# STEM-Rich and Equitable Making: Lessons from a Museum-Based Research-Practice Partnership

*By Jean J. Ryoo and Linda Kekelis*

What do museums, garages, and the White House lawn have in common? The answer: making. Maker Faires, makerspaces, and programs dedicated to making are popping up across the United States and the world, even in U.S. President Barack Obama's backyard. The White House hosted the first-ever White House Maker Faire in 2014. In 38 countries on six continents, 180 public Maker Faires are planned or have already happened in 2016 *(makerfaire.com/map)*. This year, during the U.S. National Week of Making from June 17 to 23, schools, colleges, universities, and an expansive network of organizations supported making opportunities in their communities. The Exploratorium in San Francisco, for example, launched a free online course for anyone interested in making and tinkering *(tinkering.exploratorium.edu/massive-open-online-course)*. The U.S. Patent and Trade Office worked with the YMCA to create mobile makerspaces, and the National Recreation and Park Association ran a Rec-to-Tech campaign to help its members convert underutilized recreation centers into makerspaces (White House, 2016).

A Techbridge participant shows off her Scribbling Machine. Photo © the Exploratorium

This surge of interest is due to the fact that hands-on making activities, whether with old tools or new technologies, are incredibly engaging. Research has documented how making exercises students' creative and improvisational problem-solving abilities; builds their agency, persistence, and self-efficacy; and helps them defend their ideas and understanding (Dixon & Martin, 2014; Peppler, Halverson, & Kafai, 2016; Resnick & Rosenbaum, 2013). Making also supports science, technology, engineering, and math (STEM) learning. Through making activities, youth ask questions, carry out investigations, use mathematical and computational thinking, develop models, and assert evidence-based arguments in the ways that scientists and engineers do. Thus making supports the investigating, sensemaking, and critiquing practices described by the (U.S.) National Academies of Sciences (2012) and in educational research (McNeill, Katsh-Singer, & Pelletier, 2015).

Yet there is growing concern about a lack of equitable access to these learning opportunities (Gomes, 2016; Quattrocchi, 2013; Vossoughi & Bevan, 2014). And as museums extend their making programs into community partnerships, there is an increasing need to understand how STEM-rich making can be adapted to offer expansive and equitable learning experiences for *all* youth.

## FORMING AN RPP

To address these concerns, Exploratorium researchers came together with fellow California educators and leaders engaged in afterschool and community programs—from Techbridge of Oakland, the Community Science Workshop of Fresno, the Environmental Science Workshop of Watsonville, and the Discovery Cube of Santa Ana—to form a research-practice partnership (RPP, see Coburn, Penuel, & Geil, 2013) called the California Tinkering Afterschool Network *(www.exploratorium.edu/education/california-tinkering-afterschool-network)*. In our RPP, we wanted to articulate what high-quality, STEM-rich making looks like, particularly in community-based programs serving underrepresented youth.

All members of this partnership are deeply committed to providing equitable learning experiences. Techbridge's afterschool programs are for girls in the San Francisco Bay Area. They also are held at underresourced schools that serve students underrepresented in STEM. Taught jointly by a classroom teacher and a Techbridge program coordinator, these weekly programs support girls' engagement with science, technology, and engineering activities, as well as career exploration with role models. The Environmental Science Workshop's and the Community Science Workshop's programs are organized around making. They take place in community-based workshops offering a variety of materials, tools, and models for maker projects. Primarily serving low-income, bilingual Latino families, these sites operate as drop-in centers welcoming family members of all ages. In fact, many of the staff members themselves were once drop-in participants. And Discovery Cube's program, in collaboration with the San Bernardino Community College District, involves professional development (PD) workshops for educators who want to integrate making into afterschool programs serving low-income communities in Southern California.

Together, the members of our RPP analyzed observational data collected from three years of these programs. Our full report *(researchandpractice.org/resource/stem-making-in-afterschool)*, released earlier this year, focuses on how our community-based programs support making with practices and PD that promote equitable experiences for youth underrepresented in STEM. It details how making can support valued outcomes such as engagement in STEM practices, 21st-century skills, and learning that is connected to youth's cultures and interests. These findings, outlined briefly below, apply to youth whether they are from urban or farming communities and regardless of gender, ability, or socioeconomic status.

Our report also addresses a lack of research describing effective professional learning experiences for educators who implement making. Professional learning workshops often focus on how-to elements of activities. While this is important, our study suggests more PD is needed to ensure making is STEM-rich, expansive, and equitable. In particular, our study examined how to equip educators with strategies for implementing process-oriented facilitation, careful listening and questioning, and evidence-based reflection with their students. As a

Girls in the Techbridge program made a self-zippering jacket that opens and closes based on external temperatures. Photo © the Exploratorium

result, educators didn't just learn how to do an activity but also how to effectively facilitate expansive and equitable making.

## DEFINING OUR TERMS

What do we mean by "expansive" and "equitable" making? Our collaboration defined *expansive learning* as allowing youth to imagine and create while deepening their STEM skills. We defined *equitable learning* as experiences that could help counter the inequities youth face by leveraging their interests and cultural resources toward successful and full participation in making activities.

*STEM-rich making* emphasizes real-world encounters with science (instead of text-based or abstract representations) that draw upon the investigating, sensemaking, and critiquing practices that youth use to build real stuff in the real world. For example, students in the Techbridge program were challenged to design making projects with a social purpose, an approach that has been found to appeal to girls (Martinez, 2016). One group decided to make a self-zippering jacket that opens and closes based on external temperatures, which could be useful for children too young to manipulate zippers and people with disabilities. To achieve this, they worked with a microcomputer, temperature sensors, and string that wraps around a motor according to temperature changes. Through this process, youth learned about electricity, circuitry, and computer coding. While collaboratively solving unexpected problems and testing ideas, the girls had the opportunity to design and redesign, collect data as they made observations, and discuss iterations of their original plans.

## OUR FINDINGS

**Finding #1: How making programs advance STEM learning and equity-oriented goals.** Afterschool settings commonly value socioemotional and academic learning, seeing both as essential to students' well-being and development. These programs seek to develop supportive social communities in which participants can exercise choice, leadership, and peer mentorship. Our research found that making programs supported all of these values by

Leaders and educators from the California Tinkering Afterschool Network attended the Exploratorium Tinkering Studio's Fundamentals of Tinkering professional development workshop. Attendees created circuits with materials including repurposed mechanical toy parts. Photo © the Exploratorium

- supporting persistence through intellectual and creative risk taking
- engaging students in STEM practices
- supporting 21st-century skills such as collaborative problem solving and critical thinking
- connecting experiences across the home, community, and school.

In Techbridge's program, girls designed and built projects to showcase at Maker Faire. Reflecting on personal challenges with waking up in the morning, one group decided to create a "progressive alarm clock" that became louder when the snooze button was pressed. The group worked with an Arduino, an open-source electronics platform that can be programmed to sense and control physical devices. To enhance the sound, the girls wanted to add a wave shield, which allows Arduinos to play higher-quality uncompressed audio. But the wiring was complicated. For the next several months and with the support of peers and program staff, the girls experimented with various soldering techniques. Unfortunately, none of their four prototypes worked in time for Maker Faire.

Despite facing frustration, the girls explained that they didn't want to give up. They said that they were proud of their project idea and interested in the process, and that they enjoyed the challenge of finding solutions to their own problems. At Maker Faire, they recounted what they were trying to achieve, shared what they had learned about soldering techniques and Arduino coding, and described their plans for next steps.

Along with encouraging the girls to link their interests and experiences at home and after school, the program helped them understand how their project was connected to school and future career pathways. Mentors from local graduate programs and engineering industries were present to assist girls with their projects and to talk about their own learning pathways.

Furthermore, the girls-only dynamic of Techbridge enabled the participants to take ownership of their projects and persist with confidence. Some girls lack confidence in their technical skills because they have less experience working with tools, taking things apart, and coding than boys may have. In co-ed classes and afterschool programs, girls sometimes choose to take on nontechnical roles or are relegated to them by boys in their group. In the Techbridge program, girls fill every role in their team and appreciate the

absence of teasing and competition that they sometimes experience in co-ed environments (Kekelis, 2004; Ancheta, 2006). However, simply letting girls work together on a making project does not ensure positive results. Good coaching from supportive and competent adults is essential, along with the positive, collaborative, culture-building activities that are regular features at Techbridge.

**Finding #2: Characteristics of productive making programs.** To support exploration and creative risk taking, programs need to not only offer making activities designed for open inquiry but also provide pedagogical supports that ask "What if?" questions. A "What if?" culture communicates that there are questions worth asking and ideas that students can discover. It shows that processes of understanding are valued activities. In such programs,

- social and physical environments are organized to make ideas, questions, tools, methods, and strategies visible
- youth are encouraged to see and reflect on each other's work, supporting a community ethos of investigation
- teaching leverages students' prior experiences and cultural resources


A group of Techbridge participants persisted in their goal of building a progressive alarm clock, despite setbacks. Photo © the Exploratorium

- teaching is process-oriented, with iterative design and redesign of activities to encourage careful listening, questioning, and evidence-based reflection
- activities are designed with multiple entry points.

A facilitator who had attended Discovery Cube's PD workshop wanted to introduce a circuitry tinkering activity to her fourth graders in a way that related to their experiences and cultural knowledge. Before delving into the activity, she asked the children to share what they knew about electricity from things they did at home or with their families. She then tied this experiential knowledge to the tinkering activity, in which youth tried to create a circuit using a battery, alligator clips, and a light bulb.

At first, the children struggled. Building on ideas from the PD, the facilitator wrote on the board, "Failure is not the end of the process. It's just a *step* in the process." She encouraged youth to experiment based on their hunches and helped them make connections to the circuitry knowledge they had gained at home or in school. As students' bulbs lit up, she welcomed youth to share diagrams of their various approaches, stressing that there was no single way to succeed. This process-oriented approach supported youth in working through their own ideas at their own pace.

**Finding #3: Ways to help staff foster productive making.** All of the organizations in our RPP paid careful attention to facilitators' professional learning, especially in relation to fostering equitable making experiences. PD across our organizations focused on inviting youth to contribute by helping them recognize their experiences and skills, positioning them as capable makers, and supporting them through difficulties. To achieve this, the RPP's PD included

- explicitly discussing the marginalization students experience in other settings and ways to avoid reproducing these experiences in afterschool programs

Youth in the Exploratorium's Afterschool Tinkering Program built Nature Bots made of natural objects like bark, moss, sticks, and seeds and powered by offset motors. Photo © the Exploratorium

- engaging in making activities that students would later try, and then reflecting on the challenges to solving problems or iterating on ideas
- reflecting on teaching practices necessary to support youth with "What if?" questions, group sharing, and meaning making
- exploring how to create a culture of creative inquiry using routines that develop trust and collaboration
- discussing how students can serve as mentors and leaders by sharing their skills and know-how.

Community Science Workshop offered training in which staff took on the role of a new drop-in student or facilitator. Participants developed skits exploring the challenge of being new to making and improvised possible solutions. Following this activity, staff discussed what pedagogical actions could better facilitate new learners' participation among both youth and adults. They then revised and replayed their skits, demonstrating key strategies to support a productive making culture. In this way, participants collaborated in a team-building environment to explore what they valued in their work and for students.

Later in the training, staff collaborated on a Rube Goldberg chain-reaction machine and then reflected on this making experience. One participant said she felt that her male-dominated group did not listen to her ideas during the activity. She then reflected on how a male staff member, a minority in her Fresno Community Science Workshop, must feel in the space. This conversation led to larger group reflections on the inequities youth might experience based on gender, race, and other factors, and how afterschool programs could ensure that collaborative experiences are inclusive.

At Techbridge's PD, staff engaged in hands-on, inquiry-based tinkering activities. The participants then discussed how to facilitate these activities so that learning builds on the knowledge girls bring into the program. They considered strategies for encouraging girls to turn to more experienced peers for guidance, such as pairing new students with returning students to learn skills. They also considered how youth could join adults in serving as sources of answers and knowledge. This exercise emphasized a pedagogical perspective that values youth knowledge and skills, rather than seeing youth as "blank slates" or with knowledge that "needs fixing" by adults.

## CONCLUSION

To support expansive and equitable making programs, educators need to create a culture that can fully leverage the potential of these activities. The program culture should recognize and build on what students know and can do, value process and iterative design, support "What if?" questions that help youth devise solutions to problems, and foster reflection that engages youth in the full scope of STEM practices. Equipping educators to create such a culture requires resources for PD.

Our findings highlight the positive learning and staff development outcomes that become possible when focusing on equity in STEM-rich making. As making expands into museums, and as museums seek to educate and inspire broader audiences, there is a greater need to design and study strong making programs that serve underrepresented youth. We

hope others will build on our joint efforts to improve STEM learning for all.

For more details about our findings as well as descriptions of student learning, afterschool facilitation, and professional learning in practice, read our full report at *researchandpractice.org/resource/stem-making-in-afterschool*. Watch our three-minute video on the (U.S.) National Science Foundation STEM Videohall showcase of innovative work to improve science, math, engineering, and computer science education at *stemforall2016.videohall.com/presentations/678*. For further information and resources, visit our website at *www.exploratorium.edu/ctan*. ■

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