STEM educators are interested in Making because students are interested in Making. Program after program, study after study, festival after festival testify to the excitement, engagement, and commitment that Making stimulates in learners [1, 2].

There are many different types of Making. Some programs focus on entrepreneurship and making products to bring to market; others focus on workforce development, primarily programs to support engineering skills; and yet others are more broadly educative [3]. This report addresses broadly educative Making.

There are three types of educative Making: assembly, creative construction, and open-ended inquiry.

In assembly projects, learners get materials and step-by-step instructions. The result is a set of identical or near-identical objects.

In creative construction approach, learners are given a challenge or a model to replicate. The learners can exercise choices related to the look, scale, and (sometimes) behavior of the objects. The result is many personalized versions of the same type of object.

In open-ended inquiry, learners develop their own idea or goal and figure out how to accomplish it. This third kind of Making is sometimes called “Tinkering” because it emphasizes creative, improvisational problem solving [4, 5]. An open-ended project results in a wide range of objects, each designed to address a unique purpose. For instance, students in a group may develop such diverse projects as a ping pong table whose net lights up in reaction to a ball coated in conductive paint, a self-zippering jacket that opens and closes based on external temperatures, or shoes for a user with visual impairment that sound an alarm when an object is within 10 feet of the toes.

Especially in this last form, as Tinkering or inquiry, Making provides a profound example of interest-driven, student-centered learning. But across all three types, educative Making can make STEM concepts relevant and provide a concrete purpose for engaging in STEM practices. Students learn about electricity and batteries, not to pass a test, but to build, for example, flashing Mother’s Day cards, Bluetooth speakers for their backpacks, or a lamp-lit playhouse for a favorite doll. In all of these cases, young people can develop a wide range of STEM skills, such as measurement, scaling, design, or data analysis. They grapple
with STEM concepts such as force, balance, circuits, and cause and effect as they deeply engage in practices of scientific and engineering inquiry.

Making as a Means of Engaging with STEM Practices
This report examines how afterschool educators in four different organizations have integrated Making into their programs in order to more deeply engage participants with STEM concepts, phenomena, and practices.

These programs build on key characteristics of Making and Tinkering that have been extensively documented in the research literature [2, 5, 6]:

• Making exercises students’ creative and improvisational problem-solving abilities.
• Making builds students’ agency, persistence, and self-efficacy.
• Making helps students to deepen and complexify their understanding and ideas.

When Making is organized to leverage students’ ideas and interests, it can create powerful conditions for learning, particularly for students who may not already identify as STEM learners. The combination of creativity, craft knowledge, and experimentation that Making supports has been shown to be characteristic of top-performing scientists. These skills are highly valued by STEM educators, professionals, and industries [7].

In 2012, the National Academy of Sciences issued a report that details the practices of scientific and engineering inquiry. This volume says that engaging in STEM practices provides the best context for learning STEM concepts and skills [8]. Researchers have parsed these practices into three clusters of activity [9]:

• Investigating practices: Asking questions, planning and carrying out investigations, using mathematical and computational thinking
• Sensemaking practices: Developing and using models, analyzing and interpreting data, constructing explanations
• Critiquing practices: Engaging in argument from evidence; obtaining, evaluating, and communicating information

Examples of what this looks like can be seen on the next page in the Paper Circuits activity.

This vision of STEM learning puts a primary emphasis on the firsthand phenomena of science, instead of text-based or abstract representations of science. Learning STEM and coming to want to learn STEM, according to the National Research Council (NRC), requires engaging with real stuff in the real world, a process that can motivate interest and a need to know about more abstract concepts [8].

The NRC vision of STEM learning emphasizes the role of evidence, specifically the critique of evidence, in scientific meaning making. Accordingly, unless students are taught to collect data and test hypotheses or conclusions, they lack experience with the most critical dimension of science and engineering as they are practiced in the world: their evidence-based nature. The report finds that few students gain experience with evidence in the classroom.

Making provides direct, immediate, and concrete forms of evidence relating students’ understandings to particular outcomes. For example, if students have an incorrect understanding about how to wire a battery and motor, their NatureBots will not locomote. In response, the students need to
PAPER CIRCUITS: GREETING CARDS

Making paper circuits challenges and extends students’ previous learning about how to construct an electrical circuit.

Students are given a variety of paper materials, paints, markers, and other tools with which they can create a greeting card for somebody they care about. They are also given copper tape, small LED lights, and a battery. The goal is to create a card with a circuit that is completed when the card is opened, so that the LEDs light up.

To accomplish this task, students must engage in the following STEM practices:

1. **Investigating practices.** Students develop an idea about the card they would like to create. How can they realize their vision? They begin to plan and sketch out their designs, building on the conceptual models they have developed about how circuits work. The open-and-close mechanism of a paper card forces them to extend their circuitry models across planes or dimensions so they understand how opening a card can complete a circuit—without shorting the circuit by allowing copper tape or wires to touch one another.

2. **Sensemaking practices.** Students’ initial designs frequently do not work. Applying knowledge of circuitry to achieve the goal of having the LEDs light up is difficult. Students need to rethink their model, troubleshoot, and solve the problem. If the LEDs light up intermittently, weakly, or not at all, the card itself is providing immediate feedback—evidence—about the accuracy of conceptual models and design solutions. This evidence may lead students to consider whether they need to add a second battery, devise a new switch, or rethink their design. The aesthetic and personal components of their creative vision serve as constraints to the design and engineering processes.

3. **Critiquing practices.** In Making, the object itself—whether and how it works—provides a powerful critique of the students’ thinking and conceptual models. Having students share their design and construction processes, including in cases where they could not get the circuit to work, gives them an opportunity to articulate why or how something does or doesn’t work and to share solutions, strategies, and questions.

Techbridge examples of different solutions to making open and closed paper circuits.
closely examine their design choices, recognize where their understanding or technical skills may be faulty, and adjust accordingly. Making can be implemented in ways that require students to collect data systematically in order to make something work reliably. Makers can be asked to describe and explain their thinking.

A Research-Practice Partnership
This report outlines key findings of a study of STEM-rich afterschool Making programs offered by four organizations. One program was Techbridge, an afterschool program for girls in the San Francisco Bay Area. This program, meeting weekly, supported girls’ engagement with science, technology, and engineering activities and career exploration with professional role models. Maker activities were integrated into an existing robust hands-on engineering program. These programs were hosted at school sites and taught jointly by a classroom teacher and a Techbridge program coordinator.

Two of the programs, the Environmental Science Workshop in Watsonville, CA, and the Community Science Workshop in Fresno, CA, organized their entire programs around Making. These programs took place in designated workshops replete with a wide variety of materials, tools, and models of past Maker projects. The sites operated as community drop-in centers, at which family members of all ages were welcome. In both places, many of the paid staff had themselves been community drop-in participants when they were younger. Both of these programs served primarily low-income, bilingual Latino families.

The fourth program was based at the Discovery Cube in Santa Ana, CA. This organization provided professional development workshops to educators who wanted to integrate Making into daily afterschool programs housed mostly in schools serving low-income communities in Southern California. This program was offered in collaboration with the San Bernardino Community College District.

These four organizations worked with the Exploratorium, in partnership with the San Francisco Boys & Girls Clubs, for a period of more than three years. The research-practice partnership collaborated to design and implement new Making activities and to study how to introduce Making into programs serving students from low-income communities.

Research-practice partnerships have been defined as sustained, mutualistic collaborations organized to address pressing problems of practice, produce original analysis, and foster cooperation across perspectives of researchers and practitioners [10]. Typically they sit at the intersection of research (knowledge-building) and evaluation (program improvement). They review, discuss, and analyze evidence, collected in the form of video or field notes, to gain a deep yet practical understanding of how program implementation affects youth and adults. In our research-practice partnership, the shared interest was a desire to articulate what high-quality STEM-rich Tinkering and Making look like.

After initial rounds of data analysis and reflection, the research-practice partnership began to focus its inquiry in particular on how STEM-Rich Making could provide a context for expansive and equitable learning. The partners defined expansive learning as allowing young people to imagine and create while deepening their STEM skills and practices. It defined equitable learning as engaging all young people by leveraging their prior interests and cultural resources toward successful and full participation in and contributions to the activities.

The way the focus changed to encompass expansive and equitable learning is one hallmark of a productive research-practice partnership: Questions are reframed and problems illuminated through the joint research-and-practice inquiry, in which problems of practice, from the educators’ perspective, take center stage. Such practice-informed research is intended to lead to relevant and sustainable results [11].

Analysis of our four cases revealed cross-cutting findings in three areas:
1) How Making can advance program goals (Why)
2) Characteristics of productive Making programs (What)
3) Supporting staff to foster productive Making (How)

Appended to this report is a set of vignettes, drawn from more extensive case studies, describing activities at each of the research-practice partnership sites.
1. Using Making to Advance Program Goals

“We want to do everything we can do, and if we stop in the middle when we could have kept going, that’s really disappointing and defeats me even more than just failing. Like, doing everything you can is almost more rewarding than succeeding.”

—Techbridge Student

Afterschool settings commonly value both socio-emotional 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. We found that our four Making programs both contributed to and leveraged such socially supportive communities. Making provides a powerful context for socio-emotional and academic learning in the following ways:

• **Making can provide contexts for students to take and persist in intellectual and creative risks.** Making enables participants to develop and build out their ideas with the support of program staff. This process can be both challenging and rewarding. For example, a group of Techbridge girls developed the idea of a “progressive alarm clock,” which would become increasingly loud and annoying each time the snooze button was pushed. To enhance the audio, the girls wanted to add a wave shield to the Arduino microprocessor. An Arduino is an open-source electronics platform that can be programmed to sense and control physical devices. A wave shield allows an Arduino to play higher quality uncompressed audio. But the wiring and soldering were complicated, so the girls needed to experiment with various soldering techniques. In the end, though they were unable to get the clock to work in time for the San Mateo Maker Faire, they remained committed to their vision and were proud of their work. At the Maker Faire, they showcased the different soldering versions and recounted what they had tried to do, what happened, and what they planned next. They described what they had learned about soldering techniques and Arduino coding.

• **Making engages students in STEM practices.** Makers design, build, and test a wide range of objects, such as rockets or paper circuits, and then refine them based on feedback—evidence—from the objects themselves. For example, a group of girls at the Fresno Community Science Workshop wanted to build a boat for the program’s annual summer field trip to a nearby lake. First they worked together to design a six-foot catamaran that could keep two people afloat. Then they built it using PVC pipes and copious amounts of duct tape. They first tested different ways to wrap the duct tape (in tiles, in layers, or in a weave) to see which was the strongest and most waterproof. They also had to test how to brace the catamaran. In the end, they brought the boat to the lake and took turns with their peers in taking it for a ride.

• **Making supports the development of a range of 21st century skills.** Skills such as collaborative problem solving and critical thinking have been shown to advance deeper learning [12]. For example, a Techbridge student wanted to hack into a pair of earbuds to use its Bluetooth function to power a speaker sewn into her backpack. The process of engineering, testing, and troubleshooting the Bluetooth system took weeks. The young woman engaged in ongoing problem solving while experimenting with the earbuds, taking them apart, and learning how the Bluetooth controls functioned. She used the Bluetooth buttons from the earbuds to call her friend through her cell phone and then observed whether sound was passing through the speaker. This and similar experiments enabled her to figure out the inner workings of the system so she could use it in her backpack project.
A culture of exploration and creative risk taking is a critical feature of productive after-school inquiry. This stance can also help students persist in projects that are organized around asking “what if?” set the stage for productive after-school making programs. Programs are designed with multiple entry points. Making activities can tap students’ prior knowledge and cultural resources. Making activities can support and deepen engagement. For example, before exploring how to create computer games with Makey Makey tools connected to the Scratch computer program, Techbridge educators taught the project in students’ interests in and hands-on knowledge of games. Students tested and played with games online and considered games they had played in the past. These experiences informed the goals, characters, and design elements of their own games. For example, girls built unicorns or monsters into their games, designed mazes or music-based experiences, and created collaborative or single-player games based on their previous experiences with gaming.

2. Characteristics of Productive Making Programs

A culture of exploration and creative risk taking is a critical feature of productive after-school Making programs. Programs that are organized around asking “what if?” set the stage for creative inquiry. This stance can also help students persist in troubleshooting as they run into challenges while making their projects. Creating a “what-if?” culture communicates that there are questions worth asking, things unknown that students can discover. It also shows that the process of coming to understand is a valued activity. Features of such programs include:

• **Social and physical environments are organized to establish responsive networks of assistance.** These settings make ideas, questions, and strategies visible through accessible tools, open horizons that allow everyone to see everyone else’s active work and problem solving, and regular reflective conversations to support a community ethos of investigation. In Watsonville, the organization of physical space—such as gluing stations, machine tools, and flat surfaces for building—encouraged students to engage with one another while integrating specific tools and techniques into their distinct projects. For example, when an Exploratorium researcher who was building a toy car went to use the gluing station, she started a conversation with a young girl who was using the gluing station to build a dollhouse.

• **Teaching and facilitation leverage students’ prior experiences and cultural resources.** Making activities can support and deepen engagement. For example, before exploring how to create computer games with Makey Makey tools connected to the Scratch computer program, Techbridge educators taught the project in students’ interests in and hands-on knowledge of games. Students tested and played with games online and considered games they had played in the past. These experiences informed the goals, characters, and design elements of their own games. For example, girls built unicorns or monsters into their games, designed mazes or music-based experiences, and created collaborative or single-player games based on their previous experiences with gaming.

• **Teaching and facilitation are process-oriented.** Iterative design-redesign activities encourage careful listening, questioning, and evidence-based reflection. For example, a facilitator who had gone through Discovery Cube professional development saw students in her program struggling to wire batteries. Building on Discovery Cube models, the facilitator wrote on the board, “Failure is not the end of the process. It’s just a step in the process.” She also shared different approaches to wiring batteries to stress that there was no single way for students to succeed. Such process-oriented facilitation was evident across all of the research-practice partnership sites. Process-oriented teaching and learning meant that youth worked on their own ideas at their own pace, a characteristic that may be more prevalent in after-school than in school settings. The process orientation was reinforced by the fact that objects sometimes took many days or weeks to complete.

• **Maker activities are designed with multiple entry points.** Providing multiple pathways enables students to choose their own directions based on their prior experiences and interests. For example, at the Watsonville Environmental Science Workshop, students developed individualized Rube Goldberg chain reaction machines, which they would later take to school as class projects. Each machine performed several different actions to get a rubber ball from the start of the machine to the end. One student started her machine by building a pinball plunger, another designed a pulley that would bring the ball to the top of a track, and yet a third started his machine with a ramp. At Techbridge, girls visited a local secondhand store to choose items costing less than five dollars that they could “hack” and...
that is, to invite and support all young people to contribute. Often the orientation toward equitable learning meant helping students to recognize their own prior experiences and skills, persist through difficulties. Staff development stressed the following features:

- **Engaging staff in strategies to avoid marginalization.** Program staff participated in explicit discussions about the marginalization and deficit views their students might experience in school, society, and other settings and about how to avoid reproducing these views. For example, in Techbridge professional development workshops, educators discussed unequal career access and pay for men and women. Facilitators discussed ways to talk about such issues that would not discourage girls from pursuing competitive careers and salaries. Educators also discussed how people perceive intelligence and when individuals might “feel smart.” They talked about the ways that young people might feel that their intelligence is or is not valued, especially in relation to external measures of intelligence like standardized testing. Educators discussed how Techbridge could avoid replicating these experiences for its participants.

- **Exploring and reflecting on the ways in which the iterative nature of Making deepens student learning.** Staff across the partnership engaged in the actual Making activities that their students would later do. They then reflected on the ways in which “what-if” questions, just-in-time tools or materials, and group sharing and meaning making supported their own persistence. At Discovery Cube teacher workshops, the lead staff educator modeled ways to support learner inquiry without providing answers too quickly. When a teacher asked for help in making her circuit board work, the workshop leader pointed her to the different models they had already identified. Then he engaged her in dialogue as she identified the parts of her circuit. The teacher tested her connections, rearranged wires following one of the models, and came to recognize that she had created an open circuit. “Like a jumper cable on a car!” A first pass didn’t work, but the teacher was encouraged to continue. On her third attempt, she successfully got the bulb to light up.

- **Exploring how to create a culture of inquiry and creative risk using routines that develop trust and collaboration.** For example, educators from both Fresno and Watsonville participated in a staff development workshop in which they role-played being a new drop-in student or a facilitator unfamiliar with Making. Participants developed short skits in which they explored the problem of being new to Making. They then improvised possible solutions and helpful interactions. After the skits surfaced the issues, group members discussed what actions could better facilitate the new learner’s participation, whether that learner was a student or a staff member. They then revised and replayed the skit, demonstrating key moves that could better 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.

- **Exploring how students serve as mentors and leaders for other students by sharing their skills and know-how.** At Techbridge, girls were regularly encouraged to turn to more expert peers for guidance as they built their projects. This peer-to-peer guidance was sometimes organized by adult facilitators, as when they paired new Techbridge students with returning students who could help them learn to solder wires together safely. It was also sometimes instigated by participants. For example, a group of girls who were learning to program sewable electronics solved their problems by asking peers who has used this hardware the previous year.

3. **Staff Facilitation and Professional Development to Support Productive Making**

Each of the four participating organizations paid careful attention to the professional learning of program facilitators. In particular, organizational leaders were attuned to building facilitators’ capacities to provide equitable Making activities—that is, to invite and support all young people to contribute. Often the orientation toward equitable learning meant helping students to recognize their own prior experiences and skills, positioning them as capable Makers, and supporting them to persist through difficulties. Staff development stressed the following features:

- **Engaging staff in strategies to avoid marginalization.** Program staff participated in explicit discussions about the marginalization and deficit views their students might experience in school, society, and other settings and about how to avoid reproducing these views. For example, in Techbridge professional development workshops, educators discussed unequal career access and pay for men and women. Facilitators discussed ways to talk about such issues that would not discourage girls from pursuing competitive careers and salaries. Educators also discussed how people perceive intelligence and when individuals might “feel smart.” They talked about the ways that young people might feel that their intelligence is or is not valued, especially in relation to external measures of intelligence like standardized testing. Educators discussed how Techbridge could avoid replicating these experiences for its participants.

- **Exploring and reflecting on the ways in which the iterative nature of Making deepens student learning.** Staff across the partnership engaged in the actual Making activities that their students would later do. They then reflected on the ways in which “what-if” questions, just-in-time tools or materials, and group sharing and meaning making supported their own persistence. At Discovery Cube teacher workshops, the lead staff educator modeled ways to support learner inquiry without providing answers too quickly. When a teacher asked for help in making her circuit board work, the workshop leader pointed her to the different models they had already identified. Then he engaged her in dialogue as she identified the parts of her circuit. The teacher tested her connections, rearranged wires following one of the models, and came to recognize that she had created an open circuit. “Like a jumper cable on a car!” A first pass didn’t work, but the teacher was encouraged to continue. On her third attempt, she successfully got the bulb to light up.

- **Exploring how to create a culture of inquiry and creative risk using routines that develop trust and collaboration.** For example, educators from both Fresno and Watsonville participated in a staff development workshop in which they role-played being a new drop-in student or a facilitator unfamiliar with Making. Participants developed short skits in which they explored the problem of being new to Making. They then improvised possible solutions and helpful interactions. After the skits surfaced the issues, group members discussed what actions could better facilitate the new learner’s participation, whether that learner was a student or a staff member. They then revised and replayed the skit, demonstrating key moves that could better 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.

- **Exploring how students serve as mentors and leaders for other students by sharing their skills and know-how.** At Techbridge, girls were regularly encouraged to turn to more expert peers for guidance as they built their projects. This peer-to-peer guidance was sometimes organized by adult facilitators, as when they paired new Techbridge students with returning students who could help them learn to solder wires together safely. It was also sometimes instigated by participants. For example, a group of girls who were learning to program sewable electronics solved their problems by asking peers who has used this hardware the previous year.
Conclusion

A 2015 review of the literature found a growing number of studies celebrating the potential power and excitement of the Maker movement in education [3]. Most of these studies addressed either the implementation of activities, such as e-textiles or engineering projects, or the nature of communities of practice within Makerspace environments [13, 14, 15]. Little of the research addressed core issues of teaching and learning.

The results of our study contribute to the literature by demonstrating, in some detail, the ways in which Making can support valued outcomes such as STEM practices, 21st century skills, creativity, and connected learning.

Our study also addresses a gap in the research with respect to teaching and professional learning of educators who are implementing Making. Professional learning workshops often focus on how-to elements of activities. Although educators must have firsthand experience of the Making activities in which they will engage their students, our study suggests that experience with the activities is not enough.

To support expansive and equitable Making programs, educators need to collaborate to envision a program culture that can fully leverage the potential of Making. Such a program culture:

- Recognizes and builds on what students know and can do.
- Supports process and iterative design.
- Creates a "what-if?" atmosphere to help students persist through difficulties and imagine new solutions.
- Fosters reflection and meaning making in order to engage students in the full scope of STEM practices.

Developing a Making program culture is not easy. It may require not only expert facilitation but also implementation support. For example, using co-teachers or high school student facilitators can help to provide the student-teacher ratios necessary for responsive facilitation. High turnover rates—many of the educators in the research-practice partnership have since left their organizations—compound the challenges of creating equitable STEM learning opportunities. Partnerships with community Makers or science education institutions with Maker expertise may be crucial to long-term success.

References


The Research-Practice Partnership Teams

**Fresno Community Science Workshop**
Manuel Hernandez, Jena Colvin, Melody Felten, Armando Figueroa, Kayla Shields

**Discovery Cube**
Paul Pooler

**Watsonville Environmental Science Workshop**
Emilyn Green, José Sandoval, Angelica Gonzales, Gustavo Hernandez, Martin Moreira, Nestor Orozco, Araceli Ortiz, Fabi Pizano, Aurora Torres, Omar Vigil, Alan Guzman

**Exploratorium**
Bronwyn Bevan, Jean Ryoo, Molly Shea, Nicole Bulalacao, Meg Escudé, Shirin Vossoughi

**Fontana After School Program**
Jasmine Medina, Jesy Myles

**San Bernardino Community College District**
Wendy Zinn

**San Francisco Boys & Girls Club**
Erin Gutierrez, Shu Ping Guan

**Techbridge**
Linda Kekelis, Emily McLeod, Ben Henriquez, Franco Demarinis, Claudia Muñoz, Mia Shaw


**SUGGESTED CITATION:**

Vignettes from Four CTAN Making Programs
Techbridge
Engineering and Making Programs for Girls

Partnership Members:
Ben Henriquez, Linda Kekelis, Emily McLeod, Claudia Muñoz, Mia Shaw [Techbridge]
Franco Demarinis [Oakland Technical High School]
Jean Ryoo, Nicole Bulalacao [Exploratorium]

A number of Making activities in Techbridge’s year-long afterschool and summer program support the hands-on, student-driven inquiry that is the focus of the organization’s educational approach. These activities include not only short-term activities, such as building “scribbling machines,” but also opportunities for girls to create Making projects of their own design that will later be showcased publicly. Afterschool educators partner with in-school teachers to run Techbridge programs serving 20 to 30 girls at each of 20 sites in the San Francisco Bay Area, Seattle, and Washington, DC. Because Techbridge girls may not know each other or be friends from school, attention is paid to developing trust in order to foster environments where girls feel safe to take intellectual and creative risks by articulating and pursuing ideas.

As part of a research-practice partnership between the Exploratorium and Techbridge, data were collected at one of Techbridge’s high school programs in Oakland, California. In this program, girls worked in collaborative groups using Arduinos to create projects and present them at the 2014 and 2015 San Mateo Maker Faires. Making activities with Arduinos were supported by afterschool educators, school teachers, and adult mentors. Mentors included engineering postdoctoral students from the University of California, Berkeley; an elementary school teacher; computer scientists creating their own start-ups; and other entrepreneurs. As mentors helped Techbridge participants to develop projects built on their personal interests, they also shared their career pathways and modeled expertise-based practices. Techbridge staff trained the mentors, both before and during the program activities, to support their engagement in the “Techbridge way.”

Techbridge’s mission is to “inspire a girl to change the world” by building self-confidence in young women, actively engaging girls in STEM learning, and exposing them to career opportunities that can inform future decisions. Techbridge was founded on research showing that girls want to (1) break the stereotypes that others placed on them, (2) engage with STEM in a place that was just for girls, (3) have learning experiences that differed from schools’ textbook-focused approach, and (4) meet women in STEM fields who could serve as role models. Toward these ends, the program delivers hands-on, student-driven, inquiry-based STEM activities through afterschool and summer programs offered to girls in grades 4–12 in Oakland, Seattle, and Washington, DC. Techbridge afterschool educators collaborate with school teachers both to run programs and to recruit students who reflect the school’s demographic diversity but may not identify as STEM learners. Mentors from various STEM careers engage with girls through projects, program visits, or field trips. Family members are also invited to Techbridge events in which girls showcase their projects and parents learn about resources to support their daughters’ engagement in STEM.
Advancing Program Goals

Fieldnote, 12/8/2014 – For a “hacking project” in which girls were invited to repurpose rummage-sale objects in ways that incorporated Arduinos, Linda and Mira were trying to create a table lamp whose body was made up of cassette tapes, with LED lights glowing from the centers of the tapes’ reels. After sketching out their plan, they began wiring together a complex system of LEDs to an Arduino that would sit inside their lamp. After nearly a month of testing different combinations of circuitry, the girls sought help from Edward, their afterschool teacher, because the LEDs still weren’t lighting up on a single circuit. Edward realized that they had wired some of the LED legs in the wrong direction. In some LEDs, the anode and cathode sides were swapped. He explained this while drawing a diagram of LEDs showing how reversing the legs resulted in short circuits. Trying to determine which were which, Mira pointed to specific lights as she asked, “So, should we take those ones out?” Edward replied, “They’re opposite…. The problem is when they’re the opposite, [the circuit won’t work]….You have to have all cathode or all anode. And I can’t tell you which one’s which.” The girls realized they had quite a bit more to do. However, they didn’t give up in frustration. They persisted, testing each LED to determine its polarity and then rewiring their lamp.

This vignette provides a glimpse into the typical ways that Making activities allowed Techbridge to support girls in developing ambitious projects, using computer science and engineering concepts and practices while coding Arduinos or wiring and soldering LEDs. Making projects like this cassette-tape lamp reflect Techbridge’s commitment to supporting young people to pursue creative, interest-driven projects requiring persistent troubleshooting during challenging moments.

Techbridge facilitators often took on the role of expert friend. Edward did not take over the students’ project to figure out the problem for them; he simply explained how LEDs need to be wired in a circuit. He acknowledged that he wasn’t sure which LEDs were correctly positioned, encouraging the girls to experiment to find out on their own. His acknowledgement of the complexities of LEDs and, implicitly, of the fact that adults don’t always know everything invited the girls to work through their problem using their own approach. The girls continued to test the LEDs, persisting through a challenging experience when many might have just given up. As Mira explained, she saw her Making process as a way “to respond to different problems we’re having and try new approaches if something’s not working out perfectly. So our project could be different from something we started with and
that’s fine. We just work through it and come to our end result.” Making thus supported girls in pursuing new ideas toward solving STEM-rich problems driven by personal interests and designs.

This willingness to persist through challenges was visible in other girls’ Making projects. For example, Chloe and her partners were trying to make an interactive musical instrument out of a set of wires arranged like a row of piano keys. Each wire tip when touched was supposed to play a different note along a scale. Over the course of many hours during several weeks, Chloe would sometimes capitulate with a frustrated “I’m done!” while leaning her forehead on her hand and collapsing on her desk. However, each time she picked up again while continuing to work on the problem with her partners, actively offering questions, hypotheses, and suggestions.

During an activity in which girls created paper circuits, one girl who had never worked with paper circuitry before decided that she didn’t want to use copper tape as the other girls did. Instead, she wanted to see if she could sew wire through a piece of foam to make LEDs light up.

She explained that she was curious about how many LEDs the battery could handle. In the end, none of the LEDs lit up using the wire sewn through foam. Rather than show frustration, this student simply observed the results of her experiment and tried to make LEDs light up with a shorter piece of wire that wasn’t sewn through the foam. Her test piece reflected her fearlessness in trying out an idea beyond the assignment at hand—even if it didn’t work.

In these ways, Techbridge provided pedagogical supports (time, space, encouragement) for girls to pursue their own ideas, stay committed to solving problems, and define the parameters of their own experiments. Making at Techbridge allowed girls with varying levels of expertise, skill, and confidence to work at their own pace.

**Characteristics of Productive Making**

*Fieldnote, 3/2/2015 – Chloe, Nina, Quian, and Luisa were using Arduinos to design an interactive environment for Maker Faire made up of wires that would play different notes along a scale when squeezed between two fingers. They were testing the core technology of their project. Though the circuits sometimes worked, the wires were not reacting consistently. Nina noted, “Something was happening! And now it’s not.” Quian said, “Maybe we broke it.” Nina protested with a smile, “We did not break it!” Quian clarified, “Maybe we short-circuited it.” Chloe noted, “Maybe [the battery] was too high for it” and laughed. Quian continued to fiddle with the wires, and a little sound began to emerge.*

*Going off-script: Sewing with wire and foam*

*Nina suggested attaching the wires to copper plating or tape because she thought it might have greater conductivity while providing more surface area for touching and creating sound. The girls asked their teacher for copper tape. While he searched for some, Quian continued to test different wires, and the speaker made little noises. Luisa said, “It’s like a frog.” Then Nina also started touching the wires, but she couldn’t differentiate*
whether she or Quian was making the sounds. She asked, “Is it you or me?” Luisa replied jokingly, “It’s not you, it’s me.” They laughed about how this sounded like a typical conversation during “a bad break up.”

Edward came back with a large piece of copper. After debating whether to solder or tape the wires to the copper, the girls used tape and began testing the response of the piece of copper to touch. Luisa tried flipping it over, testing both sides. The girls tried tapping it; they tested whether bent or flatter areas of the copper were more responsive to touch.

Throughout the process, the girls laughed and joked together, but they also continued to test hypotheses, make observations, challenge each other with new questions, and develop experiments to bring their project to life. They pursued their questions: “Is this copper plating too thick?” “Could we use pennies?” “Do you think it’s the wires, by any chance?” They discussed the conductivity of different metals, issues of battery power and short circuits in their wiring, and differences in individual hand warmth and moisture. By the following week, the girls had experimented with copper tape and successfully got each wire to make a different note along a scale when touched.

This vignette illustrates how Making projects engaged girls in STEM practices as they formulated questions and hypotheses, conducted investigations, made observations, discussed different perspectives, and adjusted their project accordingly. Techbridge girls worked in a supportive space where they could choose the direction of their experiments while enjoying each other’s company and building on each other’s knowledge. The availability of varied materials and the presence of an educator who offered suggestions and support while encouraging students to pursue their own ideas facilitated a productive Making experience for this collaborative group. In the resulting interactive product, which the girls called “Soundboxd,” visitors could create music by touching copper tape tabs on the outside of the box while experiencing lights changing color inside the box in response to the musical notes. At the Maker Faire, Soundboxd was a great success—a reward for the girls after months of design-and-build challenges.

Fieldnote, 3/24/2014 – Melissa and Esther were creating a self-zippering jacket with an embedded temperature sensor so the jacket would zip up when the temperature was cooler and unzip when it was warmer. In preparation, the girls were practicing with an LED to make it turn on or off depending on the temperature. However, their LED was not responding. Their mentor, Claire, asked them, “What do you want to happen?” Esther replied, “We’re trying to make the LED light up when it hits 73 degrees.” Claire asked, “But what happens when it’s under 73 degrees?” After a silence, one of the girls replied, “It does nothing.” Then Claire said, “You’re right, but what happens when it goes over?” The girls had no response. Claire asked, “Have you all learned about if/and statements?” They had not. Claire taught them about this important coding concept: “If the temperature is above 73 degrees, then turn the LED on.” Using this new knowledge, the girls edited their code and successfully got the LED to respond to temperature.

In their Making project, Melissa and Esther engaged with important STEM concepts and skills, specifically ones related to computer science and coding. Making provided a meaningful context for Techbridge girls’ learning because new concepts and skills were introduced organically in relation to students’ self-driven projects. Problem solving was embedded in the creative acts of designing and building.
Fieldnote, 9/21/2015 – Early in their Making activities, Techbridge students often sought adult approval before attempting a task. Rather than serving as judges, Techbridge educators encouraged girls to move forward in their experiments and find confidence in their own ideas. For example, when Jillian, a new 10th grader, asked design questions like “Should I put padding on the back?” Clara replied, “Try it! If it doesn’t work, you can try something else.” A little later, Jillian was trying to make a paper circuit out of the front cover of her Techbridge journal. The circuit was made of copper tape connecting an LED to a coin-cell battery. Jillian wanted to add a switch that would allow her to control when the LED would light up. She asked Clara about the options for creating paper-based switches. Clara shared various possibilities such as keeping the LED turned on all the time or using a binder clip to open or close the circuit. Jillian pointed out that her circuit was “not on the edge” of her journal cover, so a binder clip wouldn’t reach it. Clara suggested, “You can reroute it so it’s on the edge [of your binder].” Then Clara remarked that there was a third switching technique involving folding the copper tape to expose the non-sticky side. Later Jillian asked if using electrical tape would work for holding down part of the circuits. Instead of saying “yes” or “no,” Clara replied, “Let’s see!” Jillian tried it, and the circuit worked as she wanted it to.

Eventually Jillian made her circuit at the edge of her journal using a binder clip. She explained that she added a piece of paper between the circuit and the battery. The paper could be clipped down when she wanted to open the circuit and keep the LED from lighting up. Alternatively, this piece of paper could be moved out of the way so the circuit would close, allowing the LED to light up.

As Jillian’s story illustrates, Techbridge students were encouraged to pursue multiple pathways in their Making. The educators supported them to ask their unique questions and try their own solutions. Pedagogical practices like Clara’s were common in Techbridge, as visible in Elle’s facilitation moves in the next fieldnote excerpt.

Fieldnote, 4/27/2015 – Elle tried to help girls feel comfortable with deep hands-on STEM inquiry. For example, a 10th grader named Gigi wanted to build a Bluetooth speaker into her group’s project called the “Ultimate Backpack.” This Making product was supposed to address all the needs of a typical teenager: It would have a solar phone charger, Bluetooth speaker, electroluminescent wire to glow in the dark, and other interesting features. Gigi wasn’t sure how Bluetooth earbuds function. Elle encouraged her to take them apart to learn what was inside. As Gigi experimented with the earbuds, Elle acted as a sounding board to her observations and supported her in pursuing new questions. For example, Elle would ask Gigi, “So what do you think?” and offer suggestions such as, “Well, maybe we can test it…. If you use alligator clips, we could try connecting them to the wire.” Elle often emphasized that her ideas were just “theories” that Gigi could challenge based on her exploration. Furthermore, Elle used inclusive language—such as “we” and “our”—that suggested she was willing to work side by side with Gigi. She took Gigi’s ideas seriously, encouraging Gigi to take her project in her own unique direction. In these ways, Elle helped Gigi become more confident with hacking and tinkering—activities at the heart of Making.
Techbridge’s approach to Making activities built girls’ confidence in designing, building, testing, observing, and redesigning projects while exploring their own scientific questions through probing “what-if” questions. This approach was a key focus of Techbridge’s professional development. In workshops at the Exploratorium or at Techbridge, afterschool educators discussed how hands-on tinkering activities could build on inquiry-based approaches to education, engaging girls with open-ended projects driven by their own questions and interests. Educators regularly discussed how to ground new learning in youths’ perspectives and experiences while supporting inquiry-based learning in which girls could feel safe to pursue their own questions, discuss their ideas, and work through challenges. Educators physically engaged with Making by engaging in circuitry activities; creating lanterns, cardboard automata, jitter bots, paper circuits, and scribbling machines; and designing circuit-based games. Their reflections on teaching practice were rooted in their experiences as learners in Making activities.

Fieldnote, 7/23/2014 – Elle was leading a professional development workshop on facilitating inquiry through circuitry-based Making activities. She had educators work in pairs to use a battery pack and alligator clips in order to make bulbs light, buzzers sound, and motors move. After the activity, she asked participants to share the questions that had arisen during the activity. The questions included, “Why does it matter for the LED which leg you connect to the battery?” and “Why does the LED need the resistor to work?” Elle then asked people what they had observed of her teaching during the activity. One person replied, “You asked questions.” Another added, “You asked questions about our questions.” Elle explained, “Yes, I gave you a structure and task, and my job was to give you a nudge if you needed it, but not give you the answers right away…. For this kind of activity, you can let them go figure it out, let them come up with their own questions—and of course correct misconceptions, but it’s good to let these come from the students.” Elle emphasized that students’ questions can jumpstart their inquiry, placing students “at the center” in ways that “stress empowerment.”

Elle also encouraged educators to think about how to create a safe space for learning. For example, she recognized that “doing this in pairs is less threatening than the big group. But you might still struggle for girls to share out to the big group, even if they say lots in pairs.” Furthermore, she explained that there should be a “safe space” in which girls could choose to give up or change the direction of their projects. Allowing this option gives youth time to figure things out on their own instead of being told what to do, step by step. She noted that allowing girls to help each other was also important. Bringing in role models to support girls in difficult moments could create a safe environment for STEM learning.

Techbridge workshops also focused on explicitly connecting learning and activities to STEM careers so that girls could understand what types of opportunities were available to them in the future. For example, educators leading workshops would show how to frame activities in real careers, such as defining a hands-on activity in the context of the work of an actual STEM professional, as described below. They also suggested ways to incorporate role models into activities through, for example, videos, “career cards” describing real women’s career pathways, or program mentors.

Fieldnote, 7/13/2015 - Allison, the workshop leader, pretended to be a packaging engineer visiting a Techbridge program while educators played the students. Allison explained that packaging engineers “make sure packages get to your doors in one piece.” She showed some video interviews in which female packaging engineers described their work. Modeling what the educators would do with students, she asked them to look for “what you’re interested in as a person… Listen to why they enjoy what they do and who they work with in their jobs … also any vocabulary you may or may not know.” Following the video, Allison led participants in sharing their answers to these questions. She then introduced an activity in which participants could make their own packaging for an iPad, represented by a graham cracker. The packaging had to be able to withstand a series of tests including being dropped from a specific height, sitting under a heavy weight, and being thrown against a wall. Participants drew their designs, built their packages in groups, and then took turns testing each other’s packaging.
Following the activity, the educators examined engineering-related “career cards” that they could share with Techbridge students.

Techbridge workshop leaders like Allison led educators to reflect on the ways that afterschool STEM learning through Making activities could relate to specific career pathways and real-world experiences. The educators learned how to help girls explore a variety of potential future pathways connected to their Techbridge experiences.

During summer 2015, Techbridge educators took the Exploratorium’s Tinkering Fundamentals massive open online course (MOOC) on the Coursera platform. Watching videos and reading materials from the online course while simultaneously meeting in person to do the tinkering activities and discuss ideas led participants to consider the pedagogy of afterschool Making. More specifically, watching videos of young children working on Making projects motivated educators to think differently about their students, challenging deficit notions of what students might be capable of. One educator noted that watching MOOC videos of kindergartners building scribbling machines “shifted my … pre-assumptions about what the students can and can’t learn…. It was eye-opening to say, ‘Hey, you know you shouldn’t impose on students what they’re ready to learn or what they’re not ready to learn.’” Another educator emphasized that the MOOC videos, readings, and activities shifted the pedagogical approach she had learned from teaching formal school science. She said that, in school, teaching always felt rushed. Now she had learned to value “letting [Making] be a long process without a time limit” so that students could struggle through their ideas and create more complex projects. This feeling was echoed by an educator who had previously taught middle school mathematics. She explained that she learned how to “giv[e] the girls a goal but be okay if they find alternative ways to get there or if they don’t get there in the time period allotted. I guess I’m more likely to give them more freedom now, as opposed to walking them through step by step, which would be my instinct.”

Educators also highly valued the MOOC’s videos showing professionals using tinkering and Making to develop such hardware as a painting robot or a complex art project. They described sharing these videos with their girls in the following school year, showing the connections between afterschool Making and various career pathways. In these ways, the MOOC supported Techbridge’s goal to offer Making experiences in which girls could take on ambitious and messy projects, be driven by their own ideas in order to work through challenging moments, and learn how STEM content and skills connect to real career pathways.

Conclusion

Techbridge enabled girls from groups traditionally underrepresented in STEM to engage with STEM concepts and practices through authentic projects fueled by individual interests and collaborative goals. Making activities allowed girls to pursue their own designs, engaging in creative experimentation and problem solving as challenges surfaced. Techbridge also created the social scaffolding necessary for the girls to engage in complex building projects. The program fostered an inviting space where all ideas were welcome and where both successes and mistakes could be celebrated; in-school and afterschool teachers, adult mentors, and students came together as a community of learners who supported one another in exploration. Professional development for educators paid close attention to cultivating a learning environment, social norms, and teaching practices that would allow girls to feel safe asking questions, experimenting with ideas, using new tools, and identifying as STEM learners.
Making is the central activity of the Environmental Science Workshop (ESW) in Watsonville, California. The workshop building is filled with machine shop tools, art supplies, building materials, electronics, and a wide range of other objects, including natural things like shells and plants. The workshop also features Maker projects made by prior participants, such as tortilla makers, garden fountains, and birdhouses. Activity at the workshop is fully interest-driven. Learners can pick up and investigate the natural materials, select an object that they want to build, or work on special projects such as fixing bikes or building school projects. The building is open to all community members, but it is especially appealing to neighborhood youth during summer and after school hours. They drop in to design and build, use the tools to repair bikes or skateboards, and socialize with one another and with program staff. Participants build with the assistance of ESW educators, other students, and, sometimes, family members.

The ESW learning environment welcomes and integrates students’ cultural and home practices. Educators are bilingual; they easily switch back and forth between English and Spanish as young people engage in workshop activities and interactions. All signs in the shop are bilingual, recognizing and honoring the language resources and home references children bring with them to the workshop.

ESW sees Making as a context in which neighborhood youth can develop interests, feelings of accomplishment, and both social and STEM skills. A central pedagogical strategy at the workshop is to encourage young people to add complexity, in stages, to their Making projects. As they become skilled with particular tools or construction models, young people are encouraged to mentor and teach others who are still developing their facility.

Advancing Program Goals

Fieldnote, 8/4/2015 – Eddie, age 12, walked over to a shelf and picked up a model of a car made by a previous workshop participant. He turned it over, examined it closely, and indicated he’d like to make one himself. Carlos, an ESW facilitator, asked him a question: Did he want the car to run on a switch, like the model he had in his hands, or would he want a simpler model, without a switch? The downside of the simpler model was that he wouldn’t be able to control the car once it started moving. Eddie chose to make a car with a switch.

Carlos pulled out a diagram of a switch that he had drawn and stored on his smartphone the day before. Eddie studied the switch on the car he held in his hands, as well as the diagram on Carlos’s phone.
“Okay, I see. And then the two, umm, and then the ones that go to the battery in the middle... and then the last two—and then you just cross the two wires,” he murmured. Carlos pointed to components of the switch diagram as he repeated Eddie’s comments: “This one is for the motor. This one is for the batteries. And then these cross.”

They looked at it together for a bit longer, and then Eddie gathered up the supplies he needed and began to build the circuit for the switch. Carlos asked if Eddie remembered how to strip the wires. Eddie nodded and got down to work.

This short vignette illustrates how Making advances ESW’s program goals. The program engages students in interest-driven, learner-centered investigations. It seeks to nurture relationships between young people and facilitators. Above all, it seeks to position young people as capable and creative thinkers and doers.

In this context, Making activities provide students with both voice and choice: They choose what they want to do and how they want to do it. Facilitators play a critical role in advancing young people’s interests and opportunities for success. In this example, Carlos provided a diagram and helped Eddie to make careful observations so that he could turn what he saw into words and plans. Carlos checked with Eddie about whether he knew a basic skill, but he never over-directed or took over Eddie’s project.

This vignette exemplifies how a socially supportive, learner-centered Making program can support young people, especially those from economically and racially marginalized communities, to take intellectual and creative risks that can deepen their interest in and understanding of STEM.

Characteristics of Productive Making

Fieldnote, 2/20/2015 – One Friday, a small group of young people, ranging from 8 to 12 years old, chose to design and build rocket cars. The workshop’s rocket car model involved a tube of rolled-up construction paper, a set of wheels, and a nose cone. There were several variables to adjust for desired results: the length of the rocket, the placement of wheels, the addition of fins and cones for stability as the cars rocketed across the blacktop outside the building. A facilitator, Pablo, assisted students, as needed, in building the rocket cars and in loading them onto the rocket launcher outside. The launcher, built from a lawn sprinkler and plumbing parts, used compressed air to launch rockets at the push of a button. While preparing the launcher, Pablo described how it worked, explaining that students could select the air pressure level depending on what they thought would work best for the size and structure of their rocket car.

A fourth-grade girl, Katy, volunteered to go first. Pablo helped to get the rocket car into the launcher, set the pressure to 60 pounds per square inch (psi), and then released it. As the rocket car ripped out of the launcher, the wheels flew off and rolled along the blacktop. “I said 40, not 60,” a disappointed Katy murmured. She walked along the blacktop to pick up the pieces and went back into the workshop to fix the wheels. She taped and glued the end of the rocket so that less air would leak out of it.

Katy took the rocket car back out to the launcher. Just as she was beginning to set it up, she saw that the nose cone, which sealed the rocket body to allow the buildup of pressure, had come loose. She immediately grabbed the rocket car and ran back inside to conduct some new repairs. Fifteen minutes later she returned, choosing a pressure of 20 psi. Nothing happened. She increased the pressure to 40 psi. The rocket car still didn’t leave the launcher. Deflated, she was turning back to the workshop to try to figure out what was wrong when one of the high school
students who served as facilitators suggested she lift the rocket launcher an inch off the ground before releasing the air. He explained that this simple move would keep the launch tube from weighing down the car and preventing it from taking off. This time it worked!

Katy then tried to launch at 45 psi. The rocket shot across the basketball court with all its parts intact, but the top was visibly loose. After another round of adjustments, Katy returned to the launch spot. Asked how many psi she wanted, she said just two. Smiling, she added, “I’m scared!” Encouraged by the facilitator, she revised her request to 40 psi. The rocket car once again worked! She proceeded to launch at different psi levels, finding that her rocket car could withstand 45 psi.

This vignette illustrates core dimensions of Making as a context for STEM investigation. Katy had chosen to participate, along with others, in a process of building a rocket car. The students’ choice was stimulated by a model rocket car on the workshop shelves. The sample object both validated rocket car construction as a legitimate workshop activity and provided a concrete model to guide the construction. When her rocket revealed its structural flaws, Katy returned to the workshop to make revisions, working alongside others who were constructing their own objects. Tools and adult support were available on demand. At a key moment, the high school facilitator helped her adjust the launcher. As is characteristic of many high-quality Making programs, ESW facilitators had no expectation that students had to “get it right” the first time. That kind of pressure might lead to more adult intervention and less student-directed activity.

The iterative nature of the activity opened up opportunities for learning. For example, at each test, Katy observed emerging flaws in construction or design. Then, based on this feedback or evidence, she made revisions and re-launched the rocket. The activity was designed to illuminate the relationships between structural integrity and air pressure, on the one hand, and the distance travelled by the rocket cars on the other. Above all, the Making project gave Katy the opportunity to persevere and achieve success in an activity that was valued in the social space of the workshop.

Staff Facilitation and Professional Development

Fieldnote, 11/14/2014 – At the second staff development workshop of the year, Eleanor, the ESW network director, wanted to continue discussions about the relationship between program values and staff members’ work with young people. To start, the group revisited a list of those values, in the following categories: What are ESW’s core values? What do you value about facilitation? What do you value about the space of ESW, and how is it different from other learning environments?

One of the main ideas, Eleanor said, is that staff want to mentor and model what they value. They want kids to learn “to be curious, understand their connection to the community and the world around them.” She passed out student journals and asked workshop participants to consider how students’ writings and drawings reflected program values.

One of the longtime staff members, who had come to ESW as a youth, said that what he saw in the journals was “imagination, measuring, patterns, motor skills…. There’s a lot of engineering.” Another staff person remembered how a student’s birdcage project, recorded in her journal, engendered a lot of community and cooperation. A third staff person commented on a boy’s plans to make a beehive, recalling how determined and independent he was in that process. Eleanor took this moment to recollect that one of the facilitators had been actively involved in assisting the boy. Somebody noted that the student journals demonstrated a core program value: Students take charge of their learning.
In the objects youth build or the plans youth record, Making can reveal students’ thinking and understanding. Making can thus support staff reflection as well as informal, ongoing, and formative assessment of student learning. At ESW, the children’s journals provided data for staff to reflect on the ways in which student experiences related to core program goals. These data supported discussion about how the physical and social space for which facilitators were responsible could advance program goals. These data-driven discussions allowed staff to reflect on their roles in supporting a culture of inquiry and in modeling how youth could take charge of their own learning.

On other occasions, staff discussions focused on concepts like “failure” and discussed facilitators’ responsibility for helping students to reframe moments when things didn’t work as opportunities for learning. Facilitators could also make connections to the work of real scientists. Staff discussed the fact that scientists make progress by making meaning of the unexpected or unpredicted. They talked about making this process explicit as a strategy for helping students both to connect their experience to the larger world and to persist and learn in the immediate activity.

Conclusion

The Environmental Science Workshop in Watsonville was founded on the principles of Making as a powerful context for young people’s learning and development. Because the target audience is low-income youth who frequently face negative social stereotypes and marginalization, the program intentionally organized the physical and social space in ways that honored the knowledge and skills children brought with them to the workshop. It then fostered relationships that could cultivate students’ interests, deepen their skills and understanding, and position them as successful and capable both in STEM and in the social community. Making at ESW had practical implications: the workshop provided tools, space, and support for fixing bikes and building school projects. More importantly, it provided a setting in which youth could feel and be productive, pursue their own interests and ideas, and grow into positions of leadership, as many of the high school and professional staff have done since their days as program participants.
Fresno Community Science Workshop
Making Programs

Partnership Members:
Jena Colvin, Melody Felten, Armando Figueroa, Manuel Hernandez,
Kayla Shields [Fresno Community Science Workshop]
Molly Shea [Exploratorium]

The Fresno workshop, like the other Community Science Workshops (CSWs) across California, is a drop-in program focusing on student-centered, interest-driven Making activities during summer and afterschool hours. Typically, young people can build something based on a model or idea that is available in the workshop. Frequently groups of students make the same object, such as super-soaker water guns in the summer or Rube Goldberg chain reaction machines in an afterschool class. At other times, young people work independently with the assistance of CSW facilitators.

In addition to providing regular afterschool Maker programs in many area schools, Fresno CSW offers family nights and drop-in programs at two locations. In all of these programs, the CSW seeks to support and sustain students’ interest in their projects so that students take their projects and learning to the next level. The CSW challenges students to improve their designs, in the process deepening their STEM skills and understanding.

The Fresno drop-in centers also welcome families and neighbors who come in and work together on projects. They thus make connections between children’s family practices and the Making practices valued in the workshop.

Advancing Program Goals

Fieldnote, 7/8/2014 – Marta, a girl of 8 or so, had come for the first time to the Fresno CSW with her mother. After walking around the workshop to observe what others were doing and looking at the models of prior work on shelves and tables around the room, she saw a model of a small house made out of popsicle sticks. She decided that she wanted to make that house herself. Over the course of about an hour, she worked assiduously with her mother to construct the house. When she was done, she explained that she had built a “fairy house.” She described how she had painted and decorated it. Next, she said, “I’m going to make a light,” pointing to the roofline of the small house. She said that she wanted to design the light so that it turned on when the fairy came home.

Henry, the CSW facilitator, who had been working with a young boy on wiring a bulb, overheard what Marta said. He told her to come closer to see how to wire a bulb. He picked up wire strippers and demonstrated how to use
them. “The way you strip wires is like this…. You put it in the back and it strips it in like that.” Marta watched attentively. Then Henry told her to try it.

Marta making her fairy house.

Marta sang a little as she pressed down on the wire stripper handle. In no time, she had stripped the wires. Henry picked up a battery. Holding it on the table, he said, “So then we have our light, right? And the battery.” As he pressed Marta’s stripped wires to the battery, a single small bulb lit up. Henry said, “It turns on because you have a negative and a positive, right?” He began to demonstrate how to wire the bulb. Marta eagerly reached for the materials, but Henry told her to be patient and watch the process before taking over. After the demonstration was over, Marta began to work, repeating the facilitator’s phrases as she wired the bulb.

Making activities allowed young people at the Fresno CSW to pursue their interests and imaginations, thus building their sense of accomplishment and capability. Marta’s story reveals how interest-driven learning activities can, by building on a learner’s sense of ownership, lead to new learning opportunities: Marta needed to learn to wire a circuit in order to give her fairy house a light.

In a community drop in center where family members are welcomed, Making also offers opportunities for people of different ages to design and build collaboratively, as Marta’s mother helped her daughter construct and decorate the house. At the same time, the mother engaged with the facilitators to learn more about the CSW and the programs it could offer her child.

Characteristics of Productive Making

Fieldnote, 8/4/2015 – At the hot-glue gun station against the east wall of the workshop, rising second-grader Gabbie was busy building a doll room, gluing wooden walls together into a three-walled box. When Molly, the researcher, asked Gabbie if she wanted to use nails and a hammer to secure the sides of her doll room, she replied that she was happy building the room with glue. Molly looked into a bin containing recycled cardboard and found the top of a pink shoe box, which she took to make wheels for a car she was building with some other students.

A few minutes later, Molly returned to the glue station to attach a piece of the car frame to the pink cardboard. She told Gabbie that she had decided to make a doll car. Gabbie said that this was a cool idea. Molly said that Gabbie was welcome to join her in building the car after she finished her doll room.

A few minutes later, Gabbie came to the back table and told Molly she was ready to work on the doll car. Molly had the pink cardboard out on the table; she asked if Gabbie wanted to help cut it into circles of the right size to be glued to the car wheels. Gabbie took a piece of cardboard and observed what Molly was doing for a few seconds before she started cutting her own circle. The two started to talk. Gabbie had come to the workshop yesterday and again today. She liked it because she got to learn new things, “like yesterday I got to learn how to make a doll house, and today I get to learn how to make a doll car.”

After they cut out the wheels, they walked over to the glue gun station. Gabbie wielded the glue gun while Molly turned the cardboard slowly to catch the glue. Then they slowly pushed the pink cardboard against the wheel and
let it set. They returned to the back table and talked about how they would need to find the very center of each wheel and put the axle into the center so the car wouldn’t wobble when it ran. Molly got a ruler and started to measure each wheel vertically and horizontally, placing a dot at the center. Gabbie was not sure how to use a ruler, so Molly showed her how to line up the edge of the wheel with the end of the ruler, find the ruler number for the opposite edge of the wheel, and look for the number in the middle to mark where to glue the axle.

In the Fresno CSW, facilitators—and, in this case, the Exploratorium researcher—are encouraged to design and build alongside youth. Adults not only show youth that Making activities are valued but also, as in this case, spur ideas or demonstrate new techniques. Adults and older students in the CSW community create a culture of inquiry and creativity while establishing social networks students can tap for help.

Gabbie’s interest in dolls and a doll house was parlayed into work on a car—a product more often tackled by boys in the workshop. As Gabbie herself said, at the CSW, she could do and learn new things. When the opportunity arose to do something new—build a car—she felt confident to take the risk, leveraging the support Molly provided.

Gabbie’s mastery of the hot glue gun was a resource for building the car. The activity also offered Gabbie opportunities to develop new age-appropriate skills, such as wielding scissors to cut out cardboard wheels and using a ruler to determine where the center of the circle was. She needed these processes and understandings in order to meet an authentic goal: a pink doll car that wouldn’t wobble when it ran. In the Fresno CSW, STEM knowledge and skills exist to develop and realize students’ ideas and ambitions.

Staff Facilitation and Professional Development

Fieldnote, 8/24/2014 – Staff learning workshops at the Fresno CSW are organized to engage staff in working together and reflecting on both the benefits of collaboration and how facilitation can promote it. At one workshop, staff were building Rube Goldberg chain reaction machines. Such machines use many different materials—blocks of wood, marbles, tubes, dominoes—that interact in a chain reaction to move a ball from one end of the machine to the other. Staff formed teams to design and build machines together.

After about 45 minutes, the staff reflected in small groups on how they felt about working on the project together. First, each person wrote for about five minutes; then the small groups talked about what worked, what was challenging, and how the facilitation functioned. Finally, the whole group got together to discuss some of the challenges. At first, people commented on the activity itself, working with the materials, and what worked well or didn’t.

But soon the conversation turned to the social interactions involved in the collaboration. Teresa said that being listened to was a challenge. In her group, the project had been dominated by the men, who took over without listening to the women. Rather than pursuing that line of discussion, however, she related it to a counterexample, saying that the female staff at the Fresno CSW may often overwhelm the one male staff member. The point she wanted to discuss was how to ensure that collaborations are inclusive and that some groups don’t unintentionally leave out others.

This vignette shows that staff development can be organized not only to deepen facilitators’ expertise in Making activities, but also to support critical reflection on the social experiences of Making, in this case collaboration and the potential marginalization or exclusion of some team members.

In this example, a firsthand experience in Making provided a grounded and shared source of data for reflective discussion. The reflective culture the staff members had built operated to help people avoid personalizing the gender issue. Instead, the group could think more broadly about the challenges that participants and facilitators face in productive Making activities.

In follow-up discussions, we learned that the network director, because of these exchanges, organized a staff workshop specifically on gender issues.
Conclusion

Making at the Fresno Community Science Workshop is geared toward providing a safe and supportive drop-in space for youth from economically stressed communities. In the workshop, young people can investigate and experience new materials, tools, ideas, and relationships. They can design, create, and build, supporting feelings of accomplishment and capability. They can learn new concepts and skills that are relevant to both home and school. Making provides a productive learning context for their social and intellectual development.
Discovery Cube Teacher Professional Development and Making

Partnership Members:
Paul Pooler [Discovery Cube]
Jasmine Medina, Jesy Myles [Fontana After School Program]
Wendy Zinn [San Bernardino Community College District]
Jean Ryoo [Exploratorium]

Discovery Cube Director of Education Paul collaborated with the San Bernardino Community College District on a professional development series, iCreate, that taught both afterschool educators and K–12 teachers about a variety of hands-on Making curricula. Attendees came from throughout the Inland Empire, the 13th largest metropolitan area in the U.S., covering Riverside, San Bernardino, and Ontario counties in California. The Inland Empire has some of the lowest average annual wages in the country, as well as low education levels. Approximately 25 educators, mostly afterschool facilitators, regularly attended iCreate workshops, which were held monthly during the 2014–2015 school year.

In an effort to understand how Paul’s workshops affected afterschool Making activities, we collaborated with Fontana After School Program (FASP), whose staff participated in the workshops, to observe FASP educators’ implementation of STEM-rich Making with children.

Paul’s iCreate workshops focused on equity and access to quality STEM learning for all students. More specifically, Paul encouraged educators to think about how Making activities could make STEM learning relevant to students by connecting to their interests and prior knowledge. Paul framed Making as a way to engage students directly with STEM practices, so that they could experience STEM before learning the details of STEM-based concepts, vocabulary, and history. He believed that Making should be student-driven and open-ended, focusing on inquiry and project-based learning.

Paul took great pains to make the activities accessible to educators who might be uncomfortable with the open-ended, inquiry-based approach of Making. He rooted educators’ workshop experiences in what they already knew regarding STEM teaching and learning, while sharing tips on cheap, easy-to-find materials that brought Making within educators’ reach.

**Discovery Cube** is a science museum in Southern California whose mission is to “inspire and educate young minds through engaging science-based programs and exhibits to create a meaningful impact on the communities we serve.”

**iCreate** is a professional development program for teachers and afterschool instructors offered by the San Bernardino Community College District, one of 72 districts in California’s community college system. iCreate focuses on integrating the California Common Core Standards and Next Generation Science Standards with innovative, hands-on problem-solving projects and on sharing the projects and pedagogical methods with educators across the Inland Empire.

The City of Fontana, California, offers the **Fontana After School Program** to children in grades K–8 in 41 schools across the Fontana, Colton, and Etiwanda school districts. The majority of students in each of these school districts are students of color from low-income families who qualify for free or reduced-price meals. The program provides homework assistance, computer lab and library time, health and wellness activities, and social and educational enrichment.
Advancing Program Goals

Fieldnote, 3/18/2015 – Two girls in FASP were struggling to complete a circuit so that it would light a bulb. They told Katie, one of the afterschool educators, “We flashed it, but then it turned off!” Katie replied, “That’s okay. What were you doing and holding?” The student replied in a frustrated tone, “We touched it to the bottom and the top [of the battery].” Katie said, “So maybe you just need it just right! The perfect storm!” The girls looked stumped; Marisol said dubiously, “I don’t know…” Katie encouraged her with a smile, reminding her, “You’re the little scientist!” Katie recalled that, in a previous activity about taste buds, Marisol had been the one who asked the most interesting questions.

Then Katie asked the girls, “Where do you want to put the bulb?” Tawana said, “Here,” as she touched the top of the battery. Pointing to the materials in turn, Katie asked, “Do you want [the wire] to touch the bulb or the battery?” As the girls pondered, Katie continued, “Was it touching the wire or just the battery [when it flashed]?” The girls began fiddling with their set-up, touching the wires to different parts of the bulb to try to get it to flash again. Although most students in the class had made their bulbs light, these girls were not the only ones who continued to struggle. So Katie held up a battery and announced, “Here’s a hint: You want the electricity to go in one end and out the other [pointing to the two terminals], and the goal is to get the light bulb in the way.” After more tinkering, the two girls eventually succeeded in lighting their bulb.

Katie’s story shows how FASP educators supported STEM learning for children from groups traditionally underrepresented in STEM fields: They encouraged girls and students of color to see themselves as capable scientists who could achieve their inquiry goals. Rather than taking over when students became frustrated, Katie asked focused questions to support the children’s inquiries. STEM-rich Making, paired with the pedagogical practice FASP educators learned from iCreate, supported children to push through challenges and develop confidence in their ability to solve problems.

The two girls had reached a point of frustration: They had seen their light bulb flicker but could not get it to sustain a bright light. In a room full of children who were exclaiming “We did it!” and “Our bulb lit up,” the girls’ increasing disappointment was palpable. Katie—recognizing that the girls were on the verge of giving up and really just wanted an adult to do it for them—refused to put her hands on the circuitry. Instead, she encouraged the girls to pursue their experiment. To validate their feelings of frustration, she acknowledged that the materials could be challenging to work with. When Marisol expressed doubt, Katie didn’t show her how to complete the circuit; rather, Katie reminded her that she had previously demonstrated strong inquiry skills, demonstrating that she could do science. Encouraging the spirit of inquiry through Making, Katie proceeded to ask open-ended questions. When she saw other students struggling, she did not explain how to make the bulb light up. Rather, she gave students room to consider her “hint” about how electricity needed to flow from one end of the battery to the other. The sense of achievement the girls felt when they got their bulb to light must have been much greater than it would have been if the teacher had simply showed them, or even the whole group, how to do it.

As students worked through STEM challenges and educators supported their inquiry with specific questions and prompts, Making advanced FASP’s goal to support children’s intellectual and emotional development.

Characteristics of Productive Making

Fieldnote, 5/13/2015 – Ian, a fifth-grader, was struggling to get his scribbling machine to move. He had gotten his motor moving by attaching it to a battery, he had attached markers to a cup, and he had placed the motor on the inside of the cup. However, the motor’s movement was not moving the cup and markers. Katie asked him, “So what problem are you having? With it moving?” Ian replied, in a deflated tone, “Yes.” Katie began, “So you need to put
the...,” but then she stopped herself. Instead of telling him how to make his machine move, she asked, “So how are you going to get [the motor’s] movement to help this cup move?” She observed that the motor was “trying to get out!” Then Ian said that he could tape it to the cup instead of just placing it inside. “That’s an idea!” Katie replied. Ian noted, “But I tried that already.” Katie’s response was to suggest trying different ways of working with the motor and tape. Ian showed Katie where he had previously tried attaching the motor. Katie nodded and then pointed out, “There’s lots of other space on the cup. Maybe try another position? Inside, outside, upside down, right side up—you have to find what works, right? There’s lots of possibilities, so how are you going to make it work?” Then she Katie stepped away. Ian tried taping the motor to different spots on his cup. Instead of giving up, in this moment when he seemed frustrated, he took up the challenge again after Katie’s questions and suggestions inspired him to explore again.

iCreate taught FASP educators to facilitate STEM-rich Making in ways that recognized multiple pathways to learning and encouraged children to pursue their own questions and ideas. Katie kept herself from taking over Ian’s project. Instead, she encouraged Ian to consider ways to experiment. She asked questions that addressed both physical design and how form could affect function. She did not offer a specific answer, which might suggest that there was only one way to solve the problem. Rather, she asked questions that opened up a variety of possibilities. This pedagogical approach to Making allowed space for children to experiment, try different pathways to a solution, and test their ideas. It invited youth to work through challenges toward achievements that could make them proud.

Staff Facilitation and Professional Development

Paul’s iCreate workshops gave Katie the strategies she used to support FASP youth in STEM-rich Making: encouraging underrepresented students to see themselves as scientists by connecting to prior learning and welcoming multiple student-driven pathways to success.

Paul emphasized specific facilitation moves that can foster student engagement. One such key move was to develop a safe space where kids could feel comfortable exploring their ideas. For example, at the start of a circuitry Making workshop, Paul noted that some people feel uncomfortable working with circuitry because electricity can feel dangerous. Couching circuitry in Making activities that connect to what people find familiar can quell such fears, supporting new STEM learning. Acknowledging that educators have limited resources and time, he also emphasized using everyday materials that are easily accessible. Both teachers and students can feel comfortable working with things that are familiar and not too precious.

Paul also modeled teaching practices that encourage learners to explore their own ideas through Making. For example, when educators were building catapults, he emphasized that they shouldn’t worry about creating exact replicas of his own project. He said that they could see the differences in their catapults as reflecting different scientific variables that could yield interesting differences in results.

The iCreate workshops also emphasized the importance of connecting to students’ prior learning and personal knowledge, so that new knowledge builds on what students are experiencing or are interested in rather than on what teachers are telling them. In the catapult-building workshop activity, Paul modeled the practice of drawing on learners’ knowledge and interests.
Fieldnote, 1/15/2015 – In preparation for making catapults, workshop participants experimented with shooting rubber bands at different angles. Paul approached Lisette, who had been particularly quiet and sat at the back of the classroom. As she shot her rubber band, she told Paul that angling the rubber band reminded her of the way she would angle a basketball when doing a jump shot. Building on this idea, Paul encouraged her to experiment with different angles and share her observations while connecting them to basketball. After continued experiments, Lisette noted that an angle of 45 degrees allowed the rubber band to travel the farthest. Paul agreed, saying, “So, go back to basketball... If you’re doing a jump shot, if you’re further out, you’re going to need that perfect angle.” Lisette agreed, citing the performance of a star shooter in last night’s pro game. Smiling and nodding, Paul said, “So that works for distance.... But say you’ve got a center in front of you. You’ve got to shoot over the center. You know, a 45-degree angle might not be your best option.” The teacher became noticeably more engaged, nodding her head and saying “Exactly.” Accompanying his question with arm gestures, Paul continued, “So if you were to adjust it—so go back to our variables. What if I went higher, but I needed it to go further? What would I do with the rubber band?” The teacher replied, “Pull it back farther,” miming the action. Paul nodded and said, “There you go. So with shooting a basketball, if I’m shooting over someone but I need to go more distance, then I’ll need to put more force into it.” Lisette nodded, repeating the word “force” and adding, “Exactly.” Later, Paul emphasized to the whole group how important it is to make such connections to students’ prior knowledge to help them move from “I don’t know” to “This is familiar.”

Although connecting basketball to catapults may seem simple, Paul was modeling an important pedagogical practice in STEM-rich Making: He was encouraging learner experimentation by rooting new learning in everyday knowledge of the world. When Lisette—who had been quiet in group settings—shared her observation relating the rubber band experiments to basketball, Paul took the opportunity to connect the Making experience to her interest. She became noticeably more animated in her physical engagement and in her reference to the previous night’s basketball game, demonstrating a growing interest in the activity and learning at hand. Paul also connected the simple rubber band experiment with STEM vocabulary and concepts related to force and distance. He organically modeled a way to build on learners’ personal knowledge and interests to encourage experimentation toward new learning. Lisette experienced firsthand how Paul’s recognition of her observations about basketball increased her engagement and led her to think about force in relation to distance. This approach to Making education—relating new learning to what students have already experienced, know, or are interested in—was picked up by FASP educators as they reminded students about previous STEM experiences that could encourage new learning.

Similarly, when introducing tinkering with circuits, Paul demonstrated how educators could demystify electricity by showing connections to everyday life. To explain how circuits work differently when wired in parallel and in series, he described why we need both types: You wouldn’t want to have to turn on all your appliances just to use a toaster. He used the classroom lights to illustrate circuitry, emphasizing the importance of connecting to everyday life to excite students. “It goes back to making connections. Where would this be a good idea? Where would this be a bad idea? When would we want this to happen? ... It doesn’t have to be in their home; it could be in a video game—something they’re interested in.” He used this logic about how to make electricity less scary to describe the power of science: “That’s what science does. It demystifies things. You know, we’re able to explain why the sun comes up and why it goes down. We’re able to explain why it rains certain times of the year.... And if we demystify things and ... make it real for us, it can really help us understand and make those connections to other places.”

The iCreate workshops also emphasized that effective Making pedagogy involves a careful process of asking questions, instead of simply giving learners solutions. It also involves reflecting on learning by sharing ideas with peers. Paul modeled these pedagogical strategies as he supported workshop attendees in their Making inquiries.
Fieldnote, 2/19/2015 – As educators drew, Paul emphasized that their circuits were different—there was no single perfect way. Making should allow for multiple ways of knowing and thinking. Paul also emphasized the process of exploration. “And if I have journals, I’ll have them draw out the steps. Not just what worked but what didn’t.” He said the journals would “get them in the habit of documenting things,” but they would also help students reflect on the process they used—including the steps that didn’t work—to achieve the goal. This kind of reflection on the Making activity, Paul emphasized, could help students understand how circuits work.

Pairs of FASP educators went back to work, trying to create a circuit. Two educators were struggling to get their bulb to light. Referencing the pictures on the board, Paul pointed out the positive and negative terminals and where one end of the wire was touching the positive and the other end was touching the bulb. A woman at the table said, “So one end was touching [the battery]....” Without touching their set-up, Paul noted, “So the other end has to touch the other end—but what do we do with that wire?” After considering this question, the educators rearranged their circuit to make the bulb light.

As the vignettes about Katie’s pedagogical practices show, FASP educators took up Paul’s hints and his ways of supporting reflection in order to emphasize that there are multiple pathways to solving a problem. In Katie’s afterschool Making activities, students worked through challenging moments and pursued their own pathways toward new solutions.

Conclusion

The case of Discovery Cube’s iCreate professional development workshops and subsequent implementation of Making activities at FASP illustrate how STEM-rich Making served as a means to support inquiry-based teaching. These workshops gave STEM educators the opportunity to physically tinker so that they could experience Making activities as the youth participants would. This model proved effective for sharing pedagogical practices such as allowing Making projects to be student-driven, connecting new learning to what students already know, and giving youth the space to tinker by keeping hands off and asking supportive questions. Back at FASP, educators’ implementation of the activities they had learned in the workshops reflected these pedagogical strategies.