The Maker Movement and K-12 Education

Current Status and Opportunities for Engagement in California

An Emerging Topic Report prepared by the
California Council on Science and Technology

CCST
CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

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Chapter 1. Introduction

The promise of maker education is not limited to higher education.

The Maker movement, a largely grassroots effort to establish spaces where participants can use a variety of design and fabrication tools, has become a focus of interest for educational institutions throughout the U.S. in recent years. Though the DIY movement has a long history, the makerspace in its current form (as defined below) originated in the higher education environment. It is therefore not so surprising that universities nationwide are again embracing it. In 2015, the California Community College system, interested in developing a more systematic network of these spaces as open-ended learning environments, requested that the California Council on Science and Technology (CCST) help inform their efforts. CCST published a guide for the Community Colleges in 2016,[1] followed by a series of regional symposia aimed at informing community colleges about requirements for planning and operating makerspaces on their own campuses.

The promise of maker education is not limited to higher education, however. In the past few years, K-12 schools have begun exploring their connections to the Maker movement as well. There has been considerable work done on the *practical* aspects of implementing makerspaces at the collegiate level; the focus is especially on makerspace logistics. But academic discussions of makerspaces and student impacts at the K-12 level have in large part been more theoretical and speculative.[2,3] Nonetheless K-12 teachers have shown considerable interest in makerspaces; a 2016 survey of nearly 500 educators with makerspace experience or interest found over 60% taught at the K-12 level.[4] Since the Community Colleges and K-12 system have an extensive and varied partnership, a logical next step is to examine how makerspaces integrate with K-12 schools, and whether makerspaces situated in or used by K-12 institutions differ significantly from those in institutions of higher education.

The questions we set out to answer are:

- How did the idea of K-12 makerspaces originate?
- Why are K-12 educators so excited about Making?
- What do makerspaces look like in K-12 environments?
- How do K-12 makerspaces connect to higher education, including California's Community Colleges, and what opportunities may exist to build on this engagement?

Overall, we have found that colleges and K-12 schools engage with the Maker Movement differently. While higher education models readily embrace the entrepreneurial, dedicated-space maker concept advocated by organizations such as Maker Media, which publishes Make Magazine and hosts annual "Maker Faires" worldwide, K-12 institutions have more frequently explored alternative models—sometimes making without a makerspace or, more precisely, acknowledging every classroom can be a makerspace. In the K-12 sphere, the literature suggests the emphasis is placed on making *activities*—the pedagogy—while the tools and dedicated spaces that facilitate making, resources more challenging for K-12 schools to implement, are secondary.

Chapter 2. Defining 'Making' and 'Makerspace'

Scholars who investigate *making* in schools and community settings define making in a variety of ways, which has led to some inconsistency in how it is discussed in the literature.[5,6,7] Broadly speaking, making is a "class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends," with the end goal of producing a sharable artifact.[8] These activities frequently incorporate digital tools, which allow for much faster and more sophisticated design and prototyping.[9,10]

Like making, the definition of *makerspace* is somewhat variable. Fundamentally, a makerspace is a place where people create things. Makerspaces may focus on different fields, such as robotics, woodworking, sewing, programming, or any combination of these and other skills. But a makerspace is more than a space—definitions often emphasize the people who gather there because of a shared interest in creating things.[11] Indeed, makerspaces have been defined not only as the spaces where tools required to make are housed, but also as any physical space where these communities of practice gather.

It is difficult to accurately determine how many maker-spaces there are in K-12 schools.

With the variability in makerspace formats—and even titles, as a recent survey of 51 spaces found they referred to themselves in 45 different ways[12]—it is difficult to determine accurately how many makerspaces are in place in K-12 schools,[13] though this area is the focus of ongoing work.[14] In fact, even faculty from the same school disagree about whether their campus houses a makerspace; according to an informal survey taken by CCST,[15] in several instances when multiple respondents answered for the same school, answers varied from "Yes, we currently have a makerspace," to "We have plans to implement one soon," to "We do not have a makerspace on our campus, nor plans to build one." And educative making need not be limited to spaces designated specifically for maker activities; these practices can be found in dedicated makerspaces, libraries, classrooms, or anywhere a maker community and mindset is found.

The Maker Movement

Origins of the Maker Movement may be traced loosely back to activities and communities that embraced the anti-consumerism, do-it-yourself (DIY) spirit as early as the 1940's and '50's[16]—and perhaps earlier, connected to the anti-industrial ethos that spawned the Arts and Crafts movement around the turn of the century—but today's picture of a Maker has more recent roots. Though makerspaces themselves originated earlier, the Maker Movement took off in earnest in the United States in the mid-2000's, with the rise of inexpensive digital tools; the development of interactive, virtual learning communities and platforms to document and share work products and processes; and the ability to rapidly produce prototypes with increasingly economical equipment such as 3D printers. The widespread recognition and mainstream appeal of the phenomenon can largely be attributed to Maker Media, Inc. founder and CEO Dale Dougherty. His founding of *Make:* magazine in 2005—a publication that features projects and tools of interest to makers—and his promotion of maker values and Maker Faires worldwide catalyzed the movement, elevating it from an open-sourced collection of tech-savvy DIY-ers and giving it a coherent marque.

But long before the appearance of the red Maker robot (the "mascot" of *Make:* magazine), communities of like-minded DIY-ers were gathering around collections of tools, as in the "hackerspaces" that started in Europe in the mid-1990s, and were focused on encouraging open-ended software development challenges.[17] Although today the terms hackerspace and makerspace are sometimes used interchangeably—especially by people who consider themselves hackers—many in the Maker Movement have consciously sought to differentiate makerspaces from hackerspaces, as they consider the term "making" to be more inclusive than "hacking".

The Fab Lab program, short for "Fabrication Laboratory" and one of the earliest versions of a standardized makerspace template, has its roots in an educational outreach component of an innovative laboratory at the Massachusetts Institute of Technology. In 2001, the National Science Foundation funded MIT's Center for Bits and Atoms (CBA), an ambitious interdisciplinary initiative at the boundary between computer science and physical science, which states that its goal is to study "how to turn data into things, and things into data." CBA's research on technologies for personal fabrication is complemented by the field Fab Lab program, which brings prototyping capabilities to under-served communities beyond the reach of conventional technology development and deployment.[18]

Advocates have made independent attempts at bringing the makerspace concept into schools.

In the following years, other makerspace advocates have made independent attempts at bringing the makerspace concept into schools around the globe. In 2006, the TechShop company was founded, which is a membership-based workshop and fabrication studio network that consults with schools interested in having their own makerspace.[19] In 2008, Stanford University launched the FabLab@School project,[20] and started building collaborations with institutions around the world to spread the program. These and other programs were subsumed in the popular consciousness under the "makerspace" sobriquet, coined in 2005 and actively promoted over the following years by Make Media.

The 2010s began with scant mention of the promise of makerspaces to K-12 education. But since then, hundreds of popular articles have been written about the potential of makerspaces to transform us. According to a review of the popular literature carried out by Agency by Design,[21] past prevailing narratives about makerspaces have been about a new industrial revolution—fueled by wider access to rapid fabrication and unprecedented entrepreneurial activity—and the training of a new workforce in STEM skills. More recently, a narrative about the value of makerspaces and making practices in education—particularly in K-12 settings—has begun to emerge. Today, few trends in K-12 education are as "hot" as maker education.

> ***The enthusiasm for maker education is outpacing the evidence to support it.***

More recently, added to the popular articles about the need for urgent adoption of the maker model in K-12 schools, is the emerging recognition that the enthusiasm for maker education is outpacing the evidence to support it.[22,23,24] In fact, the rush to adopt and implement making in various ways within the K-12 system has brought into focus a number of education system-relevant tensions within the Maker movement. For instance, leading educational makerspace researchers and practitioners who gathered in 2014 identified the linkage between becoming a maker and engaging in STEM pathways as a critical research gap.[25] As a recent review of the field noted, the vast majority of peer-reviewed literature specifically discussing K-12 making practices has been published in the few years since, and much of it has been anecdotal, not empirical.[26]

Harnessing the momentum of the movement and preferring not to wait for empirical, quantitative research to verify what many see as obvious benefits of making to their students, some educators have already implemented making in their classrooms or partnered with makerspaces to create out-of-school maker programs. As some researchers have noted, "Currently, our research-based understanding of making is still far behind the growing enthusiasm for making in the educational world, and with it, the ongoing spread and scaling of making to formal and informal learning environments."[27]

Since the Maker movement's entry into popular culture, maker education programs and makerspaces have sprung up in K-12 schools across the country, while others have formed in collaboration with public libraries, learning museums, and local for-profit makerspaces. Many of these have been supported by organizations like the Maker Education Initiative (Maker Ed), whose goal is to make "every child a maker." In 2014, the Director of Education at Maker Ed estimated that—based on Maker Ed events, professional development activities, and direct relationships—at least 64 of California's public schools had been directly impacted by maker education, with "easily hundreds more schools benefiting in other ways . . ."[28] The California Council on Science and Technology has learned of over 180 California K-12 schools that report having makerspaces, or nearly half of the 380 California educators who responded to an informal survey in 2017.[29] And many survey respondents (46%) whose schools did not already have a makerspace reported plans to have one soon.

Making in Education

Maker education vs. makerspaces

The maker education approach aligns with aspects of pedagogical theory that have been developing for many years. While makerspaces and maker education are terms that are sometimes used interchangeably, particularly by those who are not directly engaged in maker education, it is worth articulating a distinction between the two. The makerspace is, put simply, a particular application of a maker education approach. However, it is an approach which frequently depends upon the use of transformative technologies (rapid prototyping and digital information technology). It's important to recognize that maker education is more of an incremental development, in a pedagogical sense, than a revolutionary one.

Making is often described as a novel idea in education, but many educators will recognize its roots in familiar pedagogical philosophies that highlight the fundamental role of play and hands-on problem solving in cognitive development. Numerous researchers have traced modern maker education ideas to John Dewey (and others, including Friedrich Froebel and Maria Montessori), who maintained that education should be based on experiences that are connected to real-world objects and events.[30] Add to this heritage Jean Piaget's emphasis on the importance of play, individual learning, and learning through discovery and the foundations of emerging maker education are evident.[31] A significant precursor to modern maker education is constructionism, a concept advanced by Seymour Papert, who has been called the "father of maker education."[32] Papert argued that knowledge is constructed very effectively when young learners are creating and building objects they can share with others. This type of playful, independent, hands-on/minds-on, discovery-based learning—sometimes called 'active learning'—is considered important for developing problem solving skills, as these cannot be taught but must be discovered.[33] The difference is in the approach: in a traditional classroom setting, students learn *about* circuitry and electricity; in a makerspace, students *use* circuitry and electricity to create objects they want to make.

Making runs parallel to many current approaches in education.

Given this rich background in pedagogical theory, it follows that educative making runs parallel to many current approaches in education. Better-known and widely practiced methods such as project-based science and problem-based learning "emphasize learning through making."[34] As one scholar comments, "Making expands on traditions associated with Technology Education and Design-Based learning, but differs in ways that can potentially broaden participation in science and STEM learning to include learners from communities historically underrepresented in STEM fields."[35]

Maker education partially reflects a shift in education policy concerning the ways in which engineering and technology should be taught. Traditionally, these subjects were considered "workplace skills" that needed to be explicitly included in school curricula.[36] In a 1999 report, however, the National Research Council asserted that technology was changing too fast for this "skill-based" approach to be effective, and called for a "fluency" approach which emphasized more adaptive, foundational skills that would enable students to handle unintended and unexpected problems.[37] In effect, this study articulated a distinction between technological literacy—a general set of skills that could be imparted in a traditional classroom environment—and technical competence, which reflects more in-depth applied knowledge. This pivot toward fluency aligns well with activities that can be found in makerspaces.[38]

In fact, there is a natural tendency to link making to tech fluency and STEM subjects, partly because many of the prototyping and development tools that characterize making activities are themselves technological in nature, and partly because makerspaces developed as an offshoot of computer programming environments (hackerspaces). When staff at makerspaces were asked in a survey by Maker Ed whether they believed their activities aligned with specific educational campaigns, the vast majority of respondents (94% and 89%, respectively) indicated they clearly aligned with STEM and with STEAM, which were the two most well-known movements at the time.[39] The survey authors noted the alignment with state Next Generation Science Standards (NGSS) was likely higher than indicated (49%), as 30% of all those surveyed had no knowledge of the NGSS at the time of the survey. Similarly, while only 51% of respondents indicated their Makerspace aligned with 21st Century Community Learning Centers (21st CCLC) programs, nearly 40% were unaware of the program and couldn't indicate whether they aligned. Amid the interest in STEM-focused Making, it should be recognized that the makerspace environment supports a wide range of disciplines including but not limited to STEM fields, particularly in K-12 education settings.

Chapter 3. Why Make at School?

Learning Outcomes

Assessments of the impacts of maker education on student performance are still in development, a task made more challenging by the wide range of teachers who incorporate elements of a maker education approach in a normal classroom setting. Students who have the opportunity to participate in a dedicated makerspace setting have the opportunity to develop a variety of knowledge and skills, including those that are both discipline- and maker-specific.[40] Discipline-specific knowledge and skills comprise both the practices and techniques of learning core material as well as the material itself. A growing body of literature includes myriad examples of how making aligns with the *practices* of science and engineering emphasized in the *Framework for K-12 Science Education*.[41] Making is thought to be a perfect opportunity to contextualize scientific principles that are outlined in the Next Generation Science Standards (NGSS).[42] Some researchers have even illustrated how makerspace projects have specific curricular alignments: how building robots or writing robotics programs connects to state science standards and Common Core Math, for example.[43]

Maker-specific knowledge and skills include those needed to effectively use particular tools and technologies in the makerspace. This skillset includes knowing which tools are appropriate for the task at hand, and which techniques are best for different goals and materials. In addition to the tools, techniques and technologies that can be learned in a makerspace, maker-specific practices such as tinkering, prototyping, and iteration are central. While such practices can be found elsewhere, educators who teach in makerspaces found these to be crucial components emphasized in maker education.[44] Entrepreneurialism is an added maker-specific skillset that many educators observe or encourage students to develop.

Some argue that the primary learning outcomes of making are developing agency and building character.

Some researchers argue that these skills—capacity-based, discipline-specific and practical—including the 21st century skills addressed above, are secondary outcomes of maker-centered learning.[45] The primary learning outcomes, they say, are dispositional: developing agency and building character while making. The students referenced in their studies develop agency when they make things that are meaningful to themselves or others and when they take ownership of the making process. Educators can encourage this by being thoughtful in incorporating learners' natural inclination to care about their work into maker activity design. The researchers describe "building character"—building competence, increasing confidence, and forming identities—through maker activities as a way to support the development of a resilient disposition, a foundation for a wide variety of valuable thinking dispositions, or "soft skills," as they are often called. These dispositions include problem solving, critical thinking, inquiry, a growth mindset, collaboration, curiosity, playfulness, resourcefulness, responsibility, and optimism. Together, these qualities are central to what is known in the Maker Movement as the *maker mindset*.[46]

In short, many practitioners believe a maker-centered education invites students to make not only things, but also themselves—into better problem solvers and self-directed learners of meaningful content, makers. As one review observed, "Across the making literature, researchers note the deep engagement of young people, the opportunities provided for developing and authoring ideas, and the potential for the development of new dispositions, understandings, and directions (e.g. Sheridan et al 2014, Vossoughi et al 2013)."[47]

Assessing Learning

As one researcher put it, "It looks fun, but what are they learning?"[48] Researchers have recognized the need to clearly articulate learning outcomes of maker activities, and set out to document "what learning looks like" in different maker settings. This step is important, for as two makerspace observers note, "*Learning* in making is, emphatically, not interchangeable with *schooling*,"[49] meaning that learning can happen in a multitude of different environments and may not always appear the same way in a makerspace as in a traditional classroom.

While standardized testing has shown that students engaged in project-based learning (how some may choose to teach in makerspaces) outscore their traditionally educated peers in basic academic subject knowledge, these tests do not effectively measure 21st century skills.[50] Others add that because maker education is largely self-directed, students may be learning skills and building knowledge asynchronously.[51]

There is a lack of obvious paths forward when it comes to how to best assess learning while making.

Many researchers and practitioners acknowledge a lack of obvious paths forward or right answers when it comes to how to best assess learning while making.[52] There is ongoing work on developing documentation and assessment tools designed with maker-centered environments in mind, such as the Agency by Design research initiative at the Harvard Graduate School of Education.[53] However, but developing such tools is challenging. Some see the intrinsic differences between makerspaces and traditional classroom environments as an opportunity to freely shift the focus from quantitative summative assessments (i.e. grades) to more qualitative feedback and formative assessment. Indeed, some researchers view makerspaces as inviting a revolution in assessments in the K-12 school system.[54] Not only do they advocate a change in the types of assessments students receive, but also in who does the assessing. Is the teacher always the best suited to assess the kinds of skills and knowledge maker educators seek to develop?

Student-Driven Assessment

In an alternative assessment scheme, the students themselves would be an additional source of evaluation. Both peer- and self-assessment can add value to the evaluation process in a space where student-driven work can seem overwhelming to the single teacher faced with evaluating it. Some researchers advocate a combination of student- and teacher-driven assessments and feedback, relying on self- and peer-assessment to help guide students in their learning.[55]

Many maker educators rely heavily on self-assessments. In fact, giving students the time and space to reflect on what and how they have learned is crucial to the maker learning model.[56] Self-reflection can take many forms. Perhaps the most obvious is a progress or project journal, where a student records their progress, what new learning they've accomplished, how they felt about a particular method of inquiry, how they work in certain groups, what they did or didn't like about a project. While many maker educators rely on a journal, some researchers suggest that a variety of formats is preferable. For instance, researchers working in an afterschool library-based makerspace found that a combination of journaling and teacher-mediated interviews garnered a more thorough reflection from students than either method alone.[57] In addition, giving students a choice among various journaling formats—handwriting, drawing, blog writing, audio and video logs—allowed students to articulate their learning progress in the most comfortable way. Other researchers agree that allowing students to engage in self-reflection in a manner that makes sense to them is the most effective.[58] For instance, a student who enjoys writing may wish to write out journal entries while another may prefer to create a timeline of relevant milestones or plot a metric of their choosing that reflects their progress.

Many maker educators rely heavily on self-assessments.

Maker portfolios, where students collect their artifacts for the purpose of sharing out, may be a valuable assessment tool of fuller bodies of work than a single project. These project collections may span an entire course or even multiple grade levels as they progress through school, or even multiple settings (in- and out-of-school experiences). A series of research briefs[59] discusses maker portfolios and specifically, the value of *open portfolios*, or portfolios that are "openly networked, decentralized and distributed" for easy documentation and sharing. Even the act of curating these portfolios may prove instructive for students, as they decide what aspects of their progress to highlight, and give educators insight into the parts of the process the student found to be most meaningful.

Another type of self-assessment that has been adopted by maker educators is digital badging, which tracks skills as students learn them. Researchers have found that keeping track of their growing skills collection gives students both a method to document their learning and the motivation to continue building their repertoire.[60]

Peer assessment can be a powerful way to leverage distributed knowledge in the makerspace, as students with broad backgrounds and different learning styles and experiences supplement the feedback given by a single teacher. One example is peer critiques (or "crits"), which can be done in a formal or informal manner.[61] In some makerspace classrooms, the crit is considered an invaluable part of a student's education, not only allowing for a multitude of perspectives on a particular project but also increasing the "assessment literacy" of the classroom community as a whole. As peers share their work, each student involved in peer critiques becomes a more empowered learner—they learn how to critique their own and others' work for quality, growth, and creativity; and, seeing the community's body of work, gain a more accurate understanding of their work in relationship to the field. For those who worry students may be harsh critics of one another, one educator finds the gentle reminder to "be kind, be specific, and be useful" in offering their feedback is enough to keep comments constructive.[62] Another often-used strategy is "plussing," which was popularized by the animation studio, Pixar. In plussing, one cannot offer criticism without also offering a positive suggestion. Finally, another educator offers the suggestion to allow students to cover a student's work with only "love notes," or colorful sticky notes with positive comments.[63] Students, rewarded with the positive feedback from their peers, are then encouraged to consider what was *not* expressed on a love note and improve that aspect of their project in its next iteration.

Involving students in assessments of work performed by themselves and by each other presents additional opportunities to develop and practice important skills.[64] One educator points out that student participation in peer assessment presents an opportunity to develop skills such as leadership (through setting expectations of the process, presentation and difficulty of work performed), collaboration through constructive criticism and ideas sharing; practicing the ability to defend an argument or describe a problem; self-awareness as a learner; practicing informed iteration while working toward a solution or improvement.

Teacher observations and input remain essential.

Teacher-Driven Assessment

While student-driven assessment is an important component of the learning process in a makerspace, teacher observations and input remain essential. The literature concerned with teacher-driven assessment focuses on two main themes. First, research emphasizes the role of formative assessments in a non-traditional learning environment such as a makerspace. Second, researchers present methods to capture the learning dimensions possible in makerspaces, but not traditionally included in documented learning.

The Partnership for 21st Century Skills asserts that there is a lack of tests that adequately measure development of 21st century skills. In particular, the Partnership argues that current tests fail to accurately gauge how well a student will apply what they have learned to new situations or use evolving technologies to solve problems and communicate.[65] As part of their P21 framework, the Partnership provides a list of resources as a starting point for summative and formative assessments of 21st century skills.[66]

The Learning Activation Lab (LAL), a national research and design effort with the goal of improving learning in a variety of disciplines including STEM, considers how combinations of dispositions, skills and knowledge lead to successful learning experiences. The LAL defines *science learning activation* as a set of characteristics that set a student up for success with science as they "form short-term positive feedback loops that produce long-term positive outcomes." The characteristics that lead to these positive science experiences are referred to as dimensions of activation and include: (1) fascination with natural and physical phenomena, (2) valuing science for self and society, (3) competency beliefs in science, and (4) scientific sensemaking.[67] In makerspaces funded across the United States by Cognizant,[68] the Research Group at the University of California, Berkeley's Lawrence Hall of Science developed tools to measure dimensions of activation towards STEM through youths' participation in making activities. These tools, freely available to educators along with associated literature, definitions, and instructions for implementation, include surveys designed to measure various dimensions of activation by collecting student responses pre- and post-term or activity circuit, and observation forms designed to capture group work dynamics and engagement of individual participants or whole groups of learners. Each of these tools comes with a technical report detailing optimal use cases (e.g. single hour-long activities versus months-long lesson plans), instructions on how to collect and evaluate student data, and background on the malleability, and therefore responsiveness to intervention, of each dimension. [69]

Another example of documenting learning in a maker environment is the Tinkering Learning Dimensions Framework produced by a team of researchers and practitioners in the Tinkering Studio, housed within the Exploratorium in San Francisco.[70,71] Described as a branch of making, *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."[72] Importantly, tinkering emphasizes creative, improvisational problem solving. Through 18 months of observations of youths in the studio (including several weeks of recorded interactions with museum exhibits), the group came up with four dimensions of learning, along with the indicators to identify when learning is happening along these dimensions in a tinkering context. These dimensions are: (1) Engagement, (2) Initiative and Intentionality, (3) Social Scaffolding, and (4) Development of Understanding. Observers watch for indicators such as whether learners are displaying emotions like "joy," "pride," "disappointment," or "frustration" to identify when a learner is engaged, for instance; whether they request or offer advice to gauge a learner's social scaffolding development; or whether they continue to increase the sophistication of their work when they develop their understanding. The observation tools, including a video library highlighting indicators to watch for, are available online.[73]

> ***Fun is central to the power of a student's experience in a makerspace.***

While the occasional feelings of frustration and failure inherent in the iterative process of tinkering and creating objects command a good deal of attention in the literature, fun remains central to the power of a student's experience in a makerspace. Indeed, there are many examples of researchers reminding educators how important play is to the process of learning.[74] Project Zero, a research group at the Harvard Graduate School of Education, has investigated a "pedagogy of play" with a research initiative to examine how playful learning can take a central role in formal education settings.[75] They provide indicators of playful learning---including categories such as delight, wonder and choice---as a tool to focus classroom observation. Project Zero's research on play's role in learning is ongoing, as they investigate Playful Participatory Research.[76]

Chapter 4. What Makerspaces look like in K-12 institutions

Maker education is increasingly widespread at the K-12 level; dedicated makerspaces, which involve equipment and staffing resources often beyond the reach of public schools, are less so. There does exist a range of makerspaces used by K-12 schools, but they vary in form considerably, some straining the definition of what constitutes a makerspace. While many makerspaces open to the general public—the FabLabs, TechShops, and for-profit makerspaces, as well as those in most postsecondary settings—are geared toward entrepreneurs and hobbyists in the community, makerspaces in K-12 schools tend not to emphasize the entrepreneurial aspects of making as much. Like makerspaces in libraries and museums, K-12 makerspaces tend to be designed to provide supervised and (somewhat) structured educative activities to students.[77]

The makerspace movement in K-12 may be described as a trend of remaking learning spaces.

Because the makerspace was developed as a flexible paradigm at the nexus of innovation and education, there exists a wide range of programs, especially in K-12 schools where the focus is often less on workforce skills and more on a hands-on learning experience tailored to meet the needs and goals of the school in question. As the Sonoma County Office of Education asserted in a recent interview, "A makerspace is more of a mindset than a toolset."[78] In point of fact, while it may be possible to identify networks of specific makerspace variants such as the FabLab@School project, which incorporate a particular model using a more or less standardized set of equipment (often provided in whole or in part by the organization sponsoring the model), the Maker Movement in the K-12 context may more accurately be described as a trend of remaking learning spaces. Even individual classrooms can become 'makerspaces' of a sort, and there are plenty of resources available to educators providing templates for doing so by repurposing existing resources or making do with a minimum of equipment.[79] One overview produced for the Independent Schools Association of the Central States differentiates between "innovation labs, makerspaces, Fab Labs, and library learning commons," all of which are considered part of a maker education approach.[80]

This range of appellations is largely for two reasons: first, while the STEM focused makerspace models, particularly those using a model such as FabLab or TechShop, will include various technological tools, the focus in design for learning from a pedagogical standpoint is not on the tools but on the process.[81] This is not incidentally related to the fact that K-12 schools often face resource and staffing challenges which are far more significant than many institutions of higher education. In addition, there is some concern that attempts to institutionalize making will interfere with the creativity and innovation which are at the core of the "maker revolution."[82]

That said, makerspaces in K-12 schools which rely on at least some of the transformational technologies intrinsic to the concept can be coarsely sorted into those housed within the school, those housed outside the school, and dedicated versus mobile or classroom-based. (See Figure 1 for more detail.) This superficial categorization approach allows for a general analysis of required resources for each type of makerspace, although it does not take into account the very wide range of activities that occur within these spaces. Again, attempting to define a school's maker program solely based on its makerspace location misses the point; at the K-12 level it is the process that is emphasized over the actual making. Unfortunately, while identifying dedicated makerspaces may provide only a limited overview of actual K-12 makerspace related activity on a grand scale, it is likely the most viable approach at present. This challenge is likely one of the reasons behind the lack of large-scale, systematically collected quantitative data about makerspace impacts on K-12 education.

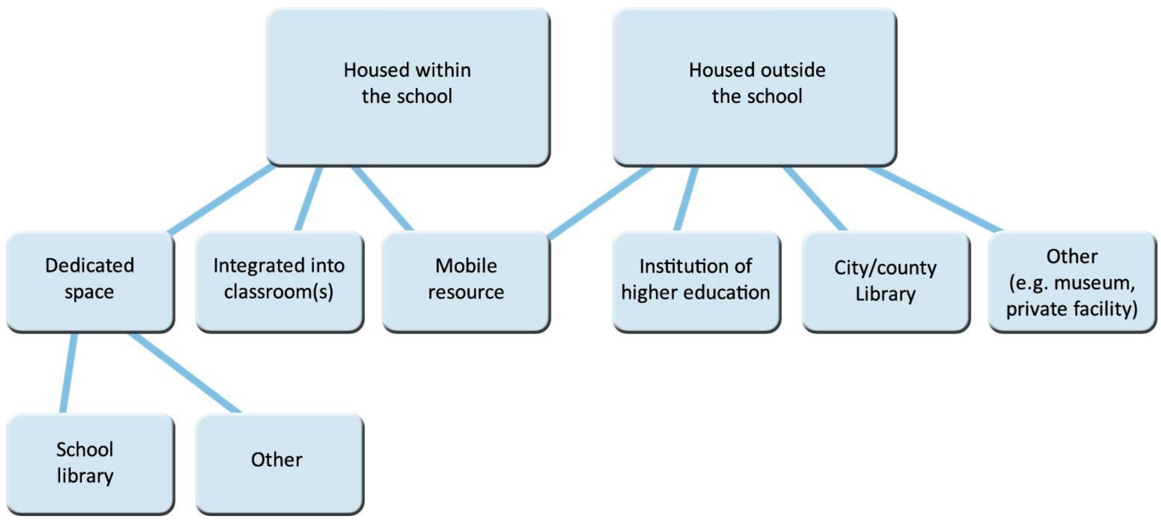

Figure 1. K-12 Makerspaces can be sorted by location in relation to school campus, but a more informative classification system would include information about the activities in the makerspace.

A more detailed, but more difficult way to classify makerspaces is by examining what sorts of activities are emphasized in each space. For instance, one makerspace model focusing on e-textile design has students work primarily on troubleshooting faulty designs rather than creating new ones.[83] The process of de- and re-construction, in this case, is presented as a viable instructional alternative to the process of making from scratch. As another example, Fab Labs, and by extension the K-12-adapted FabLabs@School spaces championed by Stanford University researchers,[84] tend to focus on the intersection of digital and physical tools. In these spaces, students often use digital tools to design a project which is then realized with fabrication tools such as 3D printers. In spaces such as these, learning focus is frequently placed upon engineering, design, and robotics.[85] In other spaces, the focus may be more on different subjects, such as the arts.

In fact, learning environments that differ from the FabLab-style makerspace have expanded this focus in a way that may allow more participants to engage and define themselves as makers.[86] Informal learning settings introduce tools to people with less access and this access allows those who don't readily self-identify as makers to become makers. Different makerspaces play different roles in the ecosystem of maker/makerspace/community.

Differences between K-12 and Other Makerspaces

Makerspaces are supposed to be flexible in design and adaptable to a range of learning environments – they represent a core concept underlying a multitude of implementations, rather than a specific model to be followed. This is true for makerspaces at every level. However, those situated in K-12 environments face environmental constraints that may not be present in an institution of higher education or community makerspace targeting a fundamentally adult audience. First, while K-12 students are certainly capable of thriving in an environment that encourages innovation and can effectively use devices such as a 3D printer, some of the more elaborate fabrication equipment considered a staple of many makerspaces may not be suitable for use by a minor without strict professional supervision (e.g. laser cutters and precision milling machines, which are standard components of the Fab Lab). Second, K-12 schools generally have much more limited resources, both financially and in terms of staffing, than many IHEs.

Makerspaces in K-12 environments face constraints that may not be present elsewhere.

Despite these limitations, the pedagogical and organizational sophistication of K-12 makerspaces is often quite pronounced, because they are able to participate in a considerable network of organizational support from the broader makerspace community. Some studies have suggested that educational networks play an important infrastructural role in inspiring the inception of makerspaces.[87] These networks can provide interested educators with a ready-made discussion framework that validates the concept of hands-on education and provides intellectual and social resources to enable the educators to realize some version of this concept in their own school environments.[88]

Chapter 5. Opportunities for engagement

Many IHE's already recognize the value of a K-12 maker experience. This fact is demonstrated by the growing number of four-year institutions that accept maker portfolios as supplemental application materials for admission: the Massachusetts Institute of Technology, Carnegie Mellon University, the University of Iowa, and Washington University at St. Louis are just some of the universities that have begun considering maker portfolios, and more have pledged to do so in the near future.[89] Some colleges, including Sierra College and Folsom Lake College in northern California, have pledged to offer scholarships to students who have demonstrated excellence in Making.[90] And there may be opportunities for more direct engagement with K-12 students in the maker context.

The best opportunities for expanding Making in K-12 lie in sharing resources with IHE and expanding training opportunities.

Given the logistical challenges inherent in funding and maintaining makerspaces in K-12 schools on a significant scale, and the wide range of approaches that K-12 educators have adopted while incorporating making into their classrooms, it seems likely that the best opportunities for IHE to foster the expansion of maker-related activities in the K-12 system lie in two areas: sharing existing makerspaces and/or related resources (including personnel), and expanding training opportunities for K-12 educators to incorporate maker education in their curricula. It should be noted that while effective use of a makerspace by K-12 educators would necessitate maker education training, the reverse is not true. Despite the relative lack of outcomes-based metrics at present, it appears likely that maker education training should prove valuable for teachers regardless of whether they have access to an actual makerspace environment.

For the California Community College (CCC) system, the former option is the most straightforward, as the CCC system has an existing (and expanding) network of makerspaces and most campuses are already involved with local K-12 systems in some capacity. In order to effectively share makerspace resources with local schools, the CCC would need to engage in a systematic and ongoing outreach program, leveraging existing channels of communication with the K-12 system. Examples of this might include hosting K-12 maker competitions (with CC student judges) and showcase events like mini Maker Faires on their campuses. To streamline this approach, as the CCC Maker initiative matures and implements the expanded network of CCC Makerspaces, the CCC could facilitate interaction with local schools by developing standardized procedures or guidelines for time- and personnel sharing, so individual campuses would not need to devise their own agreements.

As for incorporating maker-related instruction into teacher training and professional development, there already exists movement in this direction. Dale Dougherty, founder of Maker Media and one of the Maker Movement's primary evangelists, has worked to promote the makerspace concept in the K-12 system by seeking to train teachers to develop and manage makerspaces. Sonoma State University, a member of the California State University system (CSU), offers a professional development program on making for teachers and administrators; as of June 2017, approximately 400 teachers have taken the course. Initially, the Nancy C. and Dale Dougherty Foundation sought to integrate makerspace related training into the teacher training curriculum at California State University (CSU), but the certificate program was seen as more readily feasible.[91] While the certificate program was quicker to launch, the Nancy C. and Dale Dougherty Foundation and the CSU continue to explore ways to incorporate maker-related training into the teacher training curriculum.

Another potential avenue for makerspace-related collaboration between IHE and K-12 partners stems from the CSU system's growing interest in education within makerspaces. As the CSU expands its library-based makerspaces to most of its campuses, new Master's students are being encouraged to pursue research projects focused on learning in makerspaces.[92] Community college students who transfer to CSU (half of all CSU students[93]) and who have prior experience working with K-14 students in their community campus makerspaces will be ideally situated to follow this path of inquiry, adding to a very limited but growing dataset.

Professional Learning and Maker Education

Professional learning is intended as an ongoing dialogue promoting integration of new desired skill sets into existing practice. This method stands in contrast with the traditional professional development model, which involves standalone workshops or discrete training sessions that are not always integrated into a broader educational context. Per the Quality Professional Learning Standards adopted by the California State Superintendent,[94] there are seven core standards by which California's professional learning systems should be judged. Chief among these is the expectation that high-quality professional learning is guided by a variety of reliable data.

As discussed earlier, quantitative data on maker education and its impact on students or the classroom is currently extremely limited. The grassroots nature of the maker movement among K-12 educators, which has led to a particularly wide range of classroom implementation models, makes conclusions about how K-12 maker education can be most effectively implemented—or even whether it should—especially challenging to resolve.

> ***Quantitative data on Maker education and its impact is extremely limited.***

A promising path forward in growing a standardized data set to guide maker professional learning is documenting the experience of the alumni of the Sonoma State Maker Certificate Program, a first-of-its-kind teacher preparation program for maker-centered professional development that started in 2014.[95]

There may soon be an even broader alumni base to contribute data to the body of knowledge, as the CSU system will be using a grant from Chevron to expand the Sonoma State Maker Certificate Program to other campuses.[96] As these educators use these new practices, a data set of maker education efficacy will develop and it should be possible to use these data to inform ongoing efforts to understand how makerspaces can best integrate into educational institutions of all levels.

Questions to pursue

There are many swiftly moving parts to the maker movement within K-12 education systems, and they are not united or organized in a concerted manner. The grassroots nature of the movement, coupled with the inherently flexible paradigm of a makerspace designed to fit myriad different communities, makes measurement of their impact on K-12 education difficult. Despite the lack of data, educators see value in the approach, based largely on a combination of anecdotes and the pedagogical heritage that maker education shares, and are enthusiastically implementing programs in their own schools and classrooms.

A balanced approach to maker-centered education will emphasize the community, values, and practices of educative making.

While the focus in K-12 maker education is less on dedicated makerspaces and more on the activities therein, the movement still represents a good deal of investment, both in terms of personnel/time and capital resources. Educators who recall the promise of technology—a computer in every classroom!—to "save" K-12 education understand that an investment based solely on a belief that the tools themselves will bring about needed change can lead to disappointment.[97] Makerspaces are generating much of the excitement surrounding the movement, but a balanced approach to maker-centered education will emphasize not only the tools and technologies but the community, practices, and values of educative making.

Attention to this community makeup is also important. As making is being rapidly adopted throughout the K-12 and higher education spheres, tensions over issues of access and equity are becoming more apparent, though a full discussion of this important topic is beyond the scope of this overview. Making, as an emerging educative practice, can be partially distinguished from previous educative philosophies by its focus on the individuals' creativity within a community of practice that values creative agency.[98] Some research into the efficacy of making as a learning pathway focuses heavily on the ability of learners to develop identities as makers, and the importance of fostering a sense of belonging in their learning communities.[99] However, a number of researchers have remarked on the overwhelmingly skewed depiction of makers as middle-class white men, for instance in *Make:* magazine's covers and promotional materials, which may be a barrier to self-identifying as a maker.[100,101] Another obstacle is the notion of who has access to making as an educational activity; many making programs have been primarily located in private schools, museums, and higher education, according to some reviews of the literature.[102] These lines of research suggest that careful consideration should be given to how maker-centered curriculum and pedagogy might be organized to recognize and leverage the diverse backgrounds of young learners.

With so much on the line, it is crucial that researchers and educators consider what is still missing in the rush to innovate: data and metrics to track how well the program fulfills its promise and potential; access and equity issues posed by makerspaces; teacher preparation for effective maker education; a minimum set of expectations from a makerspace such that K-12 systems can efficiently leverage their resources in their unique environments; and best practices for partnering with other institutions for maximum and continuing student benefit. Therefore, these questions should be considered:

- What are the best metrics for tracking maker education impact in K-12 systems?
- Who will be able to learn well here, and how can that access be expanded?
- Should makerspace training be more integrated into professional development?
- Is greater centralization of a K-12 makerspace paradigm desirable or even possible?
- Is there an opportunity for coordinated outreach from the California Community Colleges?

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