How do designers and engineers practice design while Making? A narrative inquiry of designers who Make

Avneet Hira

Department of Engineering, Morrissey College of Arts and Sciences, Boston College, Chestnut Hill, Massachusetts, USA

Morgan Hynes School of Engineering Education, College of Engineering, Purdue University, West Lafayette, Indiana, USA

Abstract

Purpose: The purpose of this paper is to understand how designers and engineers practice design while Making. Motivated by their roots in constructionist learning principles, Makerspaces are increasingly used as sites to learn design, especially in undergraduate engineering education programs. However, there has been little work on how trained designers Make and how design emerges in their Maker practices.

Design: In this paper, a conceptual framework is constructed to identify design practices within Making informed by theories of human-centered design and designerly ways of knowing. The framework is used to analyze narratives of ten experienced designers and Makers to understand how they enact design while they Make.

Findings: The rich and compelling narratives of the participants support the proposed conceptual framework, providing qualitative evidence for how designers practice and know design while Making. This study also reports on a strong theme of realizing purpose and personal meaning while Making across the participants' narratives that sheds light on the unique and educationally meaningful value of Making, as in Making being a venue for agentive constructivist learning.

Research limitations: As an educationally meaningful practice, Making can be explored from several lenses, and this research solely uses a design lens.

Practical implications: The motivations of the study are twofold. First, to understand how designers practice human-centered design and use design knowledge while Making. Second, to support the epistemological legitimacy of Maker knowledge by establishing connections with design knowledge.

Originality: This paper contributes to the limited body of scholarly work to conceptualize experienced designers' Maker practices. Work in this area can inform learning outcomes and performance expectations in educational settings.

Keywords

Makerspaces, Maker education, design practice, design knowledge, design education

Introduction

Makerspaces¹ are environments where people use various technologies to Make physical artifacts within a community of Makers. Makerspaces provide rich experiences for individuals to conceptualize, ideate and fabricate physical prototypes in response to personal and community needs. Over the last decade there has been a movement towards educational Makerspaces motivated by their educational potential (Abram, 2013; Bilkstein & Krannich, 2013; Brahms & Crowley, 2016; Chang et al., 2019; Halverson & Sheridan, 2014; Hatch, 2014; Hira et al., 2014; Kurti et al., 2014; Maker Education Initiative, 2016; Martin, 2015; Schrock, 2014; Sheridan et al., 2014). There have been inquiries into educational Making from perspectives of entrepreneurship (Benton et al., 2013), STEM teaching and learning (Bevan et al., 2015), the inclusion of marginalized youth (Calabrese Barton & Tan, 2018), reflective and individualized learning (Bowler & Champagne, 2016; Hira & Hynes, 2016; Lande & Jordan, 2014; Meehan et al., 2014), and design learning (Bowler, 2014; Jarret, 2016). A limited amount of work has explored assessment in Makerspaces beyond assessing work that students perform as part of a formal curriculum in a Makerspace setting. The limited assessment-based studies have included work in informal settings such as libraries (Cun et al., 2019) and intervention studies based on values and frameworks such as organizational values (Welch & Wyatt-Baxter, 2018) and the Learning Dimensions framework (Kumar et al., 2019). Some work has also explored using different assessment modes such as self-assessment and portfolio development (Peppler et al., 2017) and comparing written and video-recorded project assessments (Oliver et al., 2021). Perhaps the closest to our work in this study is work by Becker and Lock (2021). They assess student work in designerly ways, i.e., educators using design thinking to assess student work in Makerspaces. Still, such work is relatively recent, often exploratory, and does not explore how or why design can be observed and assessed in Maker settings. To the best of our knowledge, there has been little work to understand how trained designers Make. With this work, we propose a framework that can serve as a protocol to understand learning and development in Makerspaces from a lens of design practice.

We propose a conceptual framework for design engagement in Makerspaces by drawing parallels between Making and design practices and then using the framework to understand the Maker practices of ten experienced designers. The conceptual framework can be used to further explore the similarities and differences between the two closely related practices of design and Making. The Makers' compelling narratives serve as examples of how design is practiced in Makerspaces, and can inform the creation of rich design education learning experiences in Maker settings.

Background and Motivation

Makerspaces are increasingly being utilized as spaces for design education, especially in undergraduate engineering education programs (Saorín et al., 2017; Taheri et al., 2020). While previous studies have captured how students learn design in Makerspaces and practices of Makers in spaces unrelated to education, there has been little work to understand how trained designers Make. Understanding trained designers' practices in Makerspaces can help inform design education in Makerspaces. Hence, in this study, we explore how experienced designers with backgrounds in engineering and design, Make and practice design in Makerspaces. This

¹ We refer to Makerspaces and Making with a capital M when referring to the Maker culture to avoid being confused with our use of make in a generic sense.

inquiry into how a group of Makers with a background in design consciously or unintentionally incorporate design into their Making can inform teaching and learning of design in Makerspaces. It also contributes to our understanding of how design and Making are related and how they can support each other in practice and teaching. Since the advent of the Maker culture, there has been a steadily growing desire to create learning experiences in Makerspaces. So, with this work, we also support Maker knowledge's epistemological legitimacy, i.e., provide a framework to understand the knowledge that individuals possess and gain while Making.

The two areas of design that we focus on in this study are the nature of design practices and that of design knowledge. Both, observable practices and the nature of knowledge can help understand educational engagement in Makerspaces and develop design curricula and assessments for Making. Depending upon the intent of the Makers and sponsors of the space, Makerspaces fulfill purposes that are people-focused, means-focused, activities-focused, or a combination of the three (Hira & Hynes, 2018). A human-centered design (Krippendorff, 2006) lens for the practices in such spaces caters to both the people and activities aspects. We also adopt Cross's (1982) work on designerly ways of knowing since knowledge is a contingency for learning and development. In the next section, we draw connections between Maker practices and the two theories that inform our conceptual framework, namely, human-centered design (Krippendorff, 2006) and designerly ways of knowing (Cross, 1982). We then draw upon tenets from both theories to construct the conceptual framework, which informs our data collection and analysis to answer the research question:

How do designers and engineers practice human-centered design and designerly ways of knowing while Making?

Conceptual Framework

Human-Centered Design Practice in Makerspaces

Krippendorff characterizes human-centered design as a semantic turn from technology-centered design 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. (Krippendorff, 2006, p. 40)

Similar to Making, participation in human-centered design is akin to participation in the social construction of reality by designing artifacts that have social roles and support the community of users. For example, the Makers at the Fab Lab in Seville (Escuela Tecnica Superior de Arquitectura, 2016) design architectural innovation for their city. Krippendorff also acknowledges the role that language plays in creating words specific to communities and allowing the use of technologies by people on their terms. The Do-It-Yourself Culture's underlying ethos, which Makers ascribe to, encourages people to use technologies how they see fit, hence allowing people to use technologies on their terms within their communities.

Designerly Ways of Knowing in a Makerspace

Cross (1982) proposed design education as a third culture for human knowledge and ability after the sciences and the humanities. He writes, "This 'material culture' of design is, after all, the culture of the technologist - of the designer, doer, and maker." (p. 222) Technology synthesizes knowledge from the sciences (e.g., physical laws) and the humanities (e.g., context and perceptions) to develop artifacts of practical use. Similarly, Makerspaces are environments where individuals use technologies to Make physical artifacts within a community of fellow Makers. Also, as a phenomenon of the human-made world that values practicality, ingenuity, empathy, and context (which are practices from the humanities), to build, model, and fabricate physical artifacts (which are applications of physical laws), designerly ways of knowing provide a constructive scaffold to begin understanding the designerly ways of knowing in the context of Makerspaces. Cross's characterization of design as that of the human-made world, in contrast to the natural world (sciences) and human experience (humanities), is similar to the human-made nature of the artifacts produced and the rich contextual human experiences Makerspaces invoke. Finally, Cross makes a case for epistemological legitimacy of design as the knowledge that resides between the sciences and humanities, similar to our goal to establish epistemological legitimacy of Making.

We synthesize core operationalizable tenets from Krippendorff and Cross's theories to construct the conceptual framework for design engagements in Making. To construct the framework, we grouped similar practices from Krippendorff and ways of knowing from Cross into five areas that can be observed and practiced in educational settings. While the subsequent interview protocol and analysis comprises constructs from both theories individually, we synthesize them into five areas for the conceptual framework. Each aspect represents an area of analysis of Maker practice. Figure 1 illustrates this framework. The five areas of analysis synthesized from work by Krippendorff and Cross are in the first block with a black background. The second block in the darker grey are tenets from Krippendorff's work, and the third block in lighter grey are from Cross's work. The final semi-structured interview protocol that we used for Makers to reflect upon and narrate their Maker practices is informed by these lines of inquiry and included in Appendix A.



Figure 1: A conceptual framework for understanding how designers practice and know design while Making.

The five areas of analysis.

The first area of balancing contrasting ill-defined needs considers how designers understand and cater to contrasting and ill-defined needs that they encounter. As a method of practice, "(re)designing the characters of artifacts" 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" in the real world that are not pre-defined or are straightforward to define.

The second area represents designers adapting to new experiences. Simply put, the practice of "designing human-centered design strategies" brings to the forefront the human-centered nature of design, designing for and with human beings. The designer's "mode of thinking is 'constructive'" as it is continuously evolving considering experiences and new knowledge gathered.

The third area looks at stories that designers tell about their artifacts. The practice of "designing original artifacts, guided by narratives and metaphors" 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." 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 fourth area captures the designers connecting with others regarding their artifacts using a shared language. Designers engage in "dialogic ways to design" in their practice by being open to unpredictable outcomes that might result from connecting with users and participants via

dialogue. Designers know how to understand and express design by using "codes to both 'read' and 'write' in 'object languages'."

Lastly, the fifth area looks at the purposes that the designers' artifacts serve. By "designing artifacts that are informative (expressive) of their working" designers create artifacts whose working and functioning are evident by themselves. Designers know that "their mode of problem solving is 'solution-focused," which makes achieving the desired functionality of the artifact a priority.

Methodology

We employ a narrative inquiry methodology for this study. Narrative inquiry as a methodology is understood as an umbrella methodology to understand the human experience (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. 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 to experience and education, which has led to its widespread adoption in educational research. Additionally, Bruner wrote about (1986) "narrative cognition" as a fundamental human activity of making sense of and representing one's life 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 our study, we seek to understand the truth and the culture of our participants' experiences. Hence, we adopt narrative inquiry as a methodology, and analysis of narratives as a research method to answer the research question:

How do designers practice human-centered design and designerly ways of knowing while Making?

Analysis of narratives as a research method consists of the researcher(s) reading through the narratives multiple times and identifying themes and stories to answer the research question. We take a similar approach to this inquiry. We inquire how designers practice human-centered and designerly ways of knowing while Making by analyzing their narratives using a deductive coding approach informed by the conceptual framework. We collected these narratives by conducting narrative interviews using a protocol (Appendix A) informed by the conceptual framework and the lines of inquiry associated with each of them. The presentation of the narratives includes reporting direct quotes from the participants along with the researcher's interpretation of how they answer the research question.

In employing analysis of narratives as a research method, we forward our understanding of the participants' narratives. In this paper we do not share how the participants believe they practice human-centered design and designerly ways of knowing, instead we as researchers communicate to the readers how we believe the participants do so. This shift of perspective from the

participants to the researchers is characteristic of analysis of narratives, and similar to the role of the teacher in most formal educational settings.

Data

Our primary data are narrative interviews. Using the lines of inquiry from the conceptual framework, we constructed the interview protocol and iterated upon it via pilot interviews. In addition to the narrative interviews, we asked the participants questions to clarify parts of the interviews, and some of them shared pictures and videos of artifacts they had Made.

Thus, we collected data from our participants in the form of narrative interviews, clarifying questions, and pictures/videos of artifacts they felt comfortable sharing. The participants for this study are adults (over the age of 18) who are aware of current conceptualizations of Maker culture and identity as Makers. Their eligibility to be a part of the study was determined by them self-identifying as Makers and not their association with a particular Makerspace. In addition to identifying themselves as Makers and being aware of Maker culture, all participants have college degrees in the fields of engineering or design. Their backgrounds give them additional context and experience to apply their design training to Making. It is important to mention that we asked all the participants if they considered Making and design to be the same, and all their responses essentially communicated that even though they consider Making and design to be related, they are separate activities to them. The participants were recruited by the authors' networks of designers and engineers, and further snowball recruitment from recommendations by the participants. Table 1 captures the participants' pseudonyms and a brief description of their Maker practices.

Pseudonym	Description				
Aaron	Pro-Making school teacher who Made a robot that played tic-tac-toe against humans. He is a full-time Makerspace teacher and teaches design in Maker settings.				
Baden	He is in the process of setting up his own studio. He works out of a Craft Development Institute and Makes handicrafts. His preferred materials to Make with include paper-mâché and leather.				
Chloe	Identified with being a designer, but started developing her Maker identity after having access to a space to Make. She is associated with several Makerspaces and similar initiatives.				
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. At his facility, they have designed several of their own equipment such as 3D printers and drill presses.				
Kandra	Founder of a pop-up Makerspace and stepped away from her job in industry to support underrepresented students to pursue careers in STEM. Her Makerspaces runs educational programs for students.				
Mario	Inspired by his curiosity of working with different materials and Makes furniture pieces made of newspapers. He was inspired by his curiosity for working with different types of materials and not necessarily solving a problem.				
Layla	Inspired to change the wasteful nature of consumerism and works with a Maker charity serving people with a history of addiction. She hosts workshops where they take apart things and teach people how to fix them.				
Shaan	Hosted a project in prison to Make theft-proof bags, set up Makerspaces in several schools, and ran Maker workshops at a Maker festival in London. Handcrafts speakers made of wood with minimalist designs.				
Saaj	Inspired to Make by different materials and recently undertook a "100 days of paper cutting" challenge. His paper craft of preference is paper quilling, and is connected to different Maker communities via social media.				
Tanya	Works as a designer for a large electronics company. Thinks of the Maker in herself as a child and her professional design practice as a way to support her Maker practice financially.				

Table 1: Pseudonyms and brief descriptions of participants.

Findings

The narratives we report below are excerpts of the participants' responses to the questions from the interview protocol in Appendix A. The interview questions are aligned with the five area of analysis described above. Where needed, we draw from other parts of their narrative interviews, and information they shared with us as part of the data collection process. In the findings below, we only capture a few of the participants' narratives for each area of the conceptual framework to provide examples of how the participants practice and know design. Appendix B provides an overview of all the participants' responses for each of the areas of the conceptual framework.

Balancing contrasting ill-defined needs

(**Re**)designing the characters of artifacts. The participants share how the different characters of the artifacts they make are in constant movement, and they continuously iterate upon them. Saaj experiences competing values when deciding materials to Make with. He shares

how he thinks through colors and textures of paper to find a good compromise to produce the end result he wants of his paper crafts.

If I'm not getting say a particular color or a particular kind of texture. Somewhere I do have to compromise on the output if I'm not getting the end results. Sometimes it's not our responsibility to find the right papers or colors ... There used to be times when I had to [just] finish it

Baden shares an example of his practice of Making bags and working with wood to explain how he works through contrasting values and reconciles incompatibilities. It is important to him for the quality of the leather and chains he uses on a bag to match. He shares that he attempts to find 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 ... It guides you to find the right thing, then find a sweet spot between viability and then aesthetics and all of that.

Mario has not had to consider competing values and redesigning the characters of his artifacts yet, but anticipates doing so in the future. Interestingly, he differentiates between an "artifact" and a "design" by saying that to convert an artifact into a design, he needs to consider the financials of putting his project on the market.

[If] I'm trying to convert my artifact into design, 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].

As depicted in Appendix B, the participants practice (re)designing the characters of their artifacts by conversations between teammates, by negotiating the materials they Make with, and aligning their practice with their ethics of prioritizing quality over other criteria. Two (Tanya and Chloe) of the participants address this theme by connecting it to their broader journey as Makers, and one (Mario) does not believe that he has done so in the past but envisions himself doing so in the future when he converts his "artifact" into a "design".

Designers tackle 'ill-defined problems'. In the narrative interviews, we asked participants about their experiences with "real world problems that are not clearly defined" instead of "ill-defined problems." Gerardo's confidence in his ability to work on ill-defined problems manifests in his ability to be able to tackle almost any problem he encounters. He believes that his and his partner's curiosity and can-do spirit make a big difference in their practice.

One thing I have and my partner also has, 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 ... 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.

Tanya shares with us about a time when some of her friends and she were attempting to Make something to reduce trash production. As they started delving deeper into the issue, they realized that instead of Making new artifacts that would contribute to the problem, they needed a different approach to work on this "wicked problem."

We were all kind(s) of disturbed with the consumerist culture that almost all of the urban cities are headed towards ... so this is kind of our meager but heartfelt attempt at solving what some might call a wicked problem.

We thought that instead of buying things, just give the people power to make their own things ... a repository where people could bring things that they did not want themselves anymore, so that others could reuse it or repurpose it ... The ukulele was one of them. They started making paper lamps ... there was a lot of lighting stuff happening, fixtures, and wooden toys ...

Upon being asked the kinds of problems he solves with his Making, Saaj responds that his Making does not solve a particular problem, but he Makes 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.

Saaj Makes because of his affinity towards the process of Making, similar to Mario who Makes to invoke surprise in people by the use of materials.

Eight of the ten participants share solving ill-defined problems as part of their Maker practice. They mentor their students and workshop participants through ill-defined problems, they solve ill-defined problems which contribute to their confidence as Makers, they scope problems and probe to find the hidden assumptions in the way they understand their problems, and they respond to ill-defined requirements and needs. Two (Saaj and Mario) of the participants do not solve ill-defined problems as doing so does not align with the purpose of their Maker practices, which are to be engaged in the process of Making, and use materials in ways that are personally interesting to them.

Adapting to new experiences

Designing human-centered design strategies. The participants narrate how they adopt human-centered strategies by Making for and with people. Shaan Makes with the users of his artifacts. He believes that doing so ensures that their ideas are a part of the final product.

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

While teaching Making to his students, Aaron encourages them to collect and address feedback from the users and other relevant sources. He also facilitates his students doing so. 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.

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 ... We spend at least a week strictly focused on end user interviews and empathy building practices

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. He believes that we have been losing the connection between objects and people, and the Maker culture is one way to revive this connection.

What is happening today in the world is, we have products which we are not emotionally connected to. In the maker culture, 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 participants practice human-centered design strategies by working with the people they Make for, by experiencing connections between humans and objects, and by enacting other human-centered techniques. Some of these techniques 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 et al., 2001) and mindfulness from law and education (Murphy, 2016; Riskin, 2004). The participants who do not explicitly claim to Make for or with people (as shown in Appendix B), Make for themselves as that aligns better with their purposes to Make. Making for, with, or as people also aligns with the conception of the engineering profession as a practice for, with, and as people (Fila et al., 2014).

Their mode of thinking is 'constructive.' The participants construct their understanding of Making and their Maker practices over time, informed by new experiences and knowledge. Mario shares that his initial understanding of Making was informed by posts on social media which often represent Making as "making for the sake of making." Later, he started finding ways to push back against the waste created while 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, 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.

Chloe's Making practice, too, has changed over time. Earlier, she Made things that made her happy or things that she wanted to Make for herself. 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.

The way she solves problems is also constructive. She shares how 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 then start figuring out different ways to solve the problem, not giving up, [and] to continue to think about different ways to solve it.

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.

What happened was that in the beginning, we didn't have much experience. We had the will ... 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 [about the] 3D printer. That's one of the reasons that we decided to not reduce our machine[s] [to a means of] doing business.

Showing their constructive modes of thinking, all our participants' conceptions of Making and Maker practices have evolved with more examples in Appendix B. Some participants explain how they have learned new skills for using tools and materials, and others explain how their understanding of Making and how they engage with it has evolved.

Telling stories with artifacts

Designing original artifacts guided by narratives and metaphors. The participants share how narratives and metaphors guide their Making. Gerardo thinks back to the time he brought a 3D printer from the US to Brazil, which inspired him and his fellow Makers to Make their own 3D printer. For them building what might have been the first-ever 3D printer built in Brazil represented their empowerment.

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 ... 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.

Layla shares the story of a cassette case with solar panels that she once Made, and later facilitated an activity to Make them at a workshop. The artifact had special meaning for Layla. She talks about the past life of the different materials she used, and how since she used the solar panels to charge rechargeable batteries, the artifact signified self-sufficiency for those Making and using it.

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. 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.

Shaan narrates the story of anti-theft bags he and his fellow Makers Made with people in prison. He believes that the project helped the people see value in and constructively use their unique knowledge.

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 ... 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.

The Makers in our study realize narratives and metaphors in their Maker practice in diverse and unique ways. They tell stories about the meaning behind the artifacts they create. The meanings range from their and others' empowerment, giving new life to old materials, and their interests in playing with textures of materials. This theme of using narratives and metaphors serves as a good juncture in this paper to begin noticing how all participants Make and yet have unique motivations and stories behind their practices.

They use 'codes' that translate abstract requirements into concrete objects. We asked the 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. Thus, we present our analysis of narratives for this theme and the theme, *they use these codes to both 'read' and 'write' in 'object languages'* in the following section.

Connecting with others using shared language

Dialogic ways to design. The participants Make in dialogic ways by connecting with others and being open to unpredictable outcomes. 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.

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.

Baden believes that open and free communication is an important characteristic of Makers and communities of Makers. He shares that he has benefited from the critiques and insight his fellow Makers have offered to him in the past.

[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.

Kandra shares a story of the time she was Making a device that 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.

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." 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.

McDonnell (2009) examined conversations between architects and their clients in design settings and noticed that the boundaries of their conversations were blurred. Both parties offer information from their domain expertise, particularly when prompted to in conversation to do so. Conversations and negotiating with each other's expertise to work together are elements of the dialogic practice Makers engage with. The participants engage in dialogic ways and remain open to unpredictable outcomes by soliciting feedback from their users, and making their users and other Makers a part of their Making practices. They seek support from Makers who might be more skilled at some tool or technology, mentor others, receive feedback and collaborate over social media to be inspired and find community.

They use codes to both 'read' and 'write' in 'object languages'. The narratives in this section also inform the theme, they use 'codes' that translate abstract requirements into concrete objects from the previous aspect of telling stories with artifacts. Most of the participants use 2D sketches and 3D models as "object languages" or to translate abstract requirements into concrete objects. Chloe finds sketching to be her preferred means for expressing what she is Making to others. She also shares how 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 ... I [just] realized how another media -- form of media is like talking with your hands, so there's a lot you 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.

Tanya, too relies on computer-generated 2D sketches and 3D models to have conversations about her artifacts. She distinguishes between 2D and 3D based on the type of artifact she is working on.

So currently the team that I am working with, we work heavily on sketch ... 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 of spatial – like drawing skills and all of that.

Shaan ends up using both 2D sketches and 3D models or a mix of both. 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.

Most of the participants communicate via 2D sketching and 3D modeling, which constitute their 'object' language, and they use this language to bring abstract ideas to clear representation. As shown in Appendix B, Mario and Saaj, similar to prior themes, converse via materials. The narratives from the two constructs of object languages and translating abstract requirements to concrete objects also align with the participants being true to their reasons and motivations to Make, and adopting techniques from design and other fields to meet their needs.

Creating artifacts that serve a purpose

Designing artifacts that are informative (expressive) of their working. The participants shared how the artifacts they Make are sometimes expressive of their working. Layla shares that one can tell the use of artifacts she makes if one is aware of the motivation and processes involved in the Making of them. She shares an example of an amplifier-less radio she once made.

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 one 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 earlier when asked about her favorite artifact.

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 ...And I don't think that those meanings will be far from my reality.

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." However, interestingly, when talking about furniture pieces he Makes using newspapers, he mentions how people might not realize how strong they are until they physically interact with them.

In understanding our participants' human-centered design practices and particularly if their artifacts are expressive of their functioning, we 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, 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 their functions. One of the 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.

Their mode of problem solving is 'solution-focused'. Similar to the prior theme, the purpose of their Maker practice dictates if their practice is solution-focused or not. 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.

Similar to Aaron, Saaj acknowledges that solving a problem and seeing the result makes him happy. However, the process of Making is of utmost importance to him while Making. His primary way of Making is by paper quilling, and he shares how sometimes, while quilling, he gets so engrossed that he continues quilling for several hours.

I think the process is more important. For me I think the process of paper quilling is more important ... 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 the 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 Layla, too, it depends on what she is Making and why she is Making it. If she's Making for herself for fun, solving the problem does not matter much. She shares an example of the Maker activities she helps with at the space in Glasgow where people with histories of addiction Make things.

[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 ... 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.

The participants' practices are solution-focused when they are Making to solve a problem for others, but at other times the experience of going through the process of Making is more important to them. These narratives and the ones in the previous subsection i.e., on designing artifacts that are informative (expressive) of their working, show that the participants Make artifacts that serve a purpose when the goal of their Making is to solve a problem. The participants also Make to experience the process, play with the materials, invoke emotions in others with objects, and construct physical manifestations of stories and metaphors.

Discussion

In the above narratives, we see how the participants, who are trained engineers and designers, practice design while Making. They find ways to balance contrasting ill-defined needs by (re)designing characters of the artifacts and by tackling ill-defined problems. This practice of solving ill-defined problems is closely related to the engineering habit of mind (Katehi et al., 2009) of optimism. These engineering habits of mind, including optimism, are skills and ways of thinking associated with engineering and are crucial for engineering problem solving. The participants who do not find themselves working on ill-defined problems do not consider problem solving to be the purpose of their Maker practices.

The participants also adapt to new experiences by designing human-centered design strategies and thinking in constructive ways about their Making and while Making. While most of the participants Make for or with others, a few also make for themselves – which is also a human-centered pursuit. The participants also think in constructive ways, both while Making and about their Maker practices. Similar modes of constructive thinking as a result of constant negotiations between the thought and object languages are a crucial aspect of engineering design, as per Bucciarelli (2002). 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 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.

They tell stories with their artifacts by being guided by narratives and metaphors, and by connecting with others using a shared language. They make sense of their rich experiences and identify the salient aspects of their Making, which is similar to previous work that studied the developing expertise of designers (Ho, 2001; Kavakli & Gero, 2002). The differences between expert and novice designers' abilities to decompose ill-structured design problems into well-structured meaningful problems are similar to the participants making sense of stories and narratives to Make a physical artifact in response. Kavakli & Gero (2002) 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 participants also use codes to communicate and translate abstract requirements into concrete objects. Designers have conversations with and through materials (Schön & Wiggins, 1992). Also, they develop an understanding of the setting they are Making in using artifacts, which is similar to the designers that Luck (2007) observed in a real-world situation of designing a building, in which they used drawings, models, and other prototypes to mediate conversations.

Finally, some of the participant's artifacts solve a problem and are informative of their working if that aligns with the reasons guiding their Maker practices. Unlike the previous areas of analysis, a majority of the participants' responses do not always align directly with the area of crating artifacts that serve a purpose i.e., their artifacts are not always expressive of their working and solution-focused. Whether their artifacts are expressive of their functioning or not is dependent

on the purpose behind their Making. These purposes range from being deceptive about 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 use them in ways that were not intended, and Making for themselves and not users. This observation of the Makers' purposes informing what they Make begins to uncover how purpose is paramount to any of the other aspects of their Making practices.

A majority of the participants provide rich descriptions of how they practice the different aspects of the conceptual framework. In addition to the participants' narratives supporting the proposed framework, the thread of realizing purpose and personal meaning across the participants' narratives sheds light on the unique and educationally meaningful value of Making. It provides a venue for individuals to express and meet their purposes. Making can be used as a means for learners to be agentive in their learning (Bandura, 1989) and connect their educational experiences to personal interests and meaning (Dewey, 1938).

The insights gathered in this study about the practice of Making and the ways of knowing while Making, help situate learning and development in Makerspaces within design practice and education. The participants' narratives and our analysis of them prove the congruencies between Making and design, thus situating Maker knowledge in between science and humanities, akin to design. Further, the participants' narratives depict rich examples of designers Making while consciously or unintentionally using their design knowledge. The study helps understand how to teach and what to look for when assessing design in Maker settings. Engineering design education in Makerspaces has been limited so far to following a design process to solve a particular problem. With this study, we bring forth dynamics of design thinking and knowing beyond the traditional design oriented prompts of "solving a problem" that learning environments can help foster in students. Finally, though with this inquiry, we elicit similarities between Making and design, this study also lends itself to exploring the uniqueness of Making. As future work, we will explore how individuals realize their purposes via Making and its implications for education.

Conclusion

Grounded in theory and observations of current day Makerspace, we propose a conceptual framework to situate Making in human-centered design practices and designerly ways of knowing. We then analyze ten experienced designers' narratives following lines of inquiry informed by the conceptual framework to understand how they practice human-centered design and designerly ways of knowing while Making.

This study's contributions include the conceptual framework for understanding how designers practice and know design while Making, the compelling narratives of individual designers to inform teaching and learning, and the theme of realizing a purpose via Making which runs through each of the participants' narratives. The framework and the associated interview protocol prove to be promising tools to understand design practices and knowledge of people who identify as Makers. The framework can also be used to situate curriculum and assessment in educational Makerspaces and other settings such as design and engineering learning environments where students work on open-ended problems. While the different aspects of our proposed framework

are not exhaustive criteria for the practice and knowledge of design in Maker practice, they provide a framework grounded in theory and empirical evidence of practices and ways of knowing to observe and teach design in educational Maker settings.

Acknowledgements

We would like to thank the participants of this study for their time and for sharing their Maker stories with us.

References

- Abram, S. (2013). Makerspaces in libraries, education, and beyond. *Internet@ Schools*, 20(2), 18–20.
- Bandura, A. (1989). Human agency in social cognitive theory. *American Psychologist*, 44(9), 1175–1184. http://psycnet.apa.org/psycinfo/1990-01275-001
- Becker, S., & Lock, J. (2021). Re-imagining Assessment: Assessing Design Thinking Within Makerspaces. *Teacher as Designer: Design Thinking for Educational Change*, 119-132.
- Benton, C., Mullins, L., Sheley, K., & Dempsey, T. (2013). Makerspaces: Supporting an entrepreneurial system. City of East Lansing & East Lansing Public Library, MSU EDA University Center for Regional Economic Innovation (REI). Michigan State University, USA.
- Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2015). Learning Through STEM-Rich Tinkering: Findings From a Jointly Negotiated Research Project Taken Up in Practice. *Science Education*, 99(1), 98–120. https://doi.org/10.1002/sce.21151
- Bilkstein, P., & Krannich, D. (2013). The Maker Movement and FabLabs in Education: Experience, Technology, and Research. *IDC '13 Proceedings of the 12th International Conference on Interaction Design and Children*.
- Bowler, L. (2014). Creativity through" maker" experiences and design thinking in the education of librarians. *Knowledge Quest*, 42(5), 58.
- Bowler, L., & Champagne, R. (2016). Mindful makers: Question prompts to help guide young peoples' critical technical practices in maker spaces in libraries, museums, and community-based youth organizations. *Library and Information Science Research*, *38*(2), 117–124. https://doi.org/10.1016/j.lisr.2016.04.006
- Brahms, L., & Crowley, K. (2016). Making sense of making: Defining learning practices in MAKE magazine. *Makeology: Makers as learners*, *2*, 13-28.
- Bruner, J. (1986). Actual minds, possible worlds. Harvard University Press. https://books.google.com/books?hl=en&lr=&id=YNuBf6W2rt0C&oi=fnd&pg=PR7&dq=A ctual+minds,+possible+worlds&ots=361yQDMtwP&sig=1aVIZte_biRAY8nWd_zKLuwA FX8
- Bucciarelli, L. L. (1994). Designing Engineers. MIT Press.
- Calabrese Barton, A., & Tan, E. (2018). A Longitudinal Study of Equity-Oriented STEM-Rich Making Among Youth From Historically Marginalized Communities. *American Educational Research Journal*, 55(4), 761–800. https://doi.org/10.3102/0002831218758668
- Case, J., & Light, G. (2011). Emerging research methodologies in engineering education research. *Journal of Engineering Education*, *100*(1), 186–210. http://onlinelibrary.wiley.com/doi/10.1002/j.2168-9830.2011.tb00008.x/abstract
- Chang, S., Penney, L., Wardrip, P., Anderson, A., Craddock I., Martin C., Millerjohn, R., Stone, N., Mohammadi, G., and Dow, K. (2019). Opportunities and vignettes for library makerspaces. In *National Forum: Research and Assessment in Library Makerspaces*.

University of Wisconsin-Madison

- Cross, N. (1982). Designerly ways of knowing. *Design Studies*, *3*(4), 221–227. http://www.sciencedirect.com/science/article/pii/0142694X82900400
- Cun, A., Abramovich, S., & Smith, J. M. (2019). An assessment matrix for library makerspaces. *Library & Information Science Research*, 41(1), 39-47.
- Dewey, J. (1938). *Experience and education*. Touchstone. https://books.google.com/books?hl=en&lr=&id=JhjPK4FKpCcC&oi=fnd&pg=PA14&dq=e xperience+and+education&ots=D9uG-lJzHg&sig=4T1Sbcii9k0PmGYi3CZXwNWqKhg
- Escuela Tecnica Superior de Arquitectura. (2016). *About fablab.* http://fablabsevilla.us.es/index.php/que-es
- 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. *IEEE Frontiers in Education Conference Proceedings*, 727–735.
- Gergen, K. (1994). Realities and relationships. Harvard University Press.
- Halverson, E., & Sheridan, K. (2014). The maker movement in education. *Harvard Educational Review*, 84(4), 495–504. http://hepgjournals.org/doi/abs/10.17763/haer.84.4.34j1g68140382063
- Hatch, M. (2014). The maker manifesto. McGraw Hill Education.
- Hira, A., & Hynes, M. M. (2016). Impromptu reflection as a means for self-assessment of design thinking skills. *ASEE 2016 Annual Conference*.
- Hira, A., & Hynes, M. M. (2018). *People, Means, and Activities: A conceptual framework for realizing the educational potential of Makerspaces. Manuscript submitted for publication.*
- Hira, A., Joslyn, C. H., & Hynes, M. M. (2014). Classroom makerspaces: Identifying the opportunities and challenges. *IEEE Frontiers in Education Conference Proceedings*, 1677–1681.
- Ho, C. H. (2001). Some phenomena of problem decomposition strategy for design thinking: Differences between novices and experts. *Design Studies*, 22(1), 27–45. https://doi.org/10.1016/S0142-694X(99)00030-7
- Ideo.org. (2018). Design Kit. Methods. http://www.designkit.org/methods
- Jarrett, K. (2016). Makerspaces and Design Thinking: Perfect Together!. *The Education Digest*, 82(4), 50.
- Katehi, L., Pearson, G., & Feder, M. (2009). The Status and Nature of K-12 Engineering Education in the United States. *The Bridge Linking Engineering and Society*, *39*(3), 5–10. https://www.nae.edu/File.aspx?id=16147
- Kavakli, M., & Gero, J. S. (2002). The structure of concurrent cognitive actions: A case study on novice and expert designers. *Design Studies*, 23(1), 25–40. https://doi.org/10.1016/S0142-694X(01)00021-7
- Kellam, N. N., Gerow, K. S., & Walther, J. (2015). Narrative Analysis in Engineering Education

Research: Exploring Ways of Constructing Narratives to have Resonance with the Reader and Critical Re- search Implications. *122nd ASEE Annual Conference & Exposition*.

Krippendorff, K. (2006). The semantic turn: A new foundation for design. Taylor & Francis Group. https://books.google.com/books?hl=en&lr=&id=xwINxyVBeuIC&oi=fnd&pg=PP1&dq=th e+semantic+turn+krippendorf&ots=XdzmY7mBO0&sig=v8Qfg6zL3BTXxPIEPg9wtOJj_ Aw

- Kumar, V., Millerjohn, R., & Wardrip, P. (2019). Designing tools for observation and assessment in makerspaces. In *Proceedings of FabLearn 2019* (pp. 197-200).
- Kurti, R., Kurti, D., & Fleming, L. (2014). The philosophy of educational makerspaces part 1 of making an educational makerspace. *Teacher Librarian*, 41(5), 8. http://search.proquest.com/openview/fb1d9b6b651d635d6408355d4ebb4a6a/1?pq-origsite= gscholar
- Lande, M., & Jordan, S. S. (2014). Methods for examining the educational pathways of adult makers. ASEE Annual Conference and Exposition, Conference Proceedings.
- Luck, R. (2007). Using artefacts to mediate understanding in design conversations. *Building Research and Information*, *35*(1), 28–41. https://doi.org/10.1080/09613210600879949
- Maker Education Initiative. (2016). History. Maker Ed.
- Martin, L. (2015). The Promise of the Maker Movement for Education. *Journal of Pre-College Engineering Education Research (J-PEER)*, 5(1), Article 4.
- McAdams, D. (2006). No The role of narrative in personality psychology today. *Narrative Inquiry*, *16*(1), 11–18.
- McDonnell, J. (2009). Collaborative negotiation in design: A study of design conversations between architect and building users. *CoDesign*, 5(1), 35-50.
- McLeod, J. (2006). Narrative thinking and the emergence of postpsychological therapies. Narrative inquiry, *Narrative Inquiry*, *16*(1), 201–210.
- Meehan, R., Gravel, B., & Shapiro, B. (2014). *Card-sorting task to establish community values in designing makerspaces*.
- Murphy, J. T. (2016). *Dancing in the rain: Leading with Compassion, Vitality, and Mindfulness in Education*. Harvard Education Press.
- Myers, D. J., Buoye, A. J., McDermott, J., Strickler, D. E., & Ryman, R. G. (2001). Signals, Symbols, and Vibes: An Exercise in Cross-Cultural Interaction. *Teaching Sociology*, 29(1), 95. https://doi.org/10.2307/1318786
- Oliver, K. M., Houchins, J. K., Moore, R. L., & Wang, C. (2021). Informing makerspace outcomes through a linguistic analysis of written and video-recorded project assessments. *International Journal of Science and Mathematics Education*, 19(2), 333-354.
- Peppler, K., Keune, A., Xia, F., & Chang, S. (2017). Survey of assessment in makerspaces. *Open Portfolio Project.*

- Polkinghorne, D. (1995). Narrative configuration in qualitative analysis. *International Journal of Qualitative Studies in Education*, 8(1), 5–23.
- Riessman, C. K. (1993). Narrative Analysis. Sage. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.470.1392&rep=rep1&type=pdf
- Riskin, L. L. (2004). Mindfulness: Foundational Training for Dispute Resolution. *Journal of Legal Education*, 54(1), 79–90.
- Saorín, J. L., Melian-Diaz, D., Bonnet, A., Carrera, C. C., Meier, C., & De La Torre-Cantero, J. (2017). Makerspace teaching-learning environment to enhance creative competence in engineering students. *Thinking Skills and Creativity*, 23, 188-198.
- Schon, D., & Wiggins, G. (1992). Kinds of seeing and their functions in designing. *Design Studies*, *13*(2), 135–156.
- Schrock, A. R. (2014). "Education in Disguise": Culture of a Hacker and Maker Space. InterActions: UCLA Journal of Education and Information Studies, 10(1). https://escholarship.org/uc/item/0js1n1qg
- Sheridan, K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review*, 84(4), 505–531. http://hepgjournals.org/doi/abs/10.17763/haer.84.4.brr34733723j648u
- Smith, B. (2007). The state of the art in narrative inquiry Some reflections. *Narrative Inquiry*, *17*(2), 391–398.
- Smith, C. (2000). Content analysis and narrative analysis. In H. T. Reis & C. M. Judd (Eds.), *Handbook of research methods in social and personality psychology* (pp. 313–335). Cambridge University Press.
- Taheri, P., Robbins, P., & Maalej, S. (2020). Makerspaces in First-Year Engineering Education. *Education Sciences*, 10(1), 8.
- Welch, A. N., & Wyatt-Baxter, K. (2018). Beyond metrics: Connecting academic library makerspace assessment practices with organizational values. *Library Hi Tech*.

Corresponding author: Avneet Hira can be contacted at avneet.hira@bc.edu

Appendix A. Interview Protocol

K – Krippendorff (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)
 - o 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)
 - o 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)
 - o 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)
 - o 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)
 - o 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)
 - o 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)
 - o 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)
 - o 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)
 - o 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?
 - o 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?

Name	(Re)designing the characters of artifacts	Designers tackle 'ill-defined' problems	Designing human-centered design strategies	Their mode of thinking is 'constructive'	Designing original artifacts, guided by narratives and metaphors
Aaron	Mentors students to consider contrasting values and reconcile incom patibilities	His students solve ill-defined real-world problems	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 understood it before	Mentors his student to Make to develop holistically as individuals prepared to face failure and uncertain challenges
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	For him Making is often about making gestures for people he cares for	Has learned to deconstruct complicated problems and understand them as parts	Makes artifacts as gestures, for e.g. the organizer for his friend
Chloe	Manages her different practices as a Maker by (re)designing her practice and life around it	Responded to a set of ill-defined prompts from a customer to Make her a painting	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	The artifacts she Makes are representative of her different identities and her journey.
3erardo	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	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 i.e. fabrication	His team's 3D printer represents their empowerment.
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	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 she often associated with Making	The educational programming for solving homelessness represented the students caring about others they went to school with and her caring for them
Mario	Does not believe he does so currently, but can see himælf 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	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"	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	Mentors workshop participants to consider contrasting values and reconcile incompatibilities	Her workshop participants do not solve such problems at their schools, but do so at her workshops	Makes for others and some artifacts she Makes support others Makers in Making	Has become more comfortable using Maker equipment, which Makes her feel more confident about her skills involving tools and machines	The cassette player with a solar panel is representative of the past life of its parts and her workshop participants' self- sufficiency
Shaan	Prioritizes quality while still keeping the final artifact financially accessible	Makes innovative speakers and encourages schoolstudents to solve real-world problems	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	The anti-theft bags that he Made with prisoners help them realize their productivity and special knowledge
Saaj	Decides materials to produce the effects he wants with his artifacts	Does not believe that his Making contributes to any purpose external to his own affinity towards the process of Making	Makes to realize his interest in working with Materials and talks with others for gathering new knowledge, but primarily Makes by himself	Has learned new techniques of paper quilling over time	His first paper quilling of the phoenix initiated him into the craft, which now is the focus of his Making
Fan ya	She was initiated into Making by (re)designing her and her friends' ideas to work on a project	Worked on different kinds of programming with her friends to deter the consumerist culture	Distinguishes between Making and design by thinking of Making as something she does for henself and design as something she does for others	Now documents her progress better and thinks of Making in more entrepreneurial ways	Her Ukulele is representative of her interests in both Making and music, and something she could carry home with her

Appendix B. labular representation of the participants' narray
--

	They use 'codes' that translate abstract requirements into concrete objects	Dialogic ways to design	They use these codes to both 'read' and 'write' in 'object languages'	Designing artifacts that are informative (expressive) of their working	Their mode of problem-solving is 'solution-focused'
Aaron	The 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, and are reported together in the theme use to 'read' and 'write' in 'object languages'.	Coaches his students through Making by engaging with his students via conversation	Uses design vocabulary and techniques such as sketching and prototyping	His students are not always able to Make artifacts that are expressive of their working, but he and the other instructors encourage and support them in doing so.	It is important for his students to find solutions to the problems they are solving, but practicing Making and learning realted skills holds highest value
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	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		Working with others on artifacts that evolve over the process of Making is her favorite aspect of Making	Communicates and conceptualizes using sketches	Believes that 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		Him and his team of Makers always work together	Him and his team use sketches from CAD software to communicate	His artifacts are expressive of their functioning to the audience 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
Kandra		Benefits from both, the users of her artifacts and her community of Makers	Prefers using sketches and prototypes to communicate	People will be able to devise uses for her artifacts, but those uses might be missing nuances	When she Makes for others, it is important for her to solve the problem, but when she Makes for herself it is not
Mario		Connects with others to learn new techniques and has also benefitted from others' advice on how to do certain things better.	Would rather speak with someone directly to guage if they are able to understand his communication	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		Hasbeen 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	People who are aware of her process of Making, can tell what she is Making	It is important for her to solve the problem when she is Making for others
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	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		Uses social media to learn new techniques, be inspired, share his work, and also collaborate with people	Believes that the conversation between two individuals is more important than the medium and language he uses	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 Making is most important to him
Tanya		Hasbeen 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	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 be cognizant of when her efforts to solve the problem outweigh the value of the solution for her