

Learning in the Making: A Comparative Case Study of Three Makerspaces

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Through a comparative case study, Sheridan and colleagues explore how makerspaces may function as learning environments. Drawing on field observations, interviews, and analysis of artifacts, videos, and other documents, the authors describe features of three makerspaces and how participants learn and develop through complex design and making practices. They describe how the makerspaces help individuals identify problems, build models, learn and apply skills, revise ideas, and share new knowledge with others. The authors conclude with a discussion of the implications of their findings for this emergent field.

Makerspaces are informal sites for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products. These spaces are a key component of a larger maker movement comprised of individual makers, local and regional maker events and publications, and a host of digital do-

it-yourself resources (Dougherty, 2012; Gershenfeld, 2007). Makerspaces and the collaborative design and making activities they support have generated interest in diverse educational realms. For instance, libraries and museums have designed makerspaces to promote creative activity, resource sharing, and active engagement with materials, processes, and ideas in their collections and exhibits (Britton, 2012; Honey & Kanter, 2013). As K–12 schools align their curricula with the Next Generation Science Standards' focus on the importance of design and technology (NRC, 2012) and engineering (Schunn, Silk, & Apedoe, 2012) and the new media arts standards across the arts disciplines (NCCAS, 2014), the multidisciplinary design work often seen in makerspaces is inspiring to educators. For instance, in Virginia's Albemarle County Public Schools, learning through making is infused in diverse subjects—through designated in-school makerspaces, making practices are embedded in the school curriculum, summer programs, and teacher professional development (P. Moran, superintendent, personal communication, May 29, 2014).

In the launch of his Educate to Innovate campaign, President Obama (2009) highlighted the value of making experiences: "I want us all to think about new and creative ways to engage young people in science and engineering, whether it's science festivals, robotics competitions, fairs that encourage young people to create and build and invent—to be makers of things, not just consumers of things." The campaign posits that providing opportunities for children to learn to design and make will yield more interest in science and engineering and more active stances toward learning. Educators in multiple contexts have taken up this call to support making by adapting principles of the maker movement to the design of informal learning environments in libraries, museums, and other community spaces (Halverson & Sheridan, 2014b).

Research and practice initiatives have emerged to develop makerspaces, train facilitators for making, and create Web resources for learning through making (Honey & Kanter, 2013; Peppler & Bender, 2013). To date, empirical studies have focused on what youth learn through targeted making activities that might occur within a makerspace, such as building circuits into textiles (Buechley, Peppler, Eisenberg, & Kafai, 2013) or using the programming language, Scratch, for interactive media design (e.g., Resnick et al., 2009). The current study builds on this work by examining the broader range of practices occurring within different makerspaces in order to gain a fuller understanding of learning in these informal multidisciplinary and often multigenerational spaces.

Despite a flurry of interest and activity around designing and creating makerspaces, we still know little about the content and processes of learning in makerspaces. In this comparative case study of three makerspaces, we seek to understand how different makerspaces function as learning environments. To this end, the guiding research questions are:

1. Who participates in these makerspaces?
2. How and to what ends are tools, materials, and processes used in each makerspace?
3. What are the arrangements for learning, teaching, and collaborating in each space?

To explore these questions, we discuss three different, purposefully selected makerspaces: Sector67, a member-based makerspace located in Madison, Wisconsin, and comprising mostly adults; Mt. Elliott Makerspace, a community makerspace located in Detroit and comprising primarily youth; and Makeshop, a museum makerspace located inside the Children's Museum of Pittsburgh and comprising largely young children and families visiting the museum, whose making is facilitated by adult makers.

We locate our work in relation to theoretical conceptions of learning through making and the study of learning environments for making. We first approach each of the makerspaces as individual cases and describe the space, participants, and their activities. We then look across cases to provide an account of the learning and activities that happen therein. Finally, we identify a set of unifying themes that may be important findings for designers and researchers of makerspaces and, more generally, any learning environments involving making to consider.

Background

Learning in the Making: Constructionism and Representation

Makerspaces are comprised of participants of different ages and levels of experience who work with varied media, but a commonality is that these spaces all involve making—developing an idea and constructing it into some physical or digital form. The centrality of developing an idea and then designing and creating an external representation of that idea is a core tenet of constructionism (Harel & Papert, 1991; Kafai, 2006; Kafai & Resnick, 1996). Constructionism aligns with, and builds on, constructivism, a long-standing perspective in the developmental and psychological sciences that holds knowledge as actively constructed by learners through experience and that sees learning as the ongoing construction and revision of mental representations. Constructionism extends the theory of constructivism to focus explicitly on how the making of external artifacts supports learners' conceptual understanding. In the constructionist view, the artifact itself functions as an evolving representation of the learner's thinking. Moreover, the artifact promotes understanding through interpretation—the learner must interpret the artifact as a representative object, and this process further develops knowledge (Papert, 1993).

Design processes are usually conceptualized in terms of an iterative sequence of ideation, or finding a problem, drafting ideas, creating a product, reflect-

ing, and revising (Cross, 2011). In science education, researchers have applied constructionist theory to explore how the design process supports students in learning physics or engineering concepts through targeted problem solving (Kolodner et al., 2003). Researchers argue that the design process—where learners generate an idea or find a problem, create a prototype, assess how it works, revise, and iterate—can surface misconceptions and help learners identify causal relationships between design features and key measurable outcomes (Fortus et al., 2005; Kolodner et al., 2003). Empirical inquiry into learning in the making in the context of arts education focuses on metarepresentational competence (MRC), the understanding of how tools support communicating an idea, when to invoke certain tools, and for what purpose. Halverson (2013) examines the relationship between interpretation and representation, describing how the art-making process helps to develop MRC. Because MRC describes an understanding of tools and ideas as reciprocally related, this is a construct valued not just in art making but across STEM fields (diSessa & Sherin, 2000). In our study, we leverage MRC to understand learning through making across a range of project scales, levels of support, and stages of completion using a wide variety of tools, materials, and processes.

Learning Environments for Making

To understand makerspaces as learning environments, we draw from literature on both formal education environments for making and informal communities of practice in order to reflect the diverse learning and teaching arrangements present in these spaces. Many makerspaces resemble studio arts learning environments, where participants work independently or collaboratively with materials to design and make (Halverson & Sheridan, 2014b). Based on analysis of intensive visual arts classes, Hetland, Winner, Veenema, and Sheridan (2013) identified four key “studio structures” as central to the design of studio learning environments: (1) in *demonstration-lectures*, teachers pose open-ended challenges, show exemplars, and demonstrate processes to engage and inform students, (2) in *students-at-work*, students work on their art and teachers circle the room observing and giving “just-in-time” instruction, (3) in *critiques*, the working process is paused as the group collectively reflects on student work, and (4) in *exhibitions*, students’ work is shared with a community beyond the studio classroom.

Although Hetland and colleagues (2013) focused on traditional visual art forms in classroom environments, the four studio structures also provide a framework for the teaching of digital media, such as computer animation and game design, and for informal educational environments where there are often more varied peer teaching, mentoring, and coaching roles than in schools (Clark & Sheridan, 2010; Halverson & Sheridan, 2014a; Sheridan, 2011; Sheridan, Clark, & Williams, 2013). We use this framework because each of the makerspaces offered—either to regular members or visitors to the space—structured workshops or classes that have elements aligned with these studio

class studies. In addition, attending to these studio structures made their functional equivalents visible in the diverse kinds of learning arrangements often present in makerspaces. Though there were often no formal teacher-student relationships, individuals and small groups regularly demonstrated techniques and processes, observed and helped others while they worked, critiqued each other's work, and found outlets to exhibit their work. The studio model helped us see pedagogical structure in the flow of the multiple informal interactions and activities characteristic of the makerspaces we observed.

While the studio structures model helps us frame the work of makerspaces, we also use the lens of *community of practice*—that is, people who work in a common domain and through their participation in the community share knowledge and experiences (Lave & Wenger, 1991; Wenger, 1998). The communities of practice framework, where learning is an ongoing part of social interaction rather than a discrete activity, allows us to see how different elements of makerspaces work in concert in each space. Specifically, it helps us frame how the shared use of space, tools, and materials; shifting teaching and learning arrangements; individual and collective goals; and emergent documentation of rules, protocols, and processes for participation and action work together to form each community of practice with its own particular features. An inherent assumption of the framework is that the community has a shared domain of interest (Morton, 2012; Wenger, 1998). This was of particular importance in our study, given that activities in one community may range from bike repair to sewing to android application programming. The communities of practice frame helps make visible how *making* broadly construed becomes the shared domain. This insight motivated us to look for common practices across making media, such as repurposing existing items and reverse engineering. In addition, a community of practice frame highlights how the environment promotes a sense of identity as a member of the community (Wenger, 1998). One of our interests in studying makerspaces is to understand who joins these communities, why they participate, and how their participation changes over time. Finally, much of the observed activity in the makerspaces (e.g., playing with resident pets, taking walks, talking, and playing) could seem peripheral to making, yet these activities are central to learning and forming a sense of community and are important to providing space and time for idea generation.

Methods

We use comparative case studies of three makerspaces that are motivated by the broad research goal of understanding makerspaces and how they function as learning environments. A case study approach allows the integration of diverse sources of evidence to build a deep within-case understanding of each makerspace (Stake, 2008). A comparative case approach, however, is particularly suited to analyzing commonalities and differences across sites (Miles, Huberman, & Saldaña, 2014), an approach we deemed appropriate given the

diversity of makerspaces and the trend toward designing youth and family spaces after adult makerspaces.

Site Selection

We used purposive sampling to select the three makerspaces. Each of the sites was founded in 2010. We chose sites that self-identify as “makerspaces” and support open-ended, self-directed, individual, or collaborative projects. Another aim was to select sites that reflect some of the diversity in types of participants and the nature of participation. We chose Sector67 as an example of a space that was created by adult makers chiefly for other adults with making interests and that is primarily supported by the membership fees paid by these participants. We chose Mt. Elliott Makerspace as an example of a space that was created to serve community needs in a neighborhood with limited economic resources and that is supported primarily by grant funding. We chose Makeshop as an example of a museum-based space that is open to all youth and families who visit the museum and that is funded through museum operations and additional grants and partnerships. While our focus is describing learning in our chosen sites, we also want readers to draw insights that may apply to makerspaces with similar approaches and features.

Data Collection

We collected the data reported in this study over the course of one year, from September 2012 to August 2013. We conducted over 150 hours of field observations and interviews as well as extensive analyses of Web-based archives, such as blog postings, online community discussions, and video and photo documentation of making activities and finished works. We employed observations, interviews, and reviews of artifacts at each site but adapted our data collection to best suit the particular site and our access to it. Each makerspace and its activities served as the functional boundary of each case study (Stake, 2008). For instance, forming collaborations with outside groups was a primary and ongoing feature of Mt. Elliott, so we collected data on those connections. Sector67 and Makeshop were local to the researchers, allowing for more frequent observations and interviews. Mt. Elliott was further away but had rich digital photo and video documentation of their activities, allowing us to conduct much of our study virtually through archive and artifact analysis and interviews with the site director, punctuated by intensive visits to observe and interview participants (Hine, 2008). We used triangulation to strengthen our analysis, collecting diverse sources of information to help ensure a full picture of participation in the makerspaces.

Both a key limitation and strength of our study is the diversity of our cases. To accommodate this diversity, our comparative case protocol focused on broad descriptive categories about space, tools, materials, participants, and activities. Building theory from diverse instances can be a powerful way to develop inclusive accounts (Stake, 2008). However, a limitation is that these

inclusive accounts may have somewhat less nuance in the constructs that apply across sites.

Data Analysis

Our analysis was ongoing, and throughout data collection we transcribed interviews and video observations, created case summary sheets, and wrote analytic memos. Our research team regularly discussed our findings and held periodic meetings with an external research advisory board where we presented our findings to date and solicited feedback to guide further data collection and analysis. We also conducted member checks to examine how our interpretations aligned with those of the founders and participants of the spaces.

Researchers collectively reviewed data from all three sites in a common shared database. For our comparative case analysis, we used *a priori* concepts drawn from literature on constructionism (Kafai, 2006), communities of practice (Wenger, 1998), the Studio Thinking Framework (Hetland et al., 2013), and concepts that emerged from our data collection. We used these to describe key qualities and patterns within each site and similarities and differences across them (Miles et al., 2014; Stake, 2008). For instance, from our initial descriptive accounts of activities and participation, we identified the range of learning arrangements we observed (e.g., peer collaboration, family interaction, structured workshop, one-on-one facilitation), how they were present across sites, and what kinds of activities they supported (e.g., learning how to use a tool or piece of equipment, introduction to basic techniques, revision of a design idea).

We resolved our analytic disagreements through discussion and by examining relevant evidence. Most differences arose as we tried to build theory about learning in the making that worked across sites. However, this discussion across the diverse sites proved to make our theory more inclusive (Stake, 2008). For instance, based on prior literature, we initially focused on how specific learning arrangements (e.g., peer collaboration, apprenticeship) functioned in the learning environment. However, as we grappled with drawing meaningful connections among, for instance, how peer collaboration was enacted between two toddlers in Makeshop, two teens in Mt. Elliott, and two adults in Sector67, we came to realize the diversity of learning arrangements *within* each space was a marked finding about learning in these spaces. Thus, we shifted our analytic focus to describe and examine the impact of that diversity in each learning environment.

Findings: Understanding Each of the Three Makerspaces as Learning Environments

Our study aims to understand how the selected makerspaces function as learning environments. In this section we look at each of our three makerspaces holistically, focusing on how activity is organized in the space. We describe (a)

who participates in the makerspace and what they appear to learn through participation; (b) how and to what ends tools, materials, and processes are used; and (c) how learning, teaching, and collaboration are arranged at the site.

Sector67: Madison, Wisconsin

Sector67,¹ a makerspace in Madison, Wisconsin, with over 8,500 square feet of work space, is described on its Web site as a “Community Workspace/Hackerspace²/Makerspace/Collaborative Environment.” Visitors are greeted by an entrance area with couches and a large table with LEGO bricks, encouraging hanging out and highlighting the social aspect of the space, which is further reflected in large common tables where people also regularly socialize and work together. Sector67’s subtitle is “Center for Prototyping, Technology, and Advanced Manufacturing,” and, as such, it offers expensive technical equipment, including welders, a suite of woodworking tools, 3-D printers, commercial sewing machines, kilns, multiple oscilloscopes, facilities for an iron pour, and a laser cutter. The space evolves continually. One member explained, “A thing that this place is good about, is kind of growing into what is necessary.” By this he meant that equipment is purchased and the space is adapted in response to project and community needs. Decisions on equipment purchases, while typically made by the director, are informed by regular community meetings and informal discussions with members about upcoming needs and wishes or in response to a growing pattern of use. For instance, a recent equipment acquisition was an extruder, which was purchased to provide a tool that can recycle the discarded 3-D printed prototypes that have been accumulating in the space to create new filament for more 3-D printing.

Sector67 is largely subsidized by members who pay a monthly fee to use the space and equipment. These are primarily adults (though a few families with children participate) who have prior expertise and/or interest in some sphere of making that the space supports. Yet, the Web site explicitly invites nonexperts to join, stating, “Zero experience necessary, only enthusiasm to learn required.” While membership is not exclusive, Chris Meyer, the director, describes an interview process that ensures that prospective members “understand what the space can do and what they can do or can’t do.” Specifically, Sector67 does not support people who “don’t want to learn how to do stuff, they just want to have it done.” Meyer identifies three types of participants: entrepreneurs, who create products for sale or under contract; hobbyists, who make for fun in their free time; and kids, who are learning to be makers. (We observed adults learning to be makers as well, so it might be more appropriate to broaden “kids” to “novices.”) Hobbyists and entrepreneurs make up the bulk of the approximately sixty members in the space. Novice adult makers and children are more likely to regularly attend classes and workshops than have a membership. Other nonmember participants include friends of members who hang out in the space, learners who attend occasional workshops

or special events, and nonlocal makers who join the online forum to discuss projects. Monthly meetings are held in the space to propose projects, discuss upcoming events and issues, and get feedback on work. These meetings are open to the public and often serve as a venue for interested people to get a better sense of the space and how it works.

We observed a wide variety of making at Sector67. Members created quick impromptu projects for personal use, such as an engraved phone case, and then got back to work on industrial design projects for their start-up companies. One member built wind turbines. Someone came in to quickly cut pipe for a plumbing repair in his house, while others worked weeks on hobbyist or art projects such as building an hourglass or welding bike chain sculptures. Members hosted diverse events in the space, including ones to collectively mend clothes, repair or repurpose broken items, and play networked games. They taught workshops or classes on a range of skills, including sewing, woodworking, computer programming, and 3-D printing. Sector67 hosts community events such as an annual iron pour attended by hundreds of people. A number of collaborative projects, such as building and racing power cars, are ongoing in the space. Power cars resemble, and may include parts from, children's motorized electric vehicles that they can ride. Multiple members at Sector67 collaborate on building these cars, mainly out of salvaged parts; they work on optimizing their engines, steering, and cooling systems and experiment with their designs for different races and obstacle course competitions against other makerspaces and engineering school teams.

— “Somebody can be the leader if they want”: Community Roles and Learning in Sector67

Members work on projects individually, in formal small-group collaborations, and through community projects distributed across Sector67 as members' interests ebb and flow. A critical feature of Sector67 is how it functions as a community; nearly everyone interviewed highlighted “people” as being the most valued aspect of the space. Meyer explained how his thinking about Sector67 transformed from considering it to be a place with accessible tools to a community space for making: “And it was only after we had a building with nothing in it except for like two tools that I realized the equipment doesn't make any difference at all. That people will show up no matter what if there are other good people there that are doing interesting things.”

Of our three sites, Sector67 functions the most clearly as a community of practice for makers. There is a flexible structure to how work, learning, and teaching happen on individual and shared projects, with roles shifting (Wenger, 1998). As one member described the process, “When it comes to leaders and stuff, it's kinda up for grabs. Somebody can be the leader if they want.” Traditionally in communities of practice, members have a shared discipline or domain about which they share ideas, insights, and experiences (Wenger, 1998). At Sector67, the broad activity of making becomes the shared

domain. Though participants make across diverse media, such as Android applications, injection molding, large-scale metal sculpture, or silk-screening, they often view this as a strength. One member explained:

I mean, I always talk about the community here being the biggest thing. You know, there's quite a few very sharp people and people that have a lot of experience . . . This being a hackerspace you get a lot of alternative experiences rather than just traditional education . . . You don't usually get the normal way of doing things, which is kind of a good thing, because you tend to learn a lot from that.

While one can imagine that a community like this supports creative work, this comment makes clear that Sector67 is principally considered a place to learn—not to just practice what one already knows but to expand skills, deepen knowledge, and tackle increasingly difficult problems. One member likened the space to a gym, where one member works on building up a repertoire of skills, while others serve as trainers and spotters to encourage and guide development.

Learning is structured in a range of ways in Sector67. Most formally, the space offers dozens of workshops ranging from introductory hands-on art and engineering workshops for kids and novice adults to more specialized classes, including industrial sewing, 3-D printing, and computer programming. Typically, classes and workshops are hosted by members in an area of their interest or expertise and are mainly attended by nonmembers. Another sphere of formalized learning in the space is equipment training. Sector67 policy states that members must be trained in using equipment safely and correctly before they can operate it. Training someone on the equipment is typically a just-in-time process with experts helping less-experienced members create something they are interested in making. Interestingly, there is often a blurring of training, designing, and making in this learning process. Specifically, when the space acquired a laser cutter, one member took informal responsibility for learning the machine:

I'm trying to learn how to use this laser cutter. And figure out what its extents are. What is the maximum thickness we can cut through? What's the weirdest material we can cut through? What happens when you cut leather? So other people walk in and they want to make something out of leather. So that fits my goal. I was doing that anyway . . . It justifies my education because it totally helps somebody else with their project and makes their day because I'm good at this stuff.

This process of teaching others provides an impetus for the trainer to test out another dimension of the laser cutter; someone needing to cut leather for a project affords him the opportunity to see what specifications suit that material. He envisions creating a resource for makers with examples of various engravings and cuts on all different materials. This approach to equipment training illustrates the creativity of the learning environment: rather than just engaging in a rote series of steps to train each new user, there is exploration,

the development of useful communal resources, and growth in understanding of the equipment for the volunteer “trainer.”

Feedback from others working in the space—solicited and unsolicited—is commonplace and a key driver of learning. One member contrasted how he learns more at Sector67 than he did when working on his own:

I was trying to do an electronics project that I hadn’t done before, working with like microcontrollers and building up some power electronics . . . [When you] do some of those things in a vacuum, you can get away with doing the wrong thing for way too long.

The makerspace community served to alert him to false paths and unproductive approaches when trying a new project. This is a common finding in studies of other communities of practice: participants learn from others’ prior frustrations (Wenger, 1998).

Nearly every instance of making that we observed involved someone wandering over with questions and suggestions. Likewise, every person who discussed their making process mentioned how others helped them develop ideas or solve problems. For instance, one entrepreneur compared the advantages of starting up a company in Sector67 versus a traditional business environment:

It’s amazing how many different ideas you’ll get in a place like this, because you have very active minds and people with different backgrounds and whatnot. So if you come up against something that’s troublesome, it’s a really easy place to get an answer to some of those situations that would normally stump somebody in a regular company where you’re pretty closed off . . . You might kinda sit there and think about it forever and maybe you come up with an answer and maybe you don’t. But in a place like this you kinda can throw it out to the community fairly quickly and get an answer really quickly.

Questions are “thrown out to the community” in a variety of ways—in the space as they arise, during monthly meetings, and in the online forums. Answers to straightforward queries such as “What programming language is best to learn first?” or “Can I weld black steel plumbing pipe?” are answered promptly and in great depth (Litts, Halverson, Stoiber, & Bakker, 2014). Other questions become challenges for a member or group of members to solve. However, this constant engagement with help and feedback can result in disagreements or be interpreted as an unnecessary interruption. In interviews, several participants mentioned that they find it hard to concentrate on a project if there are too many people in the space and expressed frustration when people offer advice or make comments on their work at a stage in the project where they do not want it.

Collaborative projects are another powerful site for learning at Sector67. The two biggest projects to date have been the power cars and multiple launches of high-altitude balloons. The scope and length of these projects reveal several key affordances of Sector67 as a collaborative learning space.

For instance, a high-altitude balloon launch involves building a balloon with a landing apparatus, wiring a microcontroller to a cell phone to track its flight and take photographs, and ensuring that all these dimensions function under the changing temperatures and air conditions at high altitudes. Thus, the project's scope requires the distributed expertise of multiple members. Knowledge of circuitry is necessary to launch and track a balloon through the atmosphere, yet those who know circuitry may not know the physics of balloon materials or how to program a GPS-enabled tracking device. Second, the duration of the projects means that makers are engaged in multiple design/review/test cycles that encourage failure and iteration as powerful forms of learning. Finally, because these projects are for public competitions, they have built-in external audiences, and so considering the audience becomes an integral part of the design process. Makers consider the criteria of the competition and expectations of the judges as they create and refine their designs.

Mount Elliott Makerspace: Detroit, Michigan

Founded in 2010 and located in the basement of a church on the east side of Detroit, Mt. Elliott's mission statement describes the space as "a village workshop where people make, tinker, and learn together."³ A key aim of its founder, Jeff Sturges, is to develop a model for makerspaces that can thrive in underresourced neighborhoods by minimizing expenses and ensuring no financial barriers to participation. Mt. Elliott is multidisciplinary, with participants focusing on diverse areas including transportation, food, digital tools and electronics, design and fabrication, music, and art. The evolving mission statement drafted collectively by makerspace participants and located at the entrance to the space explicitly states their priority for engaging in "creative work and productive learning." Bright-yellow walls enliven the large basement space that is divided into separate "shops," including areas for bike repair, woodworking, electronics, and silk-screening, as well as a kitchen and computer lab. Like Sector67, the space continually evolves, with different shops added over time as interest in or resources for new activities emerge. One teen described helping clear out an unused "junk-filled storage room" in the church, then seeing his friends and the resident woodworker transform it into a woodshop framed by a partial glass-block wall: "It looked like professionals did it. It looked so good. I couldn't believe it." These separate but connected spaces are an intentional part of Mt. Elliott's design—to support focused work in a given area while also encouraging community connections and flow among the making "disciplines." This intention translates into action, as there are frequent examples of people working in one area, watching someone in another, and drifting over to get involved. For instance, a young boy who came in to do some bike repairs walked by two older boys who had just figured out how to make a series of LEDs light up in a sequence, and he became inspired to create a lit sequence to decorate his bike. (And a few weeks later at the Detroit Maker Faire, his bike was sporting the new lights he made.)

Though participants at Mt. Elliott have diverse backgrounds, and ages ranging from toddlers to senior citizens, most regular ongoing participants are youth between eight and nineteen years from the local neighborhood and a few core adults. Some adults are highly skilled makers, such as the creator of the woodshop who regularly builds materials for the space and works on his own projects and a retired technician who is famed for “bringing to life” broken machines that are more than forty or fifty years old. Other adults begin with little making experience but volunteer to work with youth and then acquire making and technology skills in the space. The founder, Sturges, is the only consistent full-time employee; on occasion, other adults take on paid roles. Now that the makerspace has been open a few years, several teens who started as novice makers have become paid interns.

Participation is open. Anyone is welcome to join in when the makerspace is open, which is all day on Sundays and afterschool and in the evening twice a week. Some youth participate very regularly, such as one twelve-year-old girl who says she’s been there “pretty much every minute it’s been open since it opened.” About twenty people are consistent participants, many more occasionally attend, and hundreds have participated in workshops or other events that Mt. Elliott has hosted. Participation in the local community is a key feature of Mt. Elliott. Within a two-year frame, we found documentation of more than thirty examples of partnerships with other community organizations, such as soup kitchens, churches, neighborhood groups, nonprofit organizations, schools, and libraries, as well as collaborations with other makerspaces or maker events. Sharing knowledge is fundamental to the space, regardless of age. As Sturges explained, “We’re pretty specific in setting expectations for kids—that is, if you learn something, you are responsible for teaching it. I may ask you to teach to someone, and you should feel *compelled* [laughs] to share your knowledge with somebody else.” We saw this formally when youth were asked to lead workshops at community events and informally when youth regularly taught one another how they figured out to troubleshoot a game controller, edit a video, silk-screen a T-shirt, or fix a bike’s brakes. When visitors such as local teachers or reporters come to look at the space, the youth will often teach them to solder.

Some regular participants identify their first experience with Mt. Elliott as a structured workshop that then led to more individualized participation in the space. Others mention having friends there or coming in to use the computers but then getting drawn into a wider range of activities. As one youth said, “They persuade you to do things there. They persuade you into fun.” Some use the space to deepen and extend a prior interest or skill. One youth came to the space with an interest in music, learned digital music creation and editing in the makerspace, and now, at age nineteen, works in a professional music studio. An eleven-year-old girl made simple videos on her mom’s phone, then shifted into creating videos on the computer and compiling them to host a popular YouTube channel with two of her friends in the space. A mother of

seven initially learned the basics of silk-screening from her teenage daughter, received additional advice from a professional screen printer visiting the space, and has since launched a small business making and selling her own designed and printed items such as T-shirts and bags. Her entrepreneurial activities mirror what we saw in Sector67: some individuals use the makerspace as a small business incubator.

— “Now I think about everything—like, what makes it tick”: Dispositional Shifts in Mt. Elliott Participants

Unlike most Sector67 members, the majority of regular youth participants we interviewed at Mt. Elliott had little prior experience in making, and some began with little interest. A young woman who has been a regular participant for four years laughingly explained her start: “My brothers did it before me . . . And my mom kept wanting me to do it, and I was like, ‘Eh, no, oh my God I’m seventeen, so no!’” Then one day Mt. Elliott participants set up tables for a workshop on Arduino boards (physical computing platform based on simple microcontroller boards) outside her church, and her mother “forced” her to go over to it. She described how alien the activity seemed—how the word *Arduino* was unfamiliar. She had never thought about nor been interested in circuitry, yet she found the workshop enjoyable and gained skills.

I really enjoyed it, because it was something I had never done before . . . I got Arduino experience and soldering skills out of it . . . I had never heard of [Arduino], and it was such a weird word, too . . . I was totally oblivious to what it was before we did it . . . I knew nothing about circuits or the flow of electricity or anything like that . . . I like plugged stuff in all the time, and I don’t—didn’t really think, like “What makes this work?” like, how the electricity goes into it, how it works . . . Like if I’m not interested, I don’t think twice. I wasn’t thinking about it ’til I got to the makerspace. Now I kind of think about everything—like, what makes it tick.

Her statement points to a dispositional shift that was often identified by the regular participants at Mt. Elliott. They repeatedly highlighted how they were thinking about and doing things they had never even thought about before. Though things like bikes, walls, electronic music, electric appliances, and silk-screened T-shirts existed in their worlds, they reported not noticing them or thinking about how they were made until they had the opportunity to fix, design, or create them in the makerspace. Participants readily attributed changes in how they approach work and the world to their experiences in the makerspace. An eighteen-year-old detailed at length how much time he used to spend “just sitting around the house.” He said, “Now I get out, I do things, I help people, I have ideas . . . I’m still sometimes kinda lazy . . . but not *so* lazy.” Another youth said, “I am more patient. I stick with things more when they’re not working.” An eleven-year-old girl attributed broad changes in herself to being in the makerspace: “I’ve changed a lot. I’ve gotten more knowledge.

I've gotten better. I'm more useful now. I can do more stuff. I can help more people . . . I have more opportunities. I'm useful."

Makeshop, Children's Museum of Pittsburgh, Pennsylvania

As you enter the Children's Museum of Pittsburgh, Makeshop is located on the ground floor directly beyond the lobby.⁴ Established in partnership with Carnegie Mellon's Entertainment Technology Center and the University of Pittsburgh Center for Learning in Out-of-School Environments, Makeshop is an 1,800-square-foot space that supports learning in making with digital and physical materials. Makeshop is divided into three broad spaces. The first contains carefully designed materials that introduce young children to the processes of making. One set of materials, Build-It, consists of predrilled wooden boards and buckets of bolts and nuts that allow children to build walk-in-sized structures without additional tools. Another space, Digital Dream Lab, is an interactive table and projection screen where children learn the basics of object-oriented programming through the use of interlocking wooden blocks that represent parts of code and that cue changes on the screen. The configuration is flexible. During our observations, this area contained a circuit table providing handmade circuit blocks to assemble. A nearby set of tables held materials for hand sewing, including large brightly colored spools of thread, needles, pins, and fabric scraps. An iPad nearby supports the creation of digital stop-motion animations with made objects. Around the perimeter of the window-lined room are objects people have made, organized bins of assorted recycled materials and tools for construction, and a traditional foot-pedal-operated loom that museum visitors use to add to collaborative weavings. The third space can be closed off and has a large workshop table with making equipment that requires more supervision for safety reasons, including a sewing machine, woodworking tools, and soldering irons.

Makeshop is facilitated by teaching artists who have expertise in an area of making. At any given time, two to three teaching artists support individualized making projects and/or lead group hands-on workshops, thus providing more facilitated making than the other two spaces. Makeshop participants are all visitors to the museum. Annually, the museum has more than 260,000 visitors, including nearly 50,000 low-income students and families visiting through subsidized admissions programs. Young visitors to Makeshop range in age from toddlers to teens, and they often come accompanied by siblings, parents, and/or grandparents. Unlike Sector67 and Mt. Elliott, whose members work on projects over extended periods of time, most people tend to visit Makeshop for a single day—staying for a few minutes or for several hours. However, some participants have family memberships to the museum and return to Makeshop frequently to practice skills or to continue to work on projects. Makeshop also hosts weekly workshops, school field trips, youth afterschool programs, and Make Nights, which tend to draw older participants.

— “You can sew that?” Facilitating Making and Expanding Ideas in Makeshop

The Makeshop teaching artists focus on scaffolding the making process depending on the age, interest, and experience of the maker, while still encouraging an open-ended approach to design and making. Take, for example, the different ways we observed sewing in Makeshop. A toddler came in and wanted to sew. The facilitator offered a plastic grid with large holes and a plastic needle and the toddler picked out a yarn color. The facilitator held the toddler’s hand to help him thread the needle and asked, “What would you like to sew on this?” The toddler ended up sewing his initials into the card. Another time a mom threaded a tapestry needle with embroidery floss for a slightly older child to practice stitching on a piece of thin foam before he moved to fabric. After practicing, he wanted to make something but didn’t know what. The facilitator asked a few questions, such as, “Is there anything you need that you could make?” and suggested a few possibilities, including making a ball. He responded, “You can sew that?” The facilitator brought over a ball he had sewn, and the child decided he wanted to make a similar one. Meanwhile, his older sister, who had more experience with hand sewing, explained to another facilitator that she wanted to sew a hat. She sketched out some designs, and she and the facilitator talked about some of the design challenges particular to hats, such as getting them to fit properly and stay on and making the sides symmetrical. They discussed different strategies, such as sewing together two pieces and using elastic or ribbon. She used standard needle, thread, and fabric. About twenty minutes later she brought the attached pieces to the facilitator, asking, “How do I get rid of this poufy part where I sewed the edges together?” They again discussed potential approaches, and the girl returned to her work.

Family members often interact and facilitate each other’s work. Typically, in an adult-child interaction at the sewing table, the adult holds the fabric and the child operates the needle. In this way, the pair collaborate on the project, with the adult creating conditions for the child’s success. These informal interactions with learners around sewing show how the Makeshop fluidly adapts tools, materials, and design processes to the needs, skills, and interests of the participants. This fluidity is also shown in connections among the different spheres of activity.

In addition to these individualized supports, Makeshop also offers workshops, including one for very young children and their families that primarily focuses on materials exploration, as well as a youth afterschool program, where participants return weekly to engage in interest-driven making trajectories. These often begin with skill acquisition, such as how to use a soldering iron, and then progress in various directions based on interests and intentions. In addition, Makeshop hosts guest makers, who highlight an aspect of their craft through focused workshops with the public on weekends.

A Cross-Case Analysis of the Three Makerspaces

Looking across the three makerspaces (see table 1), we see how each supports making in multiple disciplines. One of the distinctive features of all the spaces is the way diverse learning arrangements (e.g., solo exploration, facilitated one-on-one or small group projects, collaborative projects, online forums, and structured classes) often informally evolve to support the projects and goals of the participants. The most striking difference in the learning arrangements within these spaces is the typical duration of making. Differences in the duration of projects reflect, perhaps, the relationship between the makers and the space itself. Sector67 is designed for people to buy in (literally and figuratively) to the space, while Makeshop, as part of a children's museum, functions much more as a drop-in space. While the average age of the participants and the scale of their projects vary across sites, learning in the making across these makerspaces involves analogous design processes where learners iteratively work with ideas, materials, tools, and processes in increasingly complex ways.

— Making with Circuits Across the Three Makerspaces

We use circuitry as a context to examine commonalities and differences in how the three makerspaces support learning. We selected circuits because they were used regularly in all three makerspaces and are a canonical activity among makers (Brahms & Crowley, 2014) and because variation in circuit use illuminates some key differences among the spaces as learning environments.

— Circuitry at Makeshop: Focus on Process, Discovery, and Connections to Everyday Life

In Makeshop, a dedicated circuit table is always open for use. It is accessible from all sides and easily reachable by young children and has circuit components in the form of handmade, rough-hewn blocks and repurposed everyday objects, such as paper clips and motors from old toys. Repurposed household wires, such as speaker cables, sit in a canister ready to connect the blocks into functioning circuits. Many children have little experience with circuits other than turning on a light switch or an appliance. Thus, they typically begin by holding the blocks and examining at their parts, looking at what others have made with them, and trying to figure out what to do. If they don't begin connecting wires, the facilitator may ask, "What do you want to make happen?" or demonstrate the most simple circuit, such as one that connects a battery to a light. Repurposing everyday items as circuitry components seems to encourage families to make connections to experiences outside the museum (e.g., holiday lights) and suggests ways they could make similar circuit blocks with things at home. Often children begin at the circuit table alone, and when a parent arrives they explain what they did and how it worked. Even the simple act of connecting a battery to a light is a first for many young children, and their excitement is evident. This initial excitement and discovery often prompts

TABLE 1 *Comparison of key features of the learning environments at Sector67, Mt. Elliott Makerspace, and Makeshop.*

Features	Sector67	Mt. Elliott	Makeshop
Participants	Primarily adults with prior interest/expertise; youth participate with parents or through classes	Intergenerational but primarily youth/adolescents; adult makers balance teaching and their own making	Primarily families with young children; adult makers focus on teaching/facilitating
Common media/making disciplines	Electronics, multi-media design and fabrication, metal work (iron pour, welding), visual art, motorized vehicles	Digital and electronic tools, bike repair and customization, multi-media (e.g., wood, metal, plastic) design and fabrication, music, art	Building, sewing, weaving, electric circuits and electronics, digital media tools
Typical duration of project	Hours to years	Hours to weeks	Minutes to hours
Common learning arrangements	Solo projects, collaborative group projects, forums for feedback on work, structured workshops	Solo projects, collaborative group projects, structured workshops	Open-ended play, solo, dyadic and small group facilitated projects, structured workshops
Key learning focuses	Learn specialized tools and equipment, practice skills, extend and apply expertise in new ways	Develop new interests, build skills in existing interests, focus on “creative productive learning”	Engage in making process, try new media, tools, and processes
How work is used and shared	Products created are often used and shared with external audiences through Web resources, competitions, exhibitions, community events, and/or sales.	Products created are sometimes used and shared with external audience through Web resources, performances, community events, and/or sales.	Products created may be used but are rarely shared with an audience outside the space and/or family.

families, with or without the aid of the facilitator, to try out more circuits. The circuit table also fosters discoveries beyond simple circuits using components such as switches with three positions and split cables, which encourage the creation of parallel circuits.

While most of the participants we observed exclusively used existing blocks to make circuits, some families used the materials to design and make additional circuit blocks to take home or add to the table’s collection. In addition, participants used materials from other areas to elaborate on their circuit design. For instance, we observed youth crafting together bits of paper, cello-

phane, and fabric to design colored lights and flowing kites powered by the circuit blocks. The circuit block table is adjacent to a sewing area, and there was often a flow of activity between the two. For instance, a seven-year-old girl was sewing a blanket for her American Girl doll bed. As she sewed, she was watching the circuit table where a young boy was making a flashlight by covering a light circuit he made with a toilet paper tube and red cellophane. After finishing her blanket, she decided to make a night-light for the bed. She talked to her mom about how to make the light, discussing design issues such as how she might attach it to the bed. She then went to the circuit table and figured out by trial and error how to make a working light. She brought the circuit back to the sewing table and rummaged through nearby recycled materials to construct the housing for the light. At Makeshop, circuitry is experienced as play and exploration and as a potential tool for designing and fashioning products.

— Circuitry at Mt. Elliott Makerspace: Discovering, Using, and Sharing Skills
At Mt. Elliott, the materials for working with circuits are readily available for general use in labeled boxes containing voltmeters, wires, batteries, motors, circuit boards, and soldering irons. In addition, there are kits for more structured making, and piles of discarded electronic equipment are ready to be repaired or harvested for pieces. Any time the makerspace is open, someone is likely to be tinkering with electronic materials (see image 1). On a typical Open Shop Sunday, we observed multiple diverse circuitry projects and informal learning arrangements. An older teen who had taught himself to repair and customize old video game consoles and controllers as a source of income helped a younger teen troubleshoot a broken controller he had brought in. Nearby, a boy played around with K'nex pieces and a motor, trying to figure out how to make a wheel spin. An older woman who attends the church that houses the makerspace asked for help fixing her lamp. Off to the side of the room was a broken, disassembled electric wheelchair that Jeff Sturges brought in earlier in the week to show how “the same principles of circuits they work with on a small scale are present in this more complex machine—it’s just on a larger scale.”

In addition to this open-ended, self-directed work with electronics, there are a variety of workshops that support electronics learning. For instance, in a workshop called “BreakMake,” over the course of a few weekly sessions, participants break apart old equipment, organize found parts, and then design and make new machines from the parts. As the facilitator describes it on the Web site blog, “There is nothing more satisfying than ripping apart old electronics to see what is inside. Printers, scanners, old computers, DVD players, clock radios . . . nothing was safe from the destruction! The best part is reusing the parts inside to make new and amazing stuff!” For instance, a ten-year-old boy began with a simple plan for an old computer mouse: he drew an oval with wheels labeled “mouse car.” However, this simple start led to a complex design

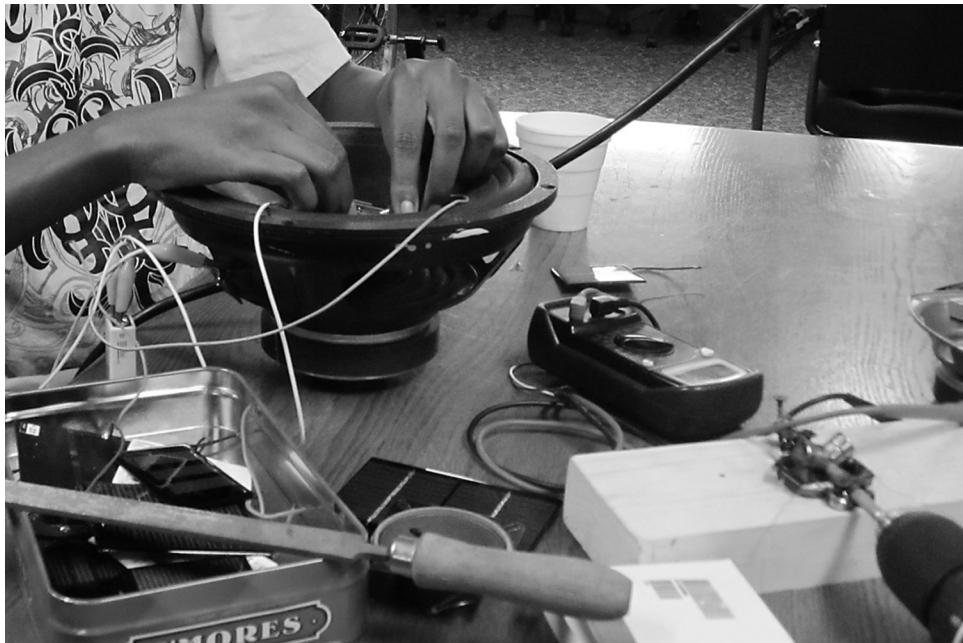


Image 1. *Example of Circuitry at Mt. Elliott Makerspace.* Photo credit: Mt. Elliott Makerspace

process lasting several weeks. He figured out how to break apart the mouse, attach wheels, find an appropriate motor, and wire a battery to it to make it move. Initially the car just went around in circles, so he made adjustments so it would drive straight. At first he stopped it by grabbing it and disconnecting the battery; later, based on a suggestion from his dad, he installed a metal switch on the top. In a video posted to the makerspace Web site, he smiles as he demonstrates that his car moves fast and straight and is easily switched on and off. His design process began with a structured, teacher-led workshop and later became a more sustained, personalized design process supported by adult mentors.

In addition to adults who focus on mentoring and teaching, some adults regularly work on their own circuitry projects at Mt. Elliott. For instance, a former television repairman who has extensive expertise with older electronics does not formally teach youth; instead, he works where they can watch and occasionally explains what he is working on, helps others troubleshoot a project, or repairs something for community use.

Circuitry activities at Mt. Elliott also provide insight into how skills work to build relationships within the makerspace and outside of it. For instance, soldering, a core skill needed for working with electronics, acts as a sort of informal initiation to Mt. Elliott participation. As soon as you enter Mt. Elliott, you often learn to solder, and once you learn it, you are expected to teach the skill

to someone else. One twelve-year-old girl noted that she has taught more than two hundred people to solder, including “grown-ups, teachers, teenagers, and reporters.” Her eleven-year-old friend exuded confidence as she described teaching soldering to college students in a workshop at a local university: “I work with them. If they’re a bit scared I try to calm them down . . . I told them that it is hot and can be a little dangerous, but as long as they have an adviser who knows what they are doing they are safe.” A young girl who repaired a stereo for the makerspace to use described how she’s getting a reputation for repairing electronics at home and how her family pushes her to learn more. “Now my mom wants me to learn to fix cell phones . . . She tells me she’s gonna give me tests, like, she’s gonna drop it . . . gonna throw it in water . . . just to see ‘Can you tell what’s wrong with this? . . . Are you able to fix this?’”

Mt. Elliott members’ skills with circuitry also become an informal collaborative bartering tool with other organizations. For instance, participants used their circuitry knowledge to help build, wire, amplify, and troubleshoot a mobile music trailer that is used for a neighborhood business that creates Caribbean-style parades. In turn, they learn more about costume and float creation and host their own parades. The business owner envisions combining his building and costuming skills with Mt. Elliott members’ circuitry skills to create floats and costumes fancifully lit with sequenced LED lights for a night parade. In Mt. Elliott, circuitry skill is positioned not just as something to learn for its own sake but as a skill that should be put to use and taught to others to build and strengthen relationships and address community needs.

— Circuitry at Sector67: A Community of Practice for Experts to Extend, Apply, and Integrate Their Knowledge

The level of work with circuits at Sector67 is technically complex, and the space houses a comprehensive suite of tools for circuitry. The founding members came to the space with engineering degrees, and several in the community have electrical expertise gained through lifelong hobbies. Collectively, the makerspace has won multiple competitions and has been featured in *Wired* magazine for collaborative projects demonstrating sophisticated knowledge and skills with circuitry. As such, Sector67 offers insight into how a community of makers with deep expertise uses that knowledge to solve problems and design products, how these makers engage in design and making practices that extend and deepen that knowledge, and how they bring novices into their community.

One example of such insight is a group of Sector67 members who have launched their high-altitude balloon at least six times to date. Using a micro-controller programmed cell phone, they launch *Apollo67* to photograph the Earth from near-space. Their first launch was prompted by their participation in a competition; launches thereafter were self-motivated iterations. These iterations demonstrate the common practice of working within a given design to explore possibilities and extend capabilities. For instance, in preparation for

their first launch, the group conducted a cold test “to determine if the foam would be sufficient to protect the phone at temperatures at altitude and if the phone would continue to operate the duration of the flight.”⁵ Other iterations included testing different hardware, refining telemetry, and conducting extreme altitude testing of some Sector67 electronics inventions—simply sending them along for the ride to see what happens. Thus, makers in Sector67 asked more than just “Does the circuit work?” They explored “Does the circuit work . . . in space?” A key aspect of their work is their drive to push beyond initial success—to optimize functioning, to explore further ways to approach the problem, and to find new problems building on what they’ve learned.

For novices who aspire to learn about circuits at Sector67, there are trade-offs to be made because of the depth of knowledge present in the site. On one hand, Sector67 electronic workshops often assume basic circuitry knowledge and skills that may present challenges for beginners. For instance, at an Arduino workshop the facilitator jumps right into the properties of different microcontrollers, gives minimal time for trial and error, and expects learners to pick up processes with little instruction. On the other hand, learning this information within a community of such deep expertise, sophisticated equipment, and rich applications of such knowledge (e.g., balloon launches) places basic circuitry knowledge—unlike simple kits—in a context of expertise.

Discussion: Unique Cases of Practice, Unifying Themes

One of the most striking features of our cross-case analysis has been how these three spaces are markedly distinct yet share an ethos that allows us to categorize them as the same kind of a space. While the spaces differ in terms of who participates, what it means to be a participant in the space, and the duration of engagement, we see key themes emerging that allow us to talk about makerspaces as being multidisciplinary both in approach and in work produced, as blending formal learning environments and informal communities of practice, and as being focused on learning as production rather than as mastery of a composite set of skills.

Makerspaces’ Multidisciplinarity Fuels Engagement and Innovation

Among us authors, we have prior experience in many sites for learning in the making—arts studios, performing arts companies, and game design and digital media labs. Unlike these disciplinary places of practice, makerspaces support making in disciplines that are traditionally separate. Sewing occurs alongside electronics; computer programming occurs in the same space as woodworking, welding, electronic music, and bike repair. This blending of traditional and digital skills, arts and engineering creates a learning environment in which there are multiple entry points to participation and leads to innovative combinations, juxtapositions, and uses of disciplinary knowledge

and skill (Brahms & Crowley, 2014). Much of the prior research on constructionism and design-based learning has been within a specific media, such as game design (Clark & Sheridan, 2010; Kafai, Peppler, & Chapman, 2009), or a posed problem (e.g., Kolodner et al., 2003).

Likewise, research in schools tends to create disciplinary boundaries for curriculum, standards, and assessments. Our work in these spaces suggests that these disciplinary boundaries are inauthentic to makerspace practice. Take, for instance, the young girl in Makeshop making accoutrements for her doll bed. The diverse materials and processes available, as well as others' work in the space, encouraged her to fluidly shift from sewing to circuitry to building with recycled materials as she envisioned new possibilities: she could make a night-light to go with her blanket. The multidisciplinarity of the environment both extended her engagement in design and expanded the range of skills she employed. Makerspaces seem to break down disciplinary boundaries in ways that facilitate process- and product-oriented practices, leading to innovative work with a range of tools, materials, and processes. This sentiment was echoed frequently by members of Sector67 who used the space for start-up companies; they saw the diversity of work as an advantage over working in a traditional business or engineering design environment.

Makerspaces Have a Marked Diversity of Learning Arrangements

In each of the three makerspaces, we saw a blending of aspects of communities of practice with more formal education environments, such as studio arts and engineering design courses. Much contemporary research on the development of communities of practice around creative work has focused on the emergence of online participatory cultures, interest-driven networks, and affinity spaces that bring diverse groups of people together around a shared creative passion (Halverson, 2012; Ito et al., 2010). While this research has provided rich ethnographic depictions of what membership looks like and what forms of expertise are demonstrated through engagement, online participatory cultures are not pedagogical in the way that we have come to understand instruction and pedagogy in formal learning environments.

We saw evidence in each makerspace of a hybrid model that includes many of the ways of seeing, valuing, thinking, and doing found in participatory cultures yet incorporates pedagogical structures found in more formal studio-based settings, such as demonstration, facilitated workshops, and critique (Hetland et al., 2013). In each space we saw demonstrations of tools, techniques, and processes. Each space held structured workshops that guided learning and making in a variety of media. Participants and facilitators gave feedback on work. Unlike many schooling structures, the work in makerspaces is voluntary; people choose which learning arrangements suit their needs, what to work on, when to work on it, and whether and how they want to continue. When participants choose to join a more structured workshop that entails fol-

lowing directions on a more prescribed project, such as Arduino workshops in Sector67 and Mt. Elliott, they often do so to acquire a skill they seek to use in more self-directed, self-motivated work.

What distinguishes makerspaces, then, from communities of practice-style participatory cultures and from formal studio-based learning environments is the marked diversity of learning arrangements we see occurring within each of the studied spaces. We observed self-directed solo projects that have been sustained for years and spontaneous group collaborative projects that emerged in minutes. The size and scale of observed projects ranged from a toddler spending minutes with a sewing card, to a youth spending weeks building a motorized car, to a team of experts spending years on high-altitude balloon launches. Structured workshop classes occur alongside novice-expert apprenticeships. Online forums supplement real-time communities of practice. Some tools and materials are explicitly designed to scaffold making practices for novices; some are repurposed to save expense and prevent waste; and some are professional-grade equipment typically inaccessible to a private user.

Each of the spaces adapted to ranges of ages and expertise. Furthermore, while making is core to these spaces, participants often refer to the space as feeling like a family or group of friends. They host birthday parties and baking fund-raisers. Mt. Elliott has a resident “maker dog,” and Sector67 has a cat. When one Sector67 member needed to stay awake all night before a diagnostic EEG, other members hosted a group all-night “hack-a-thon” to support her. While formal studio pedagogies can help us understand how engagement around making tasks functions as a learning process, they do not explain how taking a walk on a nice day is important to Mt. Elliott’s practices. And while a communities of practice frame can help us understand how individuals become core members over time and how the ethos of the space develops, this frame is ill equipped to describe some of the formalized structures that give participants just-in-time access to STEM and arts-based skills and habits of mind (Hetland et al., 2013) required to successfully complete a project.

Learning Is in and for the Making

Learning in each of these spaces is deeply embedded in the experience of making. These spaces value the *process* involved in making—in tinkering, in figuring things out, in playing with materials and tools. It is not uncommon for participants in all three spaces to mess around with materials with no project in mind or to have a series of started projects that do not come to fruition. Yet, we also observed commitment to the products that emerged from making and their tangible utility. For instance, whereas a hands-on circuit activity might be employed in a classroom to teach *about* electricity, the circuitry knowledge we observed in the makerspaces was *used* to make a night-light, customize a bike, fix a game controller, and photograph the Earth from space. The makers we observed learned skills to create things that are beautiful, useful, marketable, and fun. They also found venues to share creations with a

wider audience. We observed sharing within the makerspace community, at community events, via YouTube channels and Web sites, and at local, regional, and national maker events. In this way, skills and knowledge are treated as tools that allow participants to create new things and access new communities and learning opportunities. Things made are meant to be shown, used, sold, or shared. This deepens participants' experiences, since production-based work is more authentic and learning outcomes focused on representation more robust when audience is an embedded component of the design process (Halverson, 2012).

Conclusion

Given the dearth of empirical research on makerspaces, our careful description of these three distinct makerspaces and their features as learning environments can help educators and researchers envision some of the range of practices in makerspaces and the kinds of learning they support. Our three unifying themes represent important features for researchers and designers interested in creating makerspaces and understanding learning in these spaces to consider. While it may be easier to design, teach, and study more constrained "making activities," the learning in the making we observed in our studied makerspaces extends beyond this. Being a maker in these spaces involves participating in a space with diverse tools, materials, and processes; finding problems and projects to work on; iterating through designs; becoming a member of a community; taking on leadership and teaching roles as needed; and sharing creations and skills with a wider world.

To be sure, our work does not represent the full range of makerspace experiences in the United States and around the world; new spaces are cropping up in schools, in community centers and organizations, and in museums and public libraries. We hope that these initial case studies exploring the unique features as well as the unifying themes of different types of spaces will speak to other researchers and practitioners who are designing and studying makerspaces and add to the conversation. Further, we hope that understanding how these different educational approaches combine to create a feeling of self-directed participation, a strong community support for learning, and a sense of identity as a member of the community gives insight into the design of learning environments more broadly conceptualized.

Notes

1. See <http://www.sector67.org/blog/>.
2. Hackerspaces are a predecessor of makerspaces, typically programmers who worked on collaborative projects together. The term *makerspace* evolved as technology focused on bridging digital and physical creation and the communities focused on broader areas of making. In some spaces, like Sector67, *hackerspace* and *makerspace* are used interchangeably.

3. See <http://mtelliottmakerspace.com/>.
4. See <http://makeshoppgh.com/>.
5. See <http://apollo67.com/wiki/home-2/meeting-minutes/minutes-2011-11-01/>.

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