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The Maker Movement and Learning

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This chapter focuses on the range of teaching, learning, and design practices associated with the Maker Movement in education and how these practices are intimately connected to how the learning sciences conceptualizes, studies, and designs for learning and knowing. The Maker Movement is defined as "the growing number of people who are engaged in the creative production of artifacts in their daily lives and who find physical and digital forums to share the processes and products with others" through analog and digital practices such as woodworking, soldering, cooking, programming, painting, or crafting (Halverson & Sheridan, 2014, p. 496). As this broad definition suggests, there are many inroads into education research that are made possible through the study of the Maker Movement. Here, we suggest that research on the Maker Movement can contribute to three core topics in the learning sciences:

- The Maker Movement contributes to our *theories of how people learn* by merging a constructionist perspective (Martinez & Stager, 2013) with other big theoretical ideas in the learning sciences, including distributed cognition (Halverson, Lakind, & Willett, 2017), embodied cognition (Peppler & Gresalfi, 2014), new materialisms (Wohlwend, Peppler, & Keune, 2017), and the new literacies (Litts, 2015).
- Makerspaces provide opportunities for the *design of learning environments*, particularly to rethink the disconnect between learning in and out of schools (Peppler & Bender, 2013; Peppler, Halverson, & Kafai, 2016).
- Conceptualizing who counts as makers pushes us to think about issues of *equity and diversity*, focusing on deep connections between meaningful content and processes and cultural, historical, material, and social movements in education (Blikstein & Worsley, 2016; Buechley, 2016; Vossoughi, Hooper, & Escudé, 2016).

This chapter provides a roadmap through the emerging field of making and education while focusing on how the field is connected to the learning sciences. We begin with an overview of research on the Maker Movement and then turn to how people learn both in and through making. We conclude by offering reflections on how the three key issues we identify above are central to understanding making and learning specifically, and the learning sciences more broadly.

An Introduction to Research on the Maker Movement

While people have been "making things" forever, research on the Maker Movement, FabLabs, and DIY (do-it-yourself) culture in education has exploded over the past decade. From an educational research perspective, the larger movement encompasses *learning activities* that engage people in the creative production of artifacts, *communities of practice* where making activities occur, and the *identities of participation* that people take on as they engage in making (Halverson & Sheridan, 2014). Across these three domains of research, the Maker Movement is characterized by a "do-it-yourself" ethos in a range of domains including textile crafts, electronics, advanced robotics, and traditional woodworking (Peppler & Bender, 2013). Typically, work in these domains includes some focus on the use of new production technologies such as 3-D printers, laser cutters, and microcomputers as well as the sharing of ideas via the internet (Peppler et al., 2016).

While some research on making and learning has identified the ways in which making results in improved outcomes in sanctioned schooling practices (e.g., Peppler & Glosson, 2013), others have identified Maker Movement-specific practices that are worthy of understanding, including: a focus on interest-driven learning (Peppler et al., 2016); tinkering as a valid form of knowing and doing (Wilkinson, Anzivino, & Petrich, 2016); and the importance of sharing and audience for learning (Sheridan et al., 2014). These practices are not often present in the more defined disciplinary practices of schooling.

A Brief History

Over the past decade, there has been an interest in studying creation, sharing, and learning with new technologies within what was initially referred to as online "Do-It-Yourself (DIY) communities" (Guzzetti, Elliot & Welsch, 2010; Kafai & Peppler, 2011) and which have later been reframed by the larger discourse around the Maker Movement as popularized through Make magazine and Maker Media. Both the DIY and the "Maker Movement" share the spirit of self-produced and original projects. What was once solely the domain of in-person "hobby clubs" is now accelerated by the rise of social media, where distributed communities can congregate and share projects and techniques on sites like makezine.com or instructables.com, where members have posted hundreds of thousands of videos on virtually any topic (Torrey, McDonald, Schilit, & Bly, 2007). In some cases, these communities follow the open-source movement and have developed networks around the use of a particular programming language, such as Processing (Reas, 2006; see also processing.org) or Scratch (Brennan, Resnick, & Monroy-Hernandez, 2010). In other cases, these communities have developed around the use and development of an open-source construction kit, Arduino, which hobbyists around the world use to design projects, such as their own laser printers. In the instance of the LilyPad Arduino kit (Buechley, Eisenberg, Catchen, & Crockett, 2008), textile productions now can include sensors and LED lights to be programmed for informative feedback and artistic purposes. While these communities have much of the flair of exclusive clubs found among earlier programmers, their growing presence also signals a larger trend.

Dougherty (2011) states that the "most important thing about DIY [or making] is that it portrays the idea that you can learn to do anything." Furthermore, the resurgence of interest in DIY forms of making stems from the range of what can be produced due to the rapid rise in the number and availability of new digital fabrication technologies, like 3-D printers, wearable computers, and other tools that merge digital and physical materials (Gershenfeld, 2005). FabLabs, for example, are now becoming widespread both in and out of schools, allowing youth and adults alike access to digital fabrication tools that at one time were only accessible to industries (Blikstein, Martinez, & Pang, 2016). The success of these new makerspaces and events like Maker Faires is largely based on exposure: The driving force of the culture is about being inspired when you see someone else making, compelling you to want to make it yourself. This emergent set of artistic and technological practices,

compounded by the desire for those online to seek recognition for the work they do, is at the heart of interest-driven learning today, largely existing at the fringes of traditional education and schooling.

Research on Making

One way to explore the affordances of the Maker Movement in education is through the study of *making activities*, "designing, building, modifying, and/or repurposing material objects for playful or useful ends, oriented toward a product of some sort that can be used, interacted with, or demonstrated" (Martin, 2015, p. 31). This definition accomplishes several functions. As "a set of activities" it reminds us that making is something you *do*; multiple identities are possible for participation and multiple kinds of learning environments can support making activities. This also has implications for research; the study of activities in the learning sciences has a rich history that can be leveraged in our study of making. The creation of objects "for playful or useful ends" reminds us that making can be practical, whimsical, or both. As such, it can serve goals often associated with STEM fields—solving problems, innovating products; it can also serve its own goals—creating playful artifacts. Finally, the outcomes of making "can be used, interacted with, or demonstrated," further reminding us that making does not serve a singular purpose but must be judged based on the goal toward which the making activity is aimed.

Research on Makerspaces

Makerspaces present unique contexts for study that are different from formal classroom settings in several key ways. Making in a makerspace is guided by a different set of pedagogical practices than hands-on learning in a traditional classroom context; for example, cross-age learning is common (and often required!) and projects are not guided by predetermined learning outcomes. Current research on makerspaces sees these differences as endemic to the learning environments themselves. In one of the first empirical studies on makerspaces, Sheridan et al. (2014) defined makerspaces as "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" (p. 505). This definition suggests some reasons why makerspaces ought to be treated independently from making activities. Since schools are by definition formal, makerspaces as informal spaces struggle to integrate seamlessly into schooling structures (Lacy, 2016). Furthermore, schools resist multi-aged learning, age-segregating students by year and rarely acknowledging anyone as an expert in the classroom other than the adult in charge. Finally, it is important to note the multiple, simultaneous goals that makerspaces support; participants are likely exploring different goals while in the space together. A key feature of makerspaces is that not everyone learns the same thing at the same time—a big challenge for classrooms.

Makerspaces can be broken down into three primary categories: P–16 education, out-of-school spaces, and online spaces. As alluded to above, makerspaces in schools have been difficult to develop, implement, and study, with a few notable exceptions. While there are numerous "how to" trade books available for the development of makerspaces in schools (e.g., Blikstein, Martinez, & Pang, 2016; Martinez & Stager, 2013), there is little empirical research on how we can understand makerspaces as school-based learning environments. Lacy's (2016) dissertation chronicles the implementation of a FabLab at a Midwestern ex-urban high school, finding that the FabLab continues to reify divisions between those in the technical careers track who maintained their focus on the practical skills afforded by the school's shops and college-bound students who saw the FabLab as a natural extension of their AP STEM courses. By contrast Puckett, Gravel, and Vizner (2016) found that the addition of a makerspace to a large comprehensive high school meant that students experienced fewer status distinctions, fewer gendered practices, and came together from a range of academic

tracks as opposed to traditional STEM and shop courses. In higher education, colleges and universities have also begun to develop makerspaces for their campuses for a variety of educational contexts, ranging from studying learning through making, to hands-on approaches to various disciplines, including chemistry, engineering, design, and biology (e.g., Fields & Lee, 2016).

Case studies of makerspaces in out-of-school learning environments include museums, libraries, FabLabs, and independent for profit and non-profit organizations. These case studies describe unique features of makerspaces as learning environments, such as side-by-side multidisciplinarity and a diverse set of learning arrangements that distinguish makerspaces from other informal learning environments and participatory cultures (Peppler et al., 2016; Sheridan et al., 2014). As mentioned earlier, online places for engaging in and talking about making are also a robust part of the Maker Movement. Case studies of online makerspaces describe how internet technologies extend face-to-face communities of practice as well as create and support new communities of makers (Peppler et al., 2016).

Research on Makers

Many scholars argue that the Maker Movement, like other areas of the learning sciences, has neglected issues of culture and history (Ames & Rosner, 2014; Blikstein & Worsley, 2016) and devalued the contributions of women of all ages and communities of color (Buechley, 2016; Kafai, Fields, & Searle, 2014; Vossoughi et al., 2016). As a branded arm of the Maker Movement, the MAKE organization overwhelmingly puts White men and their sons on the covers of their magazine (Buechley, 2016) and 89% of the magazine's authors self-identify as male (Brahms & Crowley, 2016). Blikstein and Worsley (2016) argue that the "hacker culture" roots of the Maker Movement "only works for a small elite group of high end students" (p. 66) and prevents equitable access to the kind of deep learning that making can engender. As a result, a third line of research has emerged that explores "makers" as identities of participation.

Research on makers as identities of participation explicitly attends to who gets to be a maker, how we construct the maker identity, and what we can do to both broaden participation and to expand what counts as a maker identity. Efforts to focus on gender equity and making have resulted in design-based research projects that help girls develop maker identities through their interests in fashion and sewing (Erete, Pinkard, Martin, & Sandherr, 2015; Kafai et al., 2014) and through projects that explicitly connect them to their local community (Holbert, 2016). Vossoughi et al. (2016) seek to make a range of maker identities possible by embracing the historical and cultural roots of making that include longstanding making practices such as weaving and the teaching of aesthetic and pragmatic skills across generations within a community.

Other research on makers as identities of participation tries to answer the question, "What makes a maker?" The Agency by Design project describes maker identity as a set of dispositions that learners develop including the discovery of personal passions, the capacity to develop those passions, and the confidence and resourcefulness that results from learning with and from others (Ryan, Clapp, Ross, & Tishman, 2016). Rusk (2016) finds that makers display self-determination as a core characteristic of their identity. Sheridan and Konopasky (2016) provide linguistic evidence of young people's development of resourcefulness as an identity outcome of extended participation in makerspaces.

Learning in and Through Making

In order to understand how the learning sciences contributes to the emerging field of making, we ask: "How do people learn to make?" This question seeks to identify theories of learning that inform how we document, study, and represent process. Here, learning is a dynamic, ongoing process rather than a fixed entity to be evaluated. The work resonates with how the learning sciences constructs knowing, learning, teaching, and design. Learning theorists may also be interested in what making

can tell us about theories of learning, about what is learned through participation in an innovative set of practices. Toward this interest, we ask: "What do people learn through making?" Asking questions about making and learning is tricky because "making" can be seen as either a set of instrumental practices that serve as a gateway to already established, school-based disciplinary practices, or as a discipline in and of itself. In both cases, the learning sciences is fundamentally interested in the cognitive and sociocultural mechanisms by which learners engage with content, process, and practice.

How Do People Learn to Make?

The most influential learning theory that has informed learning in and through making is constructionism (see, for discussion, Harel & Papert, 1991; Kafai, 2006; Papert, 1980). The influence of constructionism is discussed in almost every text that explores the research and practice of making and learning (cf. Litts, 2015; Martinez & Stager, 2013; Peppler et al., 2016). In addition to the obvious emphasis on the making and sharing of artifacts, learning to make also includes a focus on ideation, iteration, and reflection; the use of portfolio systems for assessment; and technologies to support powerful ideas—all components of the constructionist tradition. Learning to make is more, however, than just a "leveling up" of constructionism to include the latest technologies and tools. Making also draws on a multiliteracies perspective as a way to understand how people learn (cf. Cope & Kalantzis, 2000; New London Group, 1996). Multiliteracies is built on the idea that knowledge is embedded in social, historical, cultural, and physical contexts, and that learning happens at the intersection of these, primarily through the design and sharing of representations. Although making has primarily been associated with the STEM disciplines, writing can also be considered a form of making (Cantrill & Oh, 2016) and the composition process is closely associated with a multiliteracies perspective on learning. Resnick and Rosenbaum (2013) describe how making, writing, and coding are all fundamentally about "the idea that people create meaning through the things they create" (p. 231). Understanding the process of learning to make, then, is not too different from understanding the process of learning to write, or any other creatively interpretive act, such as generating a novel or a creative "read" of a canonical work.

Proponents of both problem and project-based learning will see echoes of learning to make in their framing of how people learn (see Hmelo-Silver, Kapur, & Hamstra, this volume). Grounded in learner interest, dependent on relationships among people and tools, and fundamentally multidisciplinary, these approaches also embrace the core ideas of both a constructionist and a new literacies perspective. Similarly, scholars who take an embodied cognition perspective on the relationship between mind, body, and tools will also recognize the core ideas of constructionism in their research (see Alibali & Nathan, this volume). Finally, scholars who value a distributed cognition perspective on learning, where knowledge is stretched across people, tools, and time, can also see their research situated within making and learning (Halverson et al., 2017). This is in large part because learning to make requires that not everyone learns and does the same things at the same time. In fact, successful making is often dependent on individualized participation trajectories that converge around the creation of an artifact or artifacts that are shared with an external audience. As with distributed cognition, the answer to "Where is the learning?" in making is at the intersection of people, tools, and space.

All of these connections indicate that making sits squarely within the learning sciences as a way to articulate how people know, learn, and act. Furthermore, making contributes to our understanding of how people learn through explicit connections among theoretical strands that do not often talk to one another in research or in practice. An understanding of learning through making demonstrates that:

- Learning processes are *design processes;*
- The *creation and sharing of artifacts* is essential for learning;
- Learning requires attending to both *process and product as outcomes of participation.*

What Do People Learn Through Making?

Learning theorists are also interested in the second question—"What do people learn through making?"—in order to extend our understanding of how people learn across a range of disciplines and spaces. Most of the work on learning through making has linked making to STEM disciplines. Specifically, Martin and Dixon (2016) argue that making activities can be a gateway to K–12 engineering, and others demonstrate that hybrid digital/physical maker activities contribute to students' knowledge of computer programming, particularly when they are working at the intersection of digital programming and physical tools (Berland, 2016; Shapiro, Kelly, Ahrens, & Fiebrink, 2016). Learning arts practices are also linked to making; Peppler (2016) shows how a focus on physical computing enables young digital media artists to expand their reach into coding, electronics, and craftsmanship. Perhaps the most well-researched set of making activities are those that involve circuitry. Research has shown that students as young as third grade learn basic circuitry concepts through participation in making activities, as demonstrated both through the successful creation of operational, closed circuits and through more traditional pre/post tests identifying more abstract circuitry knowledge (Peppler & Glosson, 2013; Qi, Demir, & Paradiso, 2017).

While all of these studies are encouraging in terms of legitimizing making as practices that might be embraced in formal learning environments, it is perhaps more interesting to ask what people learn through making qua making, rather than in service of exogenous learning goals. *Tinkering* is a core component of making that is often devalued in formal educational settings (Resnick & Rosenbaum, n.d.). Bevan, Gutwill, Petrich, and Wilkinson (2015) identify "tinkering" as a set of practices unique to making that are learned through sustained engagement in making activities: "At the heart of tinkering is the generative process of developing a personally meaningful idea, becoming stuck in some aspects of physically realizing the idea, persisting through the process, and experiencing breakthroughs as one finds solutions to problems" (p. 99). While tinkering can be associated with success in STEM disciplines, the practices described in their research are not often measured or valued in formal learning environments, including playfulness, iteration, failure, experimentation, and the freedom to change course and explore new paths (Resnick & Rosenbaum, n.d.).

Learning outcomes are often determined by what is being made, rather than the abstract set of learning outcomes that are often found in school-based versions of making. For example, young people involved in a "build a bike" challenge at their local makerspace demonstrate learning through the successful creation of a bicycle that they can take with them (Sheridan & Konopasky, 2016). Unsurprisingly, most of the research on making outcomes is done in out-of-school learning spaces, primarily museums and libraries, that are interested in understanding how participants learn but have the freedom to broaden conceptions of what counts as learning outcomes. Less commonly explored are the ways that learning dispositions cultivated during making, including the familiarization with productive failure and experimentation, can help youth develop the social/affective/interpersonal learning (including "grit") sought after in recent national schooling initiatives.

So is making a discipline unto itself? Research on what and how people learn in making has identified roots in STEM, the arts, design, and entrepreneurship (themselves emerging disciplines that combine more established fields). There is evidence that incorporating making into traditional learning environments could connect students more effectively to disciplinary content that they would otherwise struggle with. But "disciplining" making also means acknowledging that practices like tinkering do not mesh well with the standardized outcome structures of traditional schooling. Furthermore, as research on makerspaces and makers points out, the promise of making as a set of democratizing practices will not be realized if we simply drop making into already established social and cultural schooling routines. Rather, this will become another set of practices reserved for those who look the part (Lacy, 2016; Vossoughi et al., 2016).

The Maker Movement in the Learning Sciences

We want to return now to the question of how research and practice within the Maker Movement connect to and advance the learning sciences as a field by exploring theories of how people learn, the design of learning environments, and issues of equity and diversity.

Theoretically, making serves as a bridging construct among theories of learning that do not always communicate with one another. As indicated earlier, learning through making embraces constructionist, multiliteracies, and embodied and distributed cognition perspectives to arrive at three core principles: designing as learning, creating and sharing artifacts, and attending to process and product as outcomes. While most public schooling reforms revolve around standardizing learning sequences and assessment measures as a pathway to equity and access, maker pedagogy is built on individualization—of interest, of skill development, and of participation in a process. This tension between individualization and standardization is of great interest to scholars in the learning sciences, who see the potential of constructionist pedagogy while eschewing the "hacker mindset" that often results from highly individualized learning environments (Blikstein & Worsley, 2016).

Learning research is often caught in the longstanding divide between formal and informal learning environments. However, research on making offers opportunities to stretch across the divide; design experiments often feature partnerships among organizations and the inherent interdisciplinarity encourages each group to bring their expertise to the table. Museum educators, for example, may encourage teachers to embrace tinkering practices, while teachers may help museum educators to link their goals to more measurable, standardized schooling outcomes. While learning theorists are not troubled by the bridging, designers of learning experiences often take this divide as foundational to their practice frequently building solely for in-school or out-school settings rather than tools that have the potential to be used across settings for a variety of purposes (Peppler et al., 2016). By starting with making and not with the setting, research on making can remind us to take a learning-first perspective on research and practice.

Making is a paradigmatic context for attending to issues of equity and diversity in research, practice, and design within the learning sciences (Esmonde & Booker, 2017), given the promise of the Maker Movement to democratize access to means of production and audiences for work (Vossoughi et al., 2016). But democratization is laden with values that are often not shared by the diverse communities we aim to reach with our teaching and learning reform efforts. There is disagreement, for instance, over whether making in its current form is dependent on the use of new technologies and online distribution; What counts as making? Are traditional crafting practices making? Does the presence of a 3-D printer in a space automatically mean that making is happening? These questions prompt many researchers who care deeply about the democratization of teaching and learning practices to criticize the Maker Movement for its lack of attention to the cultural and historical ways that marginalized communities are permitted to participate (Vossoughi et al., 2016). Dropping new ideas into already existing systems can reify inequitable access (Lacy, 2016). Likewise, adopting one-size-fits-all identities of participation often leads to resistance on the part of marginalized communities, whose identities are then not valued. Critical scholars who study making and learning remind us to design for a range of places and identities where making can happen successfully.

Further Readings

Halverson, E. R., & Sheridan, K. (2014). The Maker Movement in education. *Harvard Educational Review, 84*(4), 495–504.

This essay provides an overview of the role the Maker Movement plays in education. Furthermore, the authors offer a framework for conducting research at the intersection of making and learning by focusing on making as a set of learning activities, makerspaces as communities of practice, and makers as identities of participation.

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research, 5*(1), 30–39.

In this article, Martin offers three key components of making that are necessary for the design of maker-based learning environments: digital tools, community infrastructure, and the maker mindset. Martin argues that "good making" is well aligned with what learning scientists understand as "good learning."

Peppler, K., Halverson, E., & Kafai, Y. (Eds.). (2016). *Makeology* (Vols. 1 & 2). New York: Routledge.
This two-volume text series is a set of empirical studies by leading scholars in the field of making and learning. The volumes include studies of making activities, cases of formal, informal, and online makerspaces, as well as research on learner identities as makers.

Sheridan, K., Halverson, E. R., Brahms, L., Litts, B., Owens, T., & Jacobs-Priebe, L. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*(4).
In this piece, Sheridan and colleagues analyze three cases of makerspaces representing the range of environments that focus on making and learning: a museum-based makerspace, a community makerspace, and an adult-oriented member makerspace. They describe features of the makerspaces as well as how participants learn and develop through complex design and making practices.

Vossoughi, S., Hooper, P. K., & Escudé, M. (2016). Making through the lens of culture and power: Toward transformative visions for educational equity. *Harvard Educational Review, 86*(2), 206–232.
This article offers a critique of the Maker Movement and presents a vision for "making" as grounded in social, historical, and cultural practices. The authors argue that by ignoring the contributions of historically marginalized communities in the Maker Movement, educators reify the risks of turning a potentially radical pedagogy into another tool for establishment communities to thrive.

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The maker movement stretches across the for-mal/informal instructional divide, creating an opportunity in research and in practice to understand learning and schooling as related but independent concepts. With this work, we propose to change the conversation from being about the design of schooling as informing learning to, instead, the design for learning as informing schooling. Bringing the maker movement into the edu-cation conversation has the potential to transform how we understand â€œwhat countsâ€ as learning, as a learner, and as a learning environment. An expanded sense of what counts ma The maker movement treats children as if they were competent. Too many schools do not. Making builds on each childâ€™s passion by connecting their whole being with constructive materials in a flow that results in fantastic artifacts that almost always exceed our expectations.Â Leaders create a culture where teachers and learners are empowered to use technology in innovative ways to enrich teaching and learning. This is an updated version of a post that originally published on July 21, 2014. Sylvia Libow Martinez is a writer, speaker, maker, mom, video game designer, and electrical engineer. She co-authored the book, Invent to Learn â€” Making, Tinkering and Engineering in the Classroom. Gary S. Stager is a veteran teacher-educator and keynote speaker.