Micro Aerial Vehicles (MAVs) in gusty environments. This project was sponsored by the Aeronautical Research and Development Board of

(ARDB) India, and was advised by Dr. Sunetra Sarkar (Associate Professor, Department of Aerospace Engineering, IIT Madras).

Teaching Experience

Faculty Apprentice for ENE 504: Leadership, Policy, and Change in STEM Education with Dr. Joyce Main, Spring 2018.
Fundamental Course in the School of Engineering Education Ph.D. program at Purdue University.

Faculty Apprentice for ENE 502: History and Philosophy of Engineering Education with Dr. Robin Adams and Dr. Alice Pawley, Fall 2017.
Fundamental Course in the School of Engineering Education Ph.D. program at Purdue University.

Instructor for ENGR 103: Introduction to Engineering Practice, Fall 2017.
First-year engineering course for the Networking Learning Community at Purdue University.

Instructor for Engineering Station at Purdue Athletics Life Success (PALS) Program, Summer 2017.
Workshop for 200 students over 10 days of camp. Students worked on engineering solutions for socially and personally relevant programs in a Makerspace setting.

Instructor for ENGR 195: Makers in Cross-Cultural Perspectives: Hackers, Artisans, Tinkerers, & Inventors in Spain & Morocco, Spring 2016.
Study Abroad Course at Purdue University.

Graduate Teaching Assistant for ENGR 131: Transforming Ideas to Innovation, Fall 2015 & Spring 2016.
First-year engineering course at Purdue University.

Co-Instructor for outreach workshops:
"Everyday Engineering," Engineering Station at PALS Summer Program, Purdue University, 2016.
"Everyday Engineering," workshops for Minority Engineering Program summer camp, Purdue University, 2016.
"Introduction to Engineering Design through the Design of Games," workshop for Minority Engineering Program summer camp, Purdue University, 2015.
"Engineering Design within an interest-based framework," Engineering Classroom for students of the ITW David Speer Academy, organized by the Minorities in Engineering Program, Purdue University, November 21, 2014.

Co-Instructor for teacher professional development:
"Novel Engineering," Professional Development for Tippecanoe School County Elementary Science Committee Members, Spring 2017.
"Makerspaces in your Classrooms," INSPIRE Teaching Academy, Purdue University, Summer 2016.

"Novel Engineering" and "Classroom Makerspaces," INSPIRE Teacher Academy, Purdue University, Summer 2015.
"Classroom Makerspaces: Broadening Engineering Contexts to Broaden Participation," Workshop at the American Society of Engineering Education Annual Teachers Workshop, Indianapolis, IN, June 2014.

Professional Development for engineering lecturers:
Co-Instructor for workshops on "Student Centered Learning," Indo-US Collaboration for Engineering Education (IUCEE), International Institute for Developing Engineering Academies (IIDEA) and Footsteps, December 2015 – January 2016.
250 participants across 5 engineering colleges in India.
Instructor for workshops on "Culturally Relevant Engineering Design" and "Learning and Engagement in Laboratories," IUCEE, May 2015.
150 participants across 3 engineering colleges in India.

Publications

Journal Publications

Hira, A., & Hynes, M. (2017) Design-based research to broaden participation in pre-college engineering: Research and practice of an interest-based engineering challenges framework. *European Journal of Engineering Education.* (Available online at https://doi.org/10.1080/03043797.2017.1405243)

Hynes, M., Joslyn, C., **Hira, A.**, J. Holly, J., & Jubelt, N. (2016). Exploring Diverse Pre-College Students' Interests and Understandings of Engineering to Promote Engineering Education for All. *International Journal of Engineering Education*, *32*(5B), 2318–2327.

Hira, A. (2015). An ontological approach towards the next generation engineer: What it means to become and be an engineer. *Journal of Engineering Education Transformations*, *28*(2&3), 179–184.

Hira, A., Kansal, V., Jindal, T. K., Kansal, J., & Ganju, A. (2012). Harnessing wind energy in cryospheric regions. *International Journal of Electrical Engineering & Technology*, *3*(2), 313–319.

Hynes, W., Hynes, M., & H**ira, A.** (2015). Applying the makerspace model to the K-12 classroom. *Educational Facility Planner*, *49*(1), 35–38.

Publications in Review

Hira, A., & Hynes, M. (2017) People, Means, and Activities: A conceptual Framework for Realizing the Educational Potential of Makerspaces. In Review for the International Journal of Technology and Design Education.

Publications in Preparation

Hira, A., & Hynes, M. (2018) The role of reflection in learning and development in Makerspace settings.

Hira, A., & DeBoer, J. (2018) Achievement, democratization, and intentionality: Critical sociological perspectives on Makerspaces for Education. To be submitted to Engaging Science, Technology, and Society.

Conference Proceedings

Hira, A., Salah, S., Hurt, C., & Hynes, M. (2017). Broadening the contexts of engineering to broaden participation: A multi-method study of an interest-based engineering challenges framework. In *ASEE 2017 Annual Conference.* Colombus, OH.

Rush, J., **Hira, A**., & Hynes, M. (2017). The role of gender in pre-college students' perceptions of engineering. In *ASEE 2017 Annual Conference.* Colombus, OH.

Beebe, C., Sarwar, U., Jubelt, N., **Hira, A.**, & Hynes, M. (2016). MAKER: A Game to Make Engineering. In ASEE 2016 Annual Conference. New Orleans, LA.

Hira, A., & Hynes, M. (2016a). A thematic analysis of the maker movement in cyberspace across cultural contexts. In *ASEE 2016 Annual Conference*. New Orleans, LA.

Hira, A., & Hynes, M. M. (2016b). Impromptu reflection as a means for self-assessment of design thinking skills. In *ASEE 2016 Annual Conference*. New Orleans, LA.

Holly, J., Joslyn, C., **Hira, A.**, Hynes, M., & Beebe, C. (2016). What do you like to do? Exploring pre-college students' career aspirations and perceptions of engineering (Work in progress). In *ASEE 2016 Annual Conference*. New Orleans, LA.

Hira, A., Holly, J., & Hynes, M. (2015) Implementation of an Interest-based Engineering Challenges Framework: A Design Research Approach (Work in progress). In *Translating Research to Practice. REES.* Dublin Institute of Technology, Ireland.

Hynes, M. M., Joslyn, C. H., & **Hira, A**. (2015). Underrepresented students' interests and how they relate to engineering. In *NARST Annual International Conference*. Chicago, IL.

Hira, A., & Hynes, M. M. (2015). Broadening participation in engineering: Making in the K-12 Classroom following an interest-based framework. *ASEE Annual Conference*. Seattle, WA.

Streveler, R. A., Pitterson, N. P., **Hira, A.**, Rodriguez-Simmonds, H., & Alvarez, J. O. (2015). Learning about engineering education research: What conceptual difficulties still exist for a new generation of scholars?. In *IEEE Frontiers in Education Conference Proceeedings* (pp. 1-6). El Paso, TX.

Hira, A., Joslyn, C. H., & Hynes, M. M. (2014). Classroom makerspaces: Identifying the opportunities and challenges. In *IEEE Frontiers in Education Conference Proceedings* (pp. 1677–1681). Madrid, Spain.

Fila, N. D., Hess, J., **Hira, A.**, Joslyn, C. H., Tolbert, D., & Hynes, M. M. (2014). The people part of engineering: Engineering for, with, and as people. In *IEEE Frontiers in Education Conference Proceedings* (pp. 727–735). Madrid, Spain.

Hira, A., Jain, N., Chhjed, S., & Sarkar, S. (2013). Lift generation characteristics of an airfoil in hover with time dependent gust models. In *9th International Conference on Intelligent Unmanned Systems*. Jaipur, India.

Hira, A., Kapoor, A., Joseph, D., & Das, S. (2010). Flying cars: A dream or reality. In *National Aerospace Olympiad (Aeronautical Society of India)*. Chandigarh, India.

Invited Talks/ Presentations

Seminar Speaker, "Educational Potential of Makerspaces", Engineering Education Graduate Seminar, Virginia Tech, Blacksburg, VA, March 2018.

Special Session, "Intergenerational Panel: The Era of Synergistic Collaboration", World Engineering Education Forum, Kuala Lumpur, Malaysia, November 2017.

Seminar Speaker, "Student voice and action in engineering education", Purdue University Engineering Education Seminar, West Lafayette, IN, February 2017.

Invited Speaker, "The role of engineering education in the quest for smart societies", World Engineering Education Forum, Seoul, The Republic of Korea, November 2016.

Plenary Speaker, "Battles and conquests of the student voice in engineering education", ASEE International Forum, New Orleans, LA, June 2016.

Fellowships, Awards, and Honors

Outstanding Graduate Student Researcher Award from the College of Engineering, Purdue University, 2018.

Graduate Student Teaching Award, School of Engineering Education, Purdue University, 2018.

Bilsland Dissertation Fellowship from the College of Engineering at Purdue University, August 2017 – July 2018. This fellowship is awarded to outstanding Ph.D. students at Purdue University to complete their dissertational work.

Purdue Student Service Learning Grant by the Office of Engagement at Purdue University, Spring 2016. Amount awarded: $1405

Silver Medal for the highest technical contributions from the Aeronautical Engineering graduating batch, PEC University of Technology, 2013.

Best Capstone Project, Aeronautical Engineering, PEC University of Technology, 2013.

"College Colour" (highest non-academic achievement) for contributions in oration, quizzing and writing, PEC University of Technology, 2013.

Membership and Service

Academic Service

Reviewer for Journal of Pre-College Engineering Education Research.
Reviewer for American Society for Engineering Education Annual Conferences 2017, 2016, and 2015.
Reviewer for Research in Engineering Education Symposium 2015.
Student Member of American Society for Engineering Education.
Student Member of American Sociological Association.
Completed Safe Zone trainings level 1 and 2.

Purdue University

Chair, Multicultural Committee, Engineering Education Graduate Students Association, Fall 2017 – Present.
Reviewer, Purdue University Graduate Student Government – Travel and Professional Grant Committee. Fall 2016 – Present.
Graduate Student Advisory Council Representative. Purdue University College of Engineering, Fall 2016 – Present.
President, Indian Graduate Students Association at Purdue, Fall 2015 – Spring 2016.
Treasurer, Engineering Education Graduate Students Association, Fall 2015 – Spring 2016.

Student Platform for Engineering Education Development (SPEED)

Founded in 2006, SPEED is a non-profit student organization that functions as a network of engineering students, who provide opinion and create an impact on future development of engineering education and its effect on society and environment. SPEED's general body and network spans approximately 2000 registered members. www.worldspeed.org

President, Fall 2016 – Present.
Managed and lead a team of 11 Vice Presidents from 8 countries with individual thrust areas and collective team goals. Initiated and mediated collaborations with external academic and corporate partners. Kept a multi-national and purely voluntary team motivated to develop and achieve goals in line with the vision of SPEED.
Key achievements of SPEED in my tenure as President:

- National forums in Argentina, Colombia, Honduras, India, Nigeria, Panama, and Taiwan.
- Initiation of a multi-national research team to understand and report impact of initiatives.
- Vision setting and strategic advances towards the next decade of student voice and action in engineering education.

- Global Student Forum in Kuala Lumpur, Malaysia which attracted 94 college students from 21 countries, and 120 local school students.

Chair – Educational Content, Annual Global Student Forum (GSF) 2016, Seoul, The Republic of Korea.
Lead the GSF's first ever educational content team responsible for design and implementation of activities during the forum.

Vice President – Educational Content, SPEED, Fall 2015 – Fall 2016.
Key contribution: Lead-developer of a Facilitator Development Program to ensure quality of facilitation across SPEED's global, national, and regional forums.