[Creative Construction: Different Cardboard Automata: Same mechanism, different ideas]

Making as a Strategy for Afterschool STEM Learning

Report from the California Tinkering Afterschool Network Research-Practice Partnership*

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 (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, 4]. This report addresses broadly educative Making.

There are three types of educative Making: One type is organized around *Assembly*—learners are provided step-by-step instructions for how to make an object. The result is a set of identical or near identical objects. Other approaches to educative Making are organized around *Creative Construction*—learners are provided a challenge to address or a model to replicate, but are able to exercise a range of choices related to the ultimate look, scale, and sometimes behavior of the object. The result is many different, personalized, versions of the same type of object.

A third type of educative Making is organized around *Open-Ended Inquiry*—learners develop an individual idea or goal for making something and figure out how to accomplish it. This is sometimes called "Tinkering" because of its emphasis on creative, improvisational problem solving [5, 6]. This results in a wide range of objects, designed to address unique purposes and goals. For instance, students in a given group may develop projects such as a ping pong table with a net that lights up in reaction to a ball coated in conductive paint, a self-zippering jacket that opens and closes based on external temperatures, or a pair of shoes for the visually-impaired that alerts the wearer when an object is within 10 feet of their toes.

Especially in its last form, as Tinkering or Inquiry, Making provides a profound example of interest-driven, student-centered learning. But across all kinds of educative Making, this genre of learning can provide a concrete purpose and relevance for engaging in STEM concepts and practices. Students learn about electricity and batteries not to pass a test but to successfully build a Bluetooth-enabled radio housed in an antique radio shell, a trebuchet for a classroom assignment, or a buoyant canoe for a summer camp field trip. In all of these cases young people can learn and develop a wide range of STEM skills, such as measurement, scaling, design, or data analysis; grapple with STEM concepts such as force, balance, circuits, and cause and effect; and can deeply engage in practices of scientific and engineering inquiry.

Making as a Means for Engaging with STEM Practices

In this report we examine how afterschool educators at 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, 6, 7]:

- It exercises students' creative and improvisational problem-solving abilities;
- It builds students' agency, persistence, and self-efficacy;
- It helps students to deepen and complexify their ideas and understanding.

When Making is organized to leverage students' ideas and interests, it can create powerful conditions for learning to occur, particularly for students who may not already affiliate as STEM learners. The combination of creativity, craft knowledge, and experimentation that Making supports has been shown to be characteristic of top performing scientists; they are skills that are highly valued by STEM educators, professionals, and industries [8].

STEM Practices

In 2012, the National Academies of Sciences issued a report that detailed the practices of scientific and engineering inquiry. This volume found that engaging in STEM practices of investigation provides the best context for learning STEM concepts and skills. 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 NatureBots built by youth in the Exploratorium's Afterschool Tinkering Program.

CALIFORNIA TINKERING AFTERSCHOOL NETWORK: A RESEARCH-PRACTICE PARTNERSHIP

The findings reported here, and in the attached mini-cases, are the result of a three year research-practice partnership in which teams of educational leaders, educational practitioners, and educational researchers worked closely together to identify, innovate, and research key challenges to their work.

Partners included educational practitioners from Community Science Workshops in Fresno and Watsonville, Techbridge, Discovery Cube, and the Exploratorium's Afterschool Tinkering Program, along with researchers from the Exploratorium.

While the partnership was originally undertaken to address issues of implementation, an overriding interest of the educators was to understand how Making could provide a context for equity in science education. From this concern emerged attention to the kinds of staff development and learning needed to support equity-oriented Making.

In addition to the results reported here, the partnership produced a set of tools for the field, some pertaining to Making, others to developing equitable partnerships. These resources can be found at www.exploratorium.edu/ctan and www.researchandpractice.org.

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 current research, requires engaging with real stuff in the real world, which can motivate interest and a need-to-know about more abstract concepts [10].

Additionally, 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, its evidence-based nature, as it is practiced in the world. The report finds that few students gain such experience in the classroom. Making provides direct, immediate, and concrete forms of evidence related to students' understandings of how to design an object to achieve particular outcomes. For example, if a student's understanding about how to wire a battery and motor is incorrect, her or his NatureBot will not locomote. In response, this student needs to closely examine her or his design choices, recognize where her or his understanding or technical skills may be faulty, and adjust accordingly. Making can be implemented in ways that require students to collect systematic data in order to be able to make something work reliably. Makers can be asked to describe and explain their thinking.

PAPER CIRCUITS: GREETING CARDS

Paper Circuits is a Making activity that challenges and extends students' understanding about how to construct an electrical circuit.

Students are provided a range of paper materials, paints, markers, and other tools with which they can create a holiday, birthday, greeting, thank you, or other type of card for somebody they care about. They are also provided copper tape, small LED lights, and a battery. The goal is to create a card that integrates the LED lights into the design, and to build a circuit, so that when the card is opened the circuit is closed and the LEDs light up.

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

1. *Investigative Practices*. Students develop an idea about the kind of card that 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. Because of the open and close mechanism of the paper card, they need to extend their circuitry models across different planes or dimensions, understanding how closing a card can complete a circuit, without shorting the circuit by having copper tape/wires accidentally touching one another.

2. *Sensemaking Practices*. Applying their knowledge of circuitry in ways that allow them to achieve their goals of having the LEDs light up is difficult. Students' initial designs frequently do not work, and they need to rethink their models for circuits, trouble-shoot, and problem solve. The card itself provides immediate feedback, or evidence, about the accuracy of their conceptual models and design solutions, either lighting up intermittently, weakly, or not at all. This may lead them to determine if they need to add a second battery, to devise a new "switch," or to rethink their designs. 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—if and how it works—provides a powerful critique of the students' thinking and conceptual models. Additionally, having students share their design-build processes, including in cases where they could not get the circuit to work, provides an opportunity for articulating why or how something is working or might work, and communicating insights to one another in the form of sharing solutions, strategies, and questions.
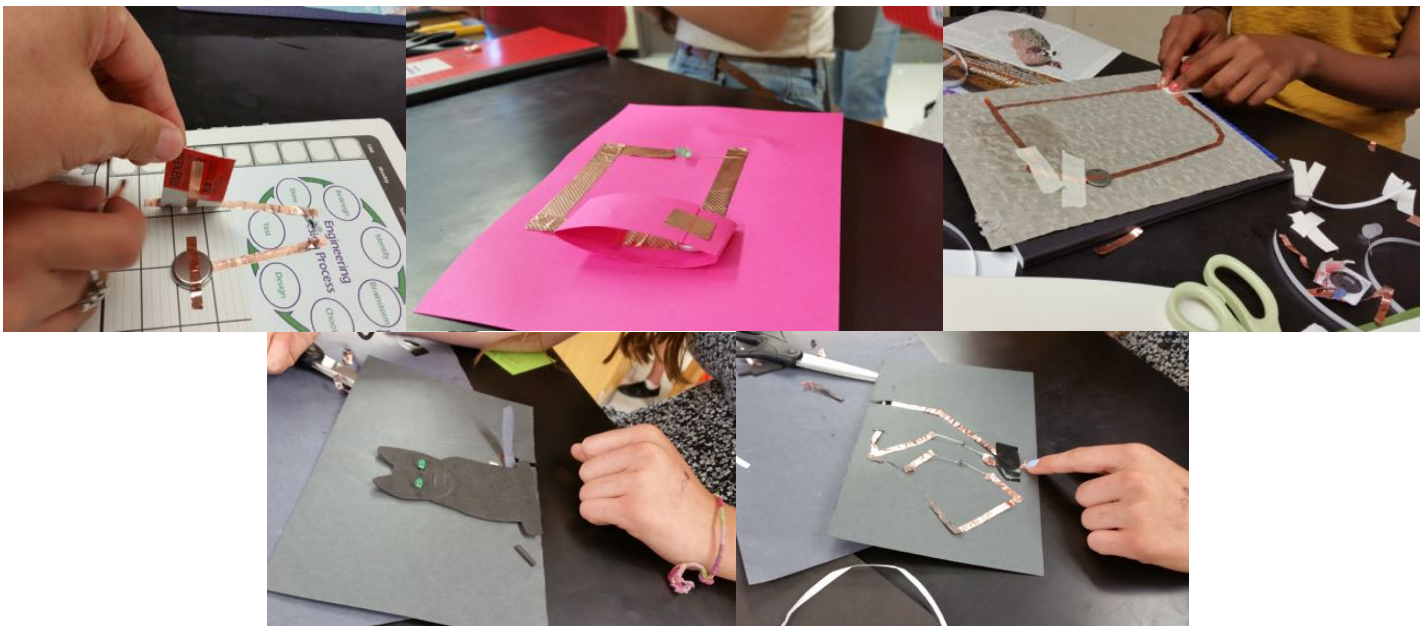
Techbridge examples of different solutions to making open and closed paper circuits.

A Research-Practice Partnership

This report outlines key findings of a study of STEM-Rich Afterschool Making programs offered by four existing organizations. Two of the programs, the Community Science Workshop in Fresno and the Environmental Science Workshop in Watsonville, organized their entire program around Making. These programs took place in designated workshops replete with a wide variety of materials, tools, and models of past Maker projects. These sites operated as community drop-in centers, in 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.

A third program was Techbridge, an afterschool program for girls. This program met weekly and 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 on school sites and taught by a classroom teacher and Techbridge program coordinator.

The fourth was based at the Discovery Cube in Santa Ana. This organization provided professional development workshops to regional educators who wanted to integrate Making into existing 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, along with the Exploratorium partnering with the San Francisco Boys & Girls Clubs, worked together for a period of over three years to design, implement, and study how Making, including new Making activities, could be introduced into programs serving students from low-income communities. Research-Practice Partnerships (RPP) have been defined as sustained, mutualistic, pragmatic, and producing original analysis [11]. Typically they sit at the intersection of research (knowledge-building) and evaluation (program improvement). They use evidence collected in the form of video or field notes about program implementation as the basis of joint review, discussion, and analysis to understand deeply, and in practical ways, what is occurring in the programs for youth and adults. The shared interest (mutualism) in this RPP was a desire to articulate what high-quality STEM-rich Tinkering and Making look like.

Through initial rounds of data analysis and reflection, the RPP (see participants listed at end of this document) began to focus its inquiry on more than simply what does high quality STEM-Rich Making look like, but in particular, how STEM-rich Making could provide a context for expansive and equitable learning. The partnership 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 towards successful and full participation in and contributions to the activities. This emergent focus is one hallmark of a productive RPP: Questions and problems are reframed and illuminated through the joint research and practice inquiry, where problems of practice and improvement, from the perspective and reality of educators, take center stage. It is conjectured that the results of such practice-informed research will lead to more relevant and sustainable results [12].

Project findings are organized into three main areas: 1) How Making advanced the programs' goals for their participants (Why); 2) Key features of the Making programs (What); and 3) Staff development needs to support productive Making programs (How). This report is appended with a set of rich vignettes, drawn from more extensive case studies, describing activities at each of the research-practice partnership sites.

Paper circuit project created at the Exploratorium's Afterschool Tinkering Program.

Cross-Case Analysis

Analysis across each of our four cases revealed the following cross-cutting findings:

### 1. Advancing Afterschool's Programmatic Goals Through Making

"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. Our research has found that Making programs both contribute to and leverage these socially supportive communities to provide a powerful context for socio-emotional and academic learning in the following ways:

- **It can provide contexts for students to take and persist in intellectual and creative risks**, by developing and building out their ideas with the support of program staff. This process can be challenging, as well as rewarding. For example, a group of Techbridge girls developed the idea of designing and building 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. But the wiring and soldering were complicated, and they needed to experiment with several different soldering techniques to get it to work. In the end, though they were unable to get the clock to work as planned in time for the San Mateo Maker Faire, they remained committed to their vision and were proud of their process. At the Maker Faire, they showcased the different soldering versions and recounted what they were trying to do, what happened, and what they planned for next steps. They described what they had learned about soldering techniques and Arduino coding.
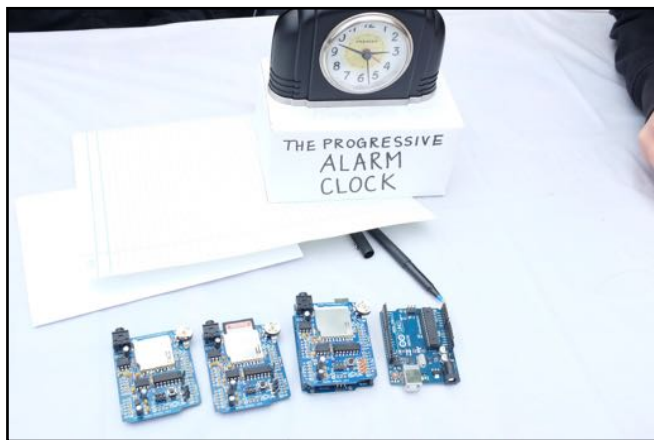
Four attempts at soldering and getting a waves shield to work for a Maker Faire project designed by Techbridge students.

- **It engages students in STEM practices**, such as designing, building, testing, and refining, based on feedback, a wide range of objects such as rockets, paper circuits, or various individualized objects. For example, at the Fresno Community Science Workshop students went on an annual summer field trip to a nearby lake. A group of girls at the program wanted to build a boat that they could bring on the field trip. They worked together to design a 6-foot long catamaran that could keep two people afloat. They constructed and built it using PVC pipes and copious amounts of duct tape. To accomplish

this task they first tested different ways to wrap the duct tape (in tiles, in layers, or in a weave) and tested 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.

Fresno Community Science Workshop students building and testing their boat.

- **It supports the development of a range of 21st century skills**, shown to advance deeper learning [13], such as collaborative problem solving and critical thinking. For example, a Techbridge student wanted to hack into a pair of ear buds to use its Bluetooth function to power a speaker sewn into her backpack. The process of engineering, testing, and trouble-shooting the Bluetooth system took weeks. Through this experience, the young woman engaged in ongoing problem-solving while experimenting with the ear buds, taking them apart, and learning how the Bluetooth controls functioned. She used the Bluetooth buttons from the ear buds to call her friend through her cell phone, then observed whether or not sound was passing through the speaker. Through this experiment, she was able to figure out the inner workings of this system to better implement its use in her backpack project.

- **It connects concepts across school, everyday, and afterschool settings**. By linking Making activities to engineering practices and professionals or by providing tools for young people to create and build school projects, youth in afterschool Making programs were able to connect their experiences across contexts. For example, students at the Watsonville Environmental Science Workshop regularly used the workshop to repair their

bikes. Many times they worked side-by-side with adult family members who were using the workshop tools for authentic family goals, such as building a doghouse or fabricating wooden tortilla makers. Students also used the workshop to complete classroom assignments, such as an annual middle school assignment to build a trebuchet or a Rube Goldberg Chain Reaction machine. The ESW workshop provided networks of assistance to help young people use their design and building skills to successfully complete their school assignments.
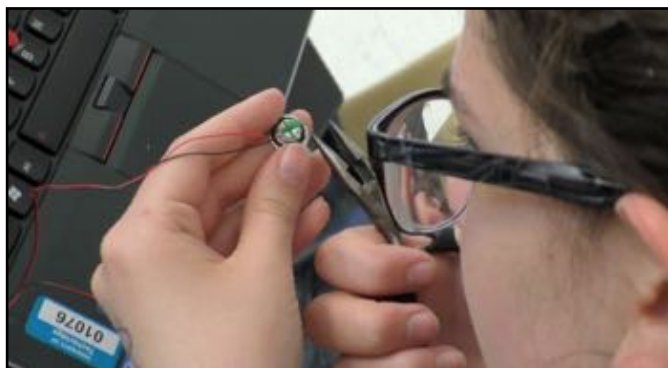
Techbridge student hacks Bluetooth ear buds to repurpose for speakers in her backpack Maker Faire project.

2. Characteristics of Productive Making Programs

Developing a culture of exploration and creative risk-taking is a critical feature of productive Afterschool Making programs. Programs that are organized around asking "what if?" questions set the stage for creative inquiry, and can also help students persist in trouble-shooting 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, and that the process of coming to understand is a valued activity. Features of such programs include:

- **Social and physical environments organized to establish responsive networks of assistance**. These settings make ideas, questions, and strategies visible through accessible tools, open horizons (being able to see the active work and problem solving of others), 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 particular tools and techniques into their different and distinct projects. For example, when an adult Exploratorium researcher, who was building a 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 that leverages students' prior experiences and cultural resources** to support and deepen engagement in the Making activities. For example, before

exploring how to create computer games with Makey Makey tools connected to the Scratch computer program, Techbridge educators couched the project in students' interests and hands-on knowledge of games. They were given the opportunity to test and play with games online and consider the games that they had experiences with in the past. These later formed the basis of their own game designs (game goals, characters, etc.). For example, girls would build unicorns or little monsters into their games, design mazes or music-based experiences, and create collaboration- or single-player based games according to their previous experiences with gaming.

- **Teaching and facilitation that is process-oriented,** encouraging careful listening and questioning and engaging in evidence-based reflection through iterative design-redesign activities. For example, at Fontana, in Southern California, as students were struggling with wiring batteries, the facilitator, building on models provided by the Discovery Cube professional development leader, wrote on the board "failure is not the end of the process, it's just a *step* in the process." She also shared models, and 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 sites, reinforced by the idea that objects sometimes took multiple days or weeks to complete. Process-oriented teaching and learning was facilitated by youth being able to work on their own ideas and at their own pace, a characteristic that may be more likely to occur in afterschool than in school settings.

- **Maker activities that are designed with multiple entry points and pathways**, creating ways for 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 consisted of several different actions that would successfully 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, yet a third started his machine with a ramp. At Techbridge, girls visited a local second-hand store to choose items under $5 that they wanted to "hack" and repurpose. Girls created things like a *Harry Potter* book that screamed when the reader turned to a page where evil character Voldemort appears, music boxes, lamps made out of projector slides, or a piggy bank whose bellybutton lit up whenever a coin was added to the collection. They realized these projects by first starting with a creative idea and then taking their items apart, combining multiple items together, and coding and integrating Arduinos wired to LEDs, speakers, sensors, etc. When comparing results across two years, the program leaders found that when students were able to select their own projects, they were far less likely to be frustrated when things didn't work, and more positive about the experience overall.
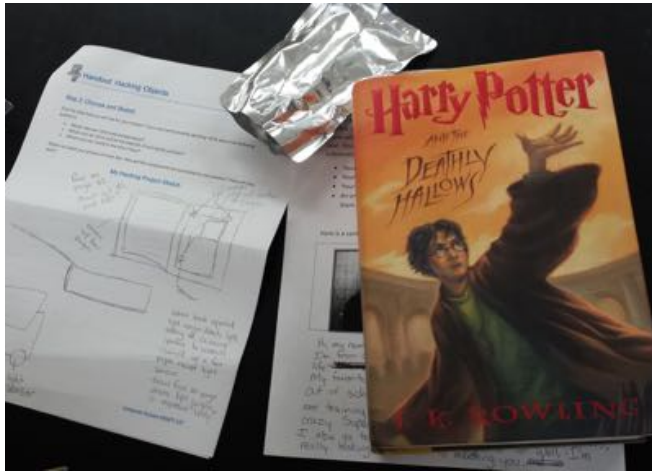
Sketch of wiring plan for screaming Harry Potter book.

3. Staff Development to Support Productive STEM-Rich Making

"I know how to do stuff!"
—*Afterschool educator experiencing a breakthrough during a Making activity in a professional development workshop.*

Across each of the four participating organizations, careful attention was paid to support the professional learning of program facilitators. In particular, organizational leaders were attuned to building facilitators' capacities to provide equity-oriented Making activities. By "equity-oriented" the group meant that it wanted to ensure that all young people were invited and supported to participate and contribute fully to the Making activities. Often this meant helping students to recognize their own prior experiences and skills, positioning them as capable and knowledgeable in Making, and supporting them as needed to persist through frustrations or difficulties. Staff development activities stressed the following features:

- **Engaging staff in explicit discussions about the ways in which their students might experience marginalization** or deficit views in school, society, and other learning settings, thus making facilitators more conscious of how to avoid reproducing these views in the afterschool program. For example, in Techbridge professional development workshops, educators discussed career access and unequal pay between men and women. Facilitators discussed the best ways to talk about such issues so that girls wouldn't be discouraged from pursuing competitive careers and salaries. Educators also discussed how people perceive intelligence and when individuals might feel "smart." This led to a conversation about the different ways that youth might feel like their intelligence is or is not valued, especially when faced with external measures of intelligence through standardized testing. Educators discussed how afterschool spaces can avoid replicating these experiences for young women in Techbridge.

- **Experiencing firsthand, and reflecting on, the ways in which the iterative nature of Making deepened student learning**. Staff across the partnership engaged in the actual Making activities that their students would later do, and 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 ongoing iteration and persistence. At Discovery Cube teacher workshops, the lead staff educator modeled ways to support learner inquiry without providing answers or solutions 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 different parts (positive and negative) 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 she was encouraged to continue and on her third attempt successfully got the bulb to light up.

- **Experiencing and exploring how to create a culture of inquiry and creative risk-taking** through a set of routines that develop trust and collaboration among students. For example, educators from both Fresno and Watsonville participated in a staff development workshop that included role playing activities where they could experience firsthand what it would mean to be a new drop-in student or facilitator unfamiliar with Making, and the kinds of support needed to initially engage in Making. Using *téatro* techniques developed by Boal, participants developed short skits where they explored the problem, and improvised solutions and interactions. After initial skits in which problems and conflicts were surfaced, the group discussed how their actions could have facilitated fuller support of and participation by the learner, in one case the learner being a new staff member. They then revised and replayed the skit, demonstrating key moves that could better support a productive programmatic culture. This group also participated in a process of articulating what they valued in their work and what they valued for students, as a way of forefronting how to develop the program.

- **Exploring how students could be positioned to serve as mentors, coaches, and leaders** for other students, by sharing their solutions or particular skills and know-how with one another. At Techbridge, girls were regularly encouraged to turn to more expert peers for guidance as they built their projects. This occurred in organized activities, such as pairing up new Techbridge students with returning students in order to jointly solder wires together and ensure all girls learned how to solder safely. It also occurred informally when, for example, a group of girls were learning how to program Lilypad and solved their problems by asking peers about their experiences using 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. Most of these studies addressed the implementation of activities, such as e-textiles or engineering, as well as the nature of communities of practice within Makerspace environments [14, 15, 16]. Little of the research addressed core issues of teaching and learning.

The results of this 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. It also addresses a gap with respect to teaching and professional learning of educators who are implementing Making. Professional learning workshops often focus on how-to elements of activities. While it is foundational to provide educators with firsthand experiences doing the same Making activities they will later provide their students, our study suggests that experience with the activities is not enough.

To support expansive and equitable Making programs, educators need to collaboratively engage in envisioning and understanding how to create a program culture that can fully leverage the potential of Making. That program culture recognizes and builds on what students know and can do, deeply supports process and iterative design, supports the creation of a "what-if?" culture that can help students persist through difficulties and imagine new solutions, and intentionally fosters reflection and meaning-making among students in order to engage them in the full scope of STEM practices.

Developing such a culture is not easy, and may require not only expert facilitation but also implementation support, in the form of co-teachers or high school facilitators, so that student-teacher ratios can allow for the kinds of responsive facilitation our research shows is critical to productive and equitable learning through Tinkering. With high turnover rates (many of the educators in the RPP have since left their organizations) these challenges are compounded; suggesting that partnerships with community Makers or science education institutions with Maker expertise may be crucial to long-term success.

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*The Research-Practice Partnership Teams

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

Discovery Cube
Paul Pooler

Environmental Science Workshop, Watsonville
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

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Techbridge: Engineering and Making Programs for Girls

Partnership Members: Nicole Bulalacao, Franco Demarinis, Ben Henriquez, Linda Kekelis, Emily McLeod, Claudia Muñoz, Jean Ryoo, Mia Shaw

Techbridge includes a number of making activities in their year-long afterschool and summer curricula that support the hands-on, student-driven, inquiry-based focus of their educational approach. This involves not only shorter-term activities such as building Scribbling Machines, but also providing 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 that serve between 20-30 girls at each of 20 sites in the Bay Area, Seattle, and Washington, DC. Because these girls may not know each other or be friends during the school day, attention is paid to developing trust among the students in order to foster environments where it is 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 was collected at one of Techbridge's high school programs in Oakland, California. In this program, girls learned to use Arduinos to create and present projects in collaborative groups for the 2014 and 2015 San Mateo Maker Faires. An Arduino is an open-source electronics platform involving hardware and software used to build digital devices that can sense and control physical devices. For example, Arduinos can be programmed to cause an object to open or close, to light up an LED, or turn on a speaker,

Explorations and Making activities with Arduinos were supported by groups of afterschool educators, school teachers, and adult mentors. Mentors included engineering postdoctoral students from UC Berkeley, computer scientists creating their own start-ups, an elementary school teacher, and other entrepreneurs. As mentors assisted students to develop youth-driven projects built on personal interests, they shared their various career pathways and expertise-based practices with young women in Techbridge. Techbridge staff trained the mentors, both before and during the program activities, to support their engagement in the "Techbridge ways."

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 that showed girls wanted 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 school's textbook-focus; 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 4th – 12th grade girls in Oakland, Seattle, and Washington, D.C. Techbridge afterschool educators collaborate with in-school teachers to both run programs and to recruit students who reflect their school's demographic diversity but who may not already 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 where girls showcase their projects and where parents learn about resources to support their daughters' engagement in STEM.

Advancing Techbridge's Programmatic Goals

For a "hacking project" in which girls were invited to repurpose used objects 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 center of each spool hole. After sketching out their plan, they began wiring together a complex system of LEDs to an Arduino that would sit inside their lamp. They had spent many weeks testing out different combinations of circuitry to make the LEDs light up on a single circuit. Nearly a month after the girls had started their project, they sought help from their afterschool teacher (Edward) because the LEDs still weren't lighting up. Edward realized that they had wired some of the LED legs in the opposite direction of what was needed in the circuit —in some cases, the anode and cathode sides of the LEDs were swapped. He explained this while drawing a diagram of LEDs showing how reversing the legs resulted in short circuits. Mira asked, "so should we take those ones out?" as she considered which might be which. Linda pointed out that two of the LEDs would flash when the Arduino was connected to a laptop. Edward replied, "so 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 before they could finish their project. However, rather than give up from this frustration, they tested each LED to determine its polarity and rewired their lamp.
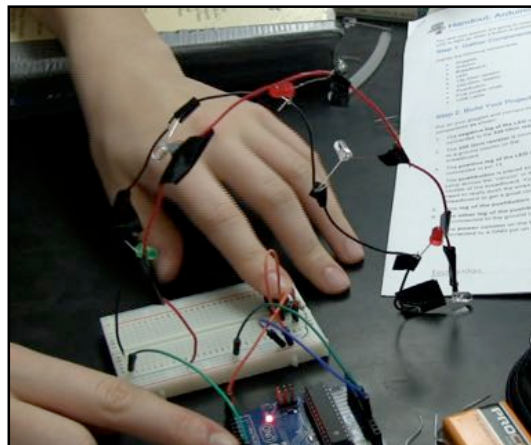
*Linda & Mira's LED wiring system.*
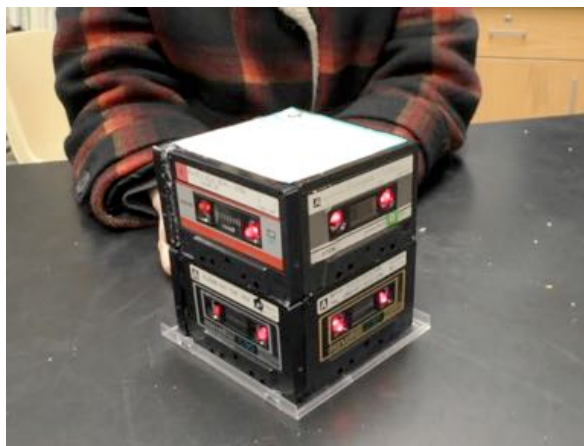
Girls complete their LED cassette tape lamp despite weeks of frustration

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 such as this cassette-tape lamp reflect Techbridge's commitment to supporting young people to pursue creative, interest-driven projects requiring persistent trouble-shooting during challenging moments.

Techbridge facilitators often take on the role of expert friend. This is demonstrated in the vignette above in which the facilitator did not take over the students' project to figure out the problem for them, but simply explained how LEDs need to be wired in a circuit. He acknowledged the fact that he wasn't sure which LEDs were correctly positioned and that the girls would have to experiment to find out on their own. His acknowledgement of the complexities of LEDs and, implicitly, that adults don't always "know everything" invited the girls to work through and figure out their problem using their own approach. In this vignette, the girls continued to test the different 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." In this way, Making supported girls in pursuing various and new ideas over time toward solving STEM-rich problems that were driven by personal interests and designs.

These dispositions came to life during other Making projects. For example, Chloe and her partners struggled to get wires to react to their touch. Each wire was supposed to play a different note along a scale. The girls were trying to create an interactive project where visitors could play music by touching the tips of these wires. Over the course of many hours and 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 and continued working 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 the way other girls were. Instead, she wanted to see if she could sew wire through a piece of foam to make LEDs light up.
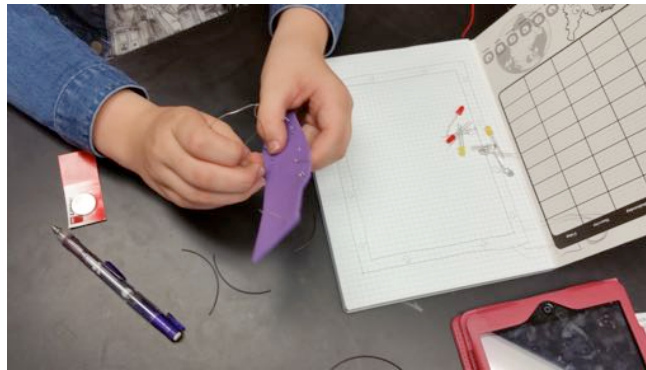

Going off-script: Sewing with wire and foam

She explained that she was curious about how many LEDs the battery could handle. In the end, none of the LEDs were lighting 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 above reflected that fearlessness with trying out ideas (even if they didn't work) beyond the assignment at hand.

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, skillsets, and confidence to work at their own pace.

Characteristics of Productive Making

Chloe, Nina, Quian, and Luisa were using Arduinos to design an interactive environment for Maker Faire made up of wires that would play a different note along a scale when squeezed between one's fingertips. At this stage in their project, they were testing the core technology of their project that they named "Soundboxd." While the project sometimes worked, the wires were not reacting consistently. Nina noted, "Something was happening! And now it's not." Quian said, "maybe we broke it" and Nina protested with a smile, "We did not break it!" and Quian clarified, "Maybe we short-circuited it." as Chloe noted, "Maybe it [the battery] was too high for it" and laughed. Quian continued to fiddle with the wires and a little sound began to emerge.
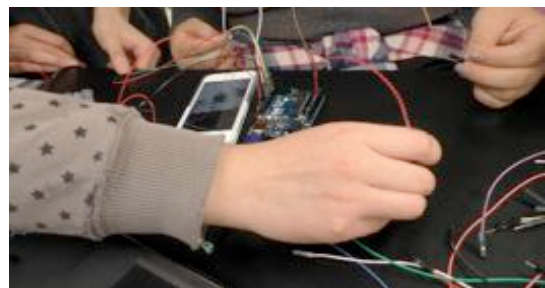
Testing wires.

Nina suggested attaching the wires to copper plating or tape. The girls asked their teacher for copper tape, and 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 who was making the

Girls collaborating and building friendships.

sounds. She asked, "Is it you or me?" and Luisa replied jokingly, "It's not you, it's me." They laughed about how this sounded like typical conversations 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 attached the copper with tape and began testing its response to touch. Luisa tried flipping it over, testing both sides. The girls tried

tapping it, then seeing if bent vs. flatter areas of the copper were more responsive to touch.

The sounds were inconsistent as the girls observed the types of sounds, if any, that were made by their touch.

Throughout the process, the girls laughed and joked together, but also continued to test hypotheses, make observations, challenge each other with new questions, and develop new experiments to make their project come to life. They pursued questions such as, "Is this copper plating too thick?" and "Could we use pennies?" and "Do you think it's the wires, by any chance?" and whether the sound was responsive to different heights of the bent metal. 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.

Girls' final project presented at
Maker Faire

This vignette illustrates how Making projects engaged girls in various STEM practices as they formulated questions and hypotheses, conducted investigations, made observations, discussed different perspectives, and adjusted their project accordingly. 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 various materials and presence of an educator who could offer suggestions and serve as support through the process while encouraging students to pursue their own ideas facilitated a productive Making experience for this collaborative group. The resulting interactive project that the girls called "Soundboxd"—in which visitors could create music by touching copper tape tabs on the outside of the box, or observe lights changing color in response to the musical notes on the inside of the box—was a great success for the girls after months of facing various design and build challenges in their project.

Self-zippering jacket.

Melissa and Esther were creating a self-zippering jacket with an embedded temperature sensor. When the temperature was cooler, the jacket would zip up, and when the temperature was warmer, the jacket would zip down. In preparation for programming the zipper to move up and down, the girls were practicing with an LED that they wanted to 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 then asked, "but what happens when it's under 73 degrees?" There was silence and then one of them replied, "it does nothing" Then Claire said, "You're right, but what happens when it goes over?" The girls had no response. Then Claire asked, 'Have you all learned about if/and statements?' The girls had never heard of this before, and so Claire taught them about this computer science concept that is important for coding (i.e., "if the temperature is above 73 degrees, turn LED on," etc.). Using this new knowledge, the girls were able to edit their code and get the LED to respond to temperature.

This vignette illustrates the ways students engaged with important STEM concepts and skills (in this case, computer science concepts and coding skills) through Making. Making provided a meaningful context for learning

because new concepts and skills were introduced organically in relation to students' self-driven projects. Problem solving was embedded within the creative acts of designing and building.

Staff Facilitation and Professional Development

It was not uncommon for students to hesitate early on in Making activities when they would seek adult approval before attempting a task. Importantly, Techbridge educators would encourage girls to move forward in their experiments and find confidence in their own ideas. For example, when Clara (Techbridge educator) worked alongside Jillian (a new 10th grader), Jillian asked design questions such as, "should I put padding on the back [of my project]?" Clara didn't tell her "yes" or "no," but rather: "Try it! If it doesn't work, you can try something else." This was typical of Clara's pedagogical practices as described in the following vignette:

Clara returned to Jillian's side. 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 what options were available 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 technique involving folding the copper tape to expose the non-sticky side that could be used as a switch as well. Later Jillian asked if using electrical tape would work for holding down part of the circuits. Instead of saying "yes" or "no," Clara again replied, "Let's see!" Jillian tried it and it worked as she wanted it to.

Eventually Jillian made her circuit at the edge of her journal using a binder clip as shown below. She explained that she added a piece of paper to the journal to place between the circuit and the battery that 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:
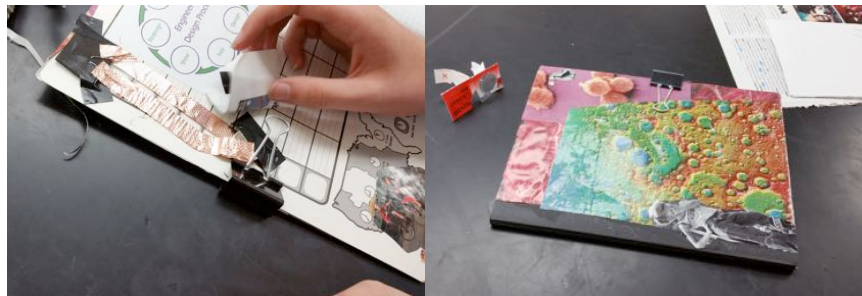
Jillian's paper circuit with switch incorporated into her journal.

As described above, students were encouraged to pursue multiple pathways in their Making with educators supporting girls in asking unique questions and trying their own solutions. These pedagogical practices were common to Techbridge. Just as Clara supported Jillian in trying out her experiments toward developing her

Elle supporting Gigi in program.

personal Making project, Elle would help girls feel comfortable engaging in hands-on, deep STEM inquiry. For example, a 10th grader (Gigi) wanted to build a Bluetooth speaker into her group's "Ultimate Backpack" (that was supposed to address all the needs of a typical teenager with solar phone charger, Bluetooth speaker, glow in the dark El-wire, etc.), When Gigi was uncertain how the Bluetooth-powered ear buds functioned, Elle encouraged her to try taking them apart to learn about what was inside. Elle acted as a sounding board to Gigi's observations, supporting Gigi in pursuing new questions with every new experiment with the Bluetooth ear buds. 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 adult 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 through her investigation. In these ways, Elle helped Gigi become more confident with hacking and tinkering—activities at the heart of making. She took Gigi's ideas seriously, encouraging Gigi to take her project in her own unique direction.

These approaches to teaching Making activities—that built girls' confidence in designing, building, testing, observing, redesigning, etc. while exploring their own scientific questions through probing "what if?" questions—were a key focus of Techbridge's professional development activities for afterschool educators. In professional development workshops, at both the Exploratorium and Techbridge, 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 the perspectives and experiences of youth while supporting inquiry-based learning in which girls can feel safe to pursue their own questions, discuss their ideas, and work through challenges. Educators physically engaged with Making through circuitry activities, creating lanterns using tilt switches, cardboard automata and jitter bots, paper circuits, scribbling machines, and designing circuit-based games. This way, reflections on teaching practice were rooted in experiences as learners in Making activities. This is described in the vignettes below.

As a way to explore focusing students at the center of inquiry through circuitry-based Making activities, Elle (who was leading the professional development workshop) had educators work in pairs to use a battery pack and alligator clips in order to make bulbs light, buzzers make sound, and motors move. She asked educators to write down any questions that arose during these Making investigations. After some time, she asked people to share their questions which included things such as "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 what people observed of her teaching actions during implementation of the activity. One person replied, "you asked questions" while another said, "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 through Making activities can jumpstart their explorations of inquiry where "students are 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 girls might give up, but that there should be "safe space for this" that allows time for kids to figure out on their own instead of just be told step-by-step." She noted that allowing girls to help each other was important or bringing on role models to support difficult moments could create a safer environment for girls to learn STEM.

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 their futures. 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 a packaging engineer) and how to incorporate role models into activities (through videos, "career cards" describing real women's career pathways, or program mentors).

Allison (leading the workshop) pretended to be a packaging engineer visiting a Techbridge program while educators engaged in the activity as students. Allison explained that packaging engineers "make sure packages get to your doors in one piece" and she proceeded to show some video interviews with female packaging engineers describing their work. She asked people 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 a share out
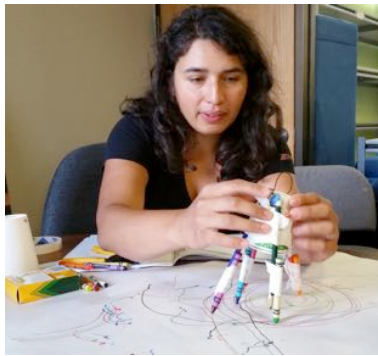

Techbridge educators in a professional development workshop.

where people described what they noticed in the video, words they found could be difficult to understand (e.g., consumer, constraints, cross-functional, etc.). Then people discussed the importance of using reusable and renewable materials for packaging to reduce waste. Following these discussions, Allison introduced an activity where people could try making their own packaging for an iPad (represented by a graham cracker) that should be able to withstand a series of tests including dropping the box from a specific height, sitting under a weight of heavy books, and being thrown against a wall three times. People had a chance to draw out their designs before building in groups, then took turns testing each other's packaging. Following the activity, educators examined some "career cards" that they could share with Techbridge students related to their experiences building like "engineers."

As described in the vignette, Techbridge educators reflected on the ways that afterschool STEM learning through Making activities could relate to specific career pathways and real world experiences. In this way, girls could explore a variety of potential future pathways that connected to their experiences as students in Techbridge.

During summer 2015, Techbridge educators also took the Exploratorium's Tinkering Fundamentals Coursera MOOC as professional development. This experience of watching videos and reading materials from the online course while simultaneously meeting in-person to do the tinkering activities and discuss ideas collectively led to important considerations of pedagogy for afterschool Making. More specifically, watching videos of young children working on Making projects motivated educators to think differently about their students. These videos challenged deficit notions of what educators thought their students might be capable of. One educator noted how watching MOOC videos of kindergartners building scribbling machines, "shifted my way of assuming—having these 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 how the MOOC videos, readings, and activities shifted her pedagogical approach learned from teaching science in formal school settings. She explained how before teaching always felt rushed, but now she learned to value "letting [Making] be a long process without a time limit" so that students could struggle

Techbridge educator experiencing an activity from the Coursera.

through their ideas and create more complex projects. This was echoed by another educator who had previously taught middle school math. 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 hardware (such as a painting robot) and complex art projects. 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 experience supported Techbridge programmatic goals to offer Making experiences where 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 experienced through Making connected to real career pathways along the way.

Conclusion

Techbridge offered an important context for girls traditionally underrepresented in STEM to engage with STEM concepts and practices through authentic projects fueled by individual interests and collaborative goals. Making activities specifically allowed girls to pursue their own designs that resulted in creative experimentation and problem solving as challenges surfaced. Techbridge also created the social scaffolding necessary for engagement in complex building projects by fostering 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 that supported one another in explorations. Professional development for educators paid close attention to thinking about how to cultivate a learning environment, social norms, and teaching practices that would allow girls to feel safe asking questions, experimenting with their ideas, using new tools, and identifying as STEM learners.

Watsonville Environmental Science Workshop: Making Programs

Partnership Members: **Emilyn Green, José Sandoval, Alan Guzman, Gustavo Hernandez, Aurora Torres, Araceli Ortiz, Omar Vigil, Martin Moreira, Fabi Pizano, Nestor Orozco, Molly Shea**

Making is the central activity of the Environmental Science Workshop (ESW) in Watsonville, California. The building is filled with machine shop tools, art supplies, building materials, electronics and a wide range of objects, including natural objects (shells, plants, etc.) as well as 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 out school projects. The building is open to all community members, but is especially appealing to neighborhood youth during summer and afterschool hours, who 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 as well as other students and, sometimes, family members.

At the ESW, Making is recognized as an activity that all community members engage with in different ways. The learning environment welcomes and integrates students' cultural and home practices into the shop. Educators are bilingual and easily change back and forth between English and Spanish as young people engage in workshop activities and interactions. All of the signs in the shop are bilingual, recognizing and honoring the language resources and home references children bring with them to the workshop.

Bilingual signage at ESW Watsonville.

At the ESW, Making activities are seen as a context for neighborhood youth to 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 to their Making projects as they progress in stages. 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.

Watsonville is a small agricultural town in the Central Coast of California. The ESW is located in a municipally-owned park building in a low-income part of town. Each week, the program serves over 600 young people, the majority Latino, who attend its free drop-in programs. The program is staffed primarily by bilingual community-members, many of whom were once participants in the program as youth.
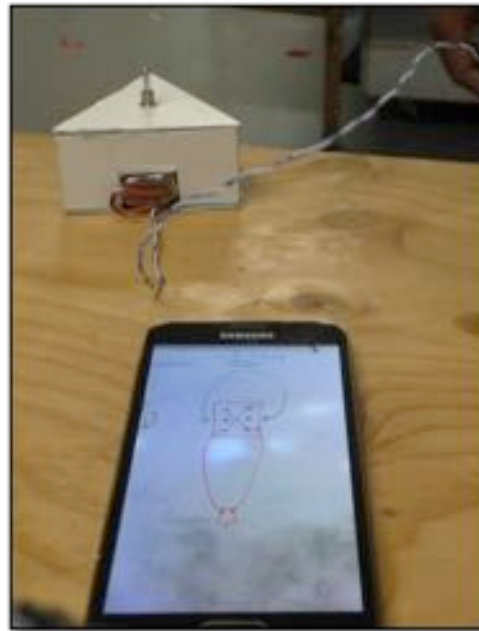
Advancing ESW'S Programmatic Goals

12-year-old Eddie 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 Eddie 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 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 how to make a switch that he had just drawn out and stored on his smart phone the day before. Eddie studied the switch on the car he held in his hands, as well as the diagram of a switch 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 revoiced 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.

Carlos shows Eddie a diagram.

The ways in which Making connect to and advance the programmatic goals of ESW are evident in this short vignette. The program seeks to engage 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 access to a diagram and helped Eddie to make careful observations and turn them into words and plans. Carlos checked with Eddie about whether or not he knew how to start stripping wires, but he never over-directed or took over Eddie's project.

This vignette exemplifies the socially supportive, learner-centered context in which young people, especially those from economically and racially marginalized communities, can be supported in Making programs to take intellectual and creative risks that can deepen their interest and understanding in STEM.

Characteristics of Productive Making

One Friday, a small group of young people, ranging from 8-12 in age, chose to design and build rocket cars. The model at the workshop 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 like the length (12"-18"), placement of wheels and the addition of fins and cones to add stability as the cars rocket across the blacktop. A facilitator, Pablo, assisted students, as needed, in building the rocket cars and also in loading them onto the rocket launcher outside. The launcher was built from a lawn sprinkler and plumbing parts. The chamber was filled with compressed air. It could be used to launch rockets vertically or rocket cars horizontally, when a push of a button released the compressed air. While preparing the launcher, Pablo described how it worked, explaining that students could select the pressure level (psi levels of 20, 40 or 60) based on what they thought would work best given the size and structure of their rocket car.

A 4th grade girl, Katy, volunteered to go first. Pablo helped to get the rocket car into the launcher, set the psi to 60, and then released it. As the rocket car ripped out of the launcher, the wheels flew off and rolled along the blacktop (basketball court). "I said 40 [psi] 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 and her rocket car.

Katy *took the rocket car back out to the launcher, but just as she was beginning to set it up, she saw the nose cone which sealed the rocket body to allow the buildup of pressure had come loose and would let air escape, loosing pressure and foiling a launch. She immediately grabbed the rocket car and ran back inside to conduct some new repairs. 15 minutes later she returned, and chose a 20 psi pressure to launch. Nothing happened. She increased it to 40 psi. It didn't leave the launcher. Deflated, she was starting to turn back to the workshop to try to figure out what was wrong when one of the high school facilitators came up and suggested she lift the rocket launcher an inch off the ground before releasing the air pressure. He explained to her how 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 of the parts intact but the top of the car was visibly loose. After another round of adjustments, Katy returned to the launch spot. When asked how many psi she wanted, she said just 2, smiling, pounding her fists, and saying, "I'm scared!" Encouraged, she raised the psi to 40 and launched the rocket. It worked! She proceeded to launch the rocket at multiple different psi levels. Her rocket car was able to withstand 45 psi.

In this vignette, core dimensions of Making as a context for STEM practices of investigation are made apparent. The student had chosen to participate, along with others, in a process of building a rocket car. Their choice was stimulated by examining a model of a rocket car that was accessible on the workshop shelves. The availability of the object both validated it as a legitimate activity in the workshop and provided a concrete model for how it could be constructed. When the rocket revealed its structural flaws, she was able to return to the workshop and make revisions, working alongside others who were constructing their own objects. At a key moment, she had the assistance of the high school facilitator who helped her adjust the launcher. Characteristic of many high quality Making programs, there was not an expectation that she had to get it right the first time—those kinds of pressures might lead to more adult intervention and less student-directed activity. Tools and adult support were available on an on-demand basis.

The iterative nature of the activity opened up opportunities for learning. For example, at each test, Katy was able to observe emergent flaws relevant to the construction or design, and then, based on this feedback or evidence, make revisions and re-launch the rocket. The activity was designed to illuminate relationships between structural integrity, air pressure (psi levels), and distance travelled by the rocket cars. Above all, the Making project gave the young girl the opportunity to persevere and achieve success in a valued activity within the social space of the workshop.

Staff Facilitation and Professional Development

At the second staff development workshop of the year, Eleanor, the ESW network director, wanted to continue staff discussions about the relationship between program values and their work with young people. To start, the group revisited a list of those values, which fell into categories of: 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, was that we want to mentor and model what we value. We want kids to learn "to be curious, understand their connection to the community and the world around them." She passed out student journals to the staff assembled in the workshop and asked them to look at what students had been writing or drawing and to consider how the journals reflected the program values.

One of the long-time 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, Benjamin, had been actively involved in assisting the young boy. Somebody noted how the student journals demonstrated the core programmatic value of students taking charge of their learning.
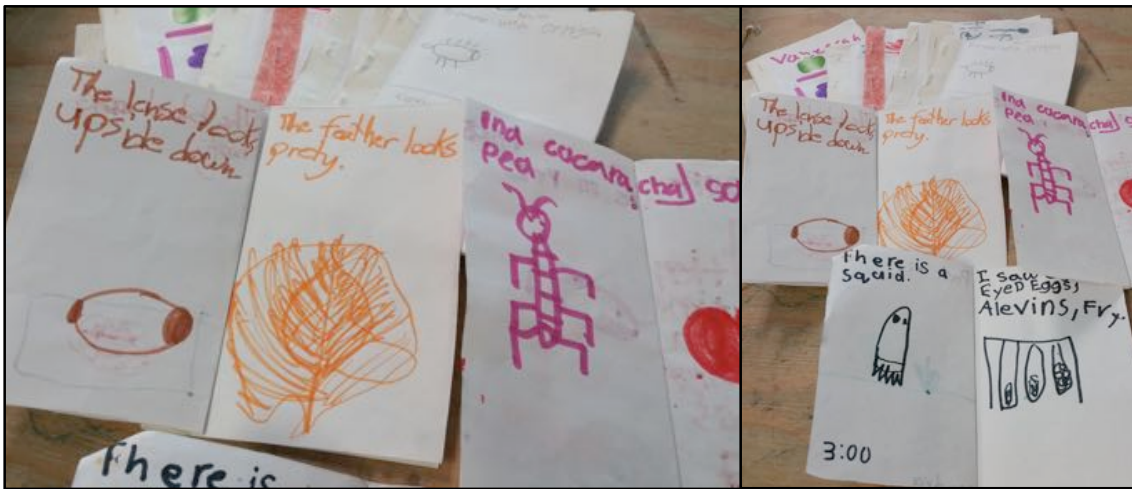
Students' journals.

Making reveals and makes visible student thinking and understanding, in the objects that they build or the plans that they record. As such, it can support staff reflection as well as informal, ongoing, and formative assessment of student learning. At ESW, the children's journals also provided data for staff to reflect on the ways in which student experiences related to core program goals. This could support discussion about how the physical and social space facilitators were responsible for fostering, could advance program goals.

These data-driven discussions allowed staff to reflect on their roles in supporting a culture of inquiry, and modeling how youth could take charge of their own learning. On other occasions, staff discussions focused on concepts like "failure" and discussed their responsibility for helping students to reframe moments when things didn't work as planned to serve as opportunities for learning. Facilitators could also make connections to the work of real scientists, and the ways in which progress in science was making meaning of the unexpected or unpredicted was also discussed as a strategy for helping students connect their experience to the larger world, and to remain encouraged to persist and to 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 their target audience is low-income youth who frequently are faced with negative social stereotypes and marginalization, the program intentionally organized the physical and social space in ways that recognized and 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 in the context of STEM, as well as in the context of a social community. Making at ESW had practical implications—providing tools, space, and support for fixing bikes and building school and other projects. But most importantly it provided a setting for youth to feel and be productive, pursuing their own interests and ideas, and growing into positions of leadership, as many of the high school and professional staff exemplify.

Fresno Community Science Workshop: Making Programs

Partnership Members: Jena Colvin, Melody Felten, Armando Figueroa, Manuel Hernandez, Molly Shea, Kayla Shields

Fresno, like the other Community Science Workshops across the state of California, focuses its curriculum on student-centered, interest-driven activities in which young people can build something based on a model or idea that is available in the workshop during summer or afterschool hours. Frequently sub-groups of students may make the same object, such as super soaker water guns on a hot summer day or Rube Goldberg Chain Reaction machines in an afterschool class. Other times they work individually with the assistance of CSW facilitators or other sources of expertise in the workshop.

In addition to providing regular afterschool Maker programs at a wide range of school settings, Fresno offers family nights and drop-in programs at two different locations. In all of these programs, the CSW seeks to support and sustain student interest in their projects so that students take their projects and learning the next step, challenging themselves to improve and strengthen their designs, and in the process deepening their STEM skills and understanding.

Children exploring bones at CSW Fresno.

The Fresno drop-in centers also welcome families, siblings, and neighbors who come in and work together on projects. In the process it seeks to make connections between children's family practices and the Making practices valued in the workshop.

Founded in 1994, Fresno Community Science Workshop operates hands-on science programs at more than 25 area schools; at the drop-in Science Workshop Programs located at Highway City Science Center, and throughout the Central Valley via the Mobile Science Workshop. The Fresno CSW reaches underserved youth, many from families of agricultural workers, with more than 25,000 visits and classes annually. Through teaching experiential science education, the program seeks to stimulate curiosity, respect, and passion in participating students.

Advancing Program Goals

Marta was a young girl of about 8 or so, who, with her mother, had come to the Fresno CSW for the first time. After some time walking around the workshop observing what others were doing, and looking at the models of prior work located on shelves and tables around the room, she saw a model of a small house, made out of popsicle sticks, and decided that she wanted to make that house herself. Over the course of an hour or so, 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.

A CSW facilitator who had been working with a young boy wiring a bulb, overhearing what Marta had said, 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 he told her to try it.

Marta sang a little as she pressed down on the wire stripper handle. In no time she had stripped all of the wires. The facilitator picked up a battery and held it to the table and said, "So then we have our light, right? And the battery." He pressed the wires Marta had stripped to the battery and a single Christmas bulb lit up. He 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 he 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.

Marta making her fairy house.

Making activities allowed young people at the Fresno CSW to pursue their interests and imaginations, thus building their sense of accomplishment and capability. The except above reveals the ways in which interest-driven learning activities can, by building on a sense of ownership and authorship on the part of the learner, lead to the creation of new learning opportunities, in this case the need to learn how to wire a circuit in order to give the fairy house a light.

In the context of a community drop-in center where family members are welcomed, Making also offers activities in which multiple people of different ages can collaborate to design and build together. In this case the mother assisted the daughter in the construction and decoration of the house. At the same time she engaged with the facilitators to learn more about the organization and the programs it could offer her child.

Characteristics of Productive Making

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 I [the researcher] asked her if she might want 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. I looked into a recycled cardboard bin and found the top of a pink shoe box which I took to make wheels for a car I was building along with some of the students.

A few minutes later I returned to the glue station to glue a piece of the car frame together with the pink cardboard from the recycled bin. I told Gabbie that I had decided to make a doll car. Her head spun and she said that it's a cool idea. I said she was welcome to build it with me after she finished her doll room.

A few minutes later Gabbie came to the back table and told me she was ready to work on the doll car. I told her she could have it for her doll when we were finished. I had the pink cardboard out on the table and cut into circles. I asked if Gabbie wanted to help cut the pink cardboard into circles that we could glue to the car wheels. She could do one and I could do another. We needed to get the cardboard cut to the right size for the wheels and then we needed to connect the wheels to the axle. Gabbie took a piece of cardboard and observed what I was doing for a few seconds before she started cutting her own circle. We started talking. She had come to the workshop yesterday and again today and 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 we cut out the wheels, we walked over to the glue gun station and Gabbie applied the glue while I turned the cardboard slowly to catch the glue. Then we slowly pushed the pink cardboard against the wheel and let it set. We

returned to the back table and talked about how we would need to find the center of the circle in order to put the axle of the doll car into the very center of the wheel so that the car wouldn't wobble when it ran. We got a ruler and started to measure the wheels vertically and horizontally and placed a dot at the center of the wheel. Gabbie was not sure how to use a ruler so we lined up the outside of the wheel with the edge of the ruler marking zero and then looked for the other edge of the wheel to see what number the ruler said. We then looked for the number in the middle to mark a spot on the back of the pink cardboard rims.

At the workshop, facilitators, and in this case the researcher, are encouraged to build and design alongside youth, modeling the ways in which design-build activities are valued, but also, as in this case, spurring ideas and interests, as well as sometimes demonstrating new techniques or tool uses. The role of adults or older students in the CSW community is a critical part of creating a culture of inquiry, creativity, and networks of assistance that can be tapped for help or guidance.

In this example, the first grader's interest in dolls and a doll house was parlayed into working on building a doll car, oftentimes the province of boys in the workshop. As she herself described, at the CSW she felt she could do and learn new things. So when the opportunity arose to do something new, like build a car, she was able to leverage her feelings of confidence and support for creative risk-taking to take on a new task.

Gabbie's mastery of the hot glue gun was used as a resource for building the car. The activity also offered opportunities to develop new skills and experiences, appropriate to her age, such as wielding scissors to cut out cardboard wheels and learning how to use a ruler to measure and determine where the center of the circle was, a process and understanding that she needed to know so that she could produce a pink doll car that wouldn't wobble when it ran. STEM knowledge and skills in the CSW exist for authentic reasons: For developing and realizing students' ideas and ambitions.

Staff Facilitation and Professional Development

Staff learning workshops at CSW are organized to engage staff in working together and reflecting on both benefits of collaboration and how facilitation can promote it. At this workshop, staff were building Rube Goldberg Chain Reaction Machines. This involves using blocks of wood, marbles, tubes, dominoes, and a range of other materials that interact with one another as a chain reaction is triggered by an initial action. Staff formed teams to design and build machines together.

After about 45 minutes of building, the staff formed small groups to reflect on what it felt like to work on the chain reaction project together. First, each person wrote for about five minutes; then they talked in their small groups about what worked within the exercise, what was challenging, and how the facilitation worked within the activity. At the end of the small group time they got together in a large group 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 it was a challenge to be listened to during the project, as the conversation had been dominated by the men in her group. She said that the men took over the project without listening to the women on the team. Rather than pursuing that line of discussion, however, she related it to a counterexample where the female staff at Fresno may often overwhelm the one male staff member there at present. The point she wanted to discuss was how to ensure that collaborations are inclusive, and that different affinity groups don't unintentionally leave out somebody.

This short vignette demonstrates the ways in which staff development can be organized to not only deepen facilitators' expertise in Making activities, but to support critical reflection on the social experiences of Making, in this case collaboration and the potential marginalization or exclusion of some members in design teams.

Firsthand experiences in Making thus provide a grounded and shared source of data for reflective discussions. The reflective culture they help to build then operates to help avoid personalizing a particular experience, here a gendered one, and instead to 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, based on these exchanges, organized a staff workshop specifically on gender issues.

Conclusion

Making at the Fresno Community Science Workshop is geared towards 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, 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: Jasmine Medina, Jesy Myles, Paul Pooler, Jean Ryoo, Wendy Zinn

Discovery Cube leader—Paul—collaborated with the San Bernardino Community College District to lead professional development workshops that taught both formal and informal educators about a variety of hands-on Making curricula through a program called "iCreate." iCreate was attended by majority afterschool educators as well as K-12 teachers throughout the Inland Empire, the 13th largest metropolitan area in the US that covers Riverside, San Bernardino, and Ontario counties. The Inland Empire has some of the lowest average annual wages in the country as well as low education completion rates. Approximately 25 educators regularly attended these workshops that were held monthly during the 2014-15 school year. In an effort to understand how Paul's Making workshops impacted implementation of Making activities at a local afterschool site, we collaborated with Fontana After School Program (FASP) to compare observations of Paul's workshops with FASP educators' implementation of STEM-rich Making with children.

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

Furthermore, Paul made great efforts to make the activities accessible to educators who could potentially 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 how to involve easily-found and cheap materials that made implementation of activities feel more accessible to educators.

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 (which is one of 72 community college districts within 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 that can be shared with educators across the Inland Empire.

The City of Fontana offers the **Fontana After School Program** (FASP) to children in grades K-8 across 41 schools in the Fontana, Colton, and Etiwanda school districts. These school districts serve majority students of color from low-income families who qualify for free/reduced-price meals. The program provides homework assistance, computer lab/library time, health and wellness activities, and social and educational enrichment programs for youth.

Advancing FASP's Programmatic Goals

In the vignette below, a FASP educator supported STEM learning for children underrepresented in STEM fields by developing an environment that encouraged youth to see themselves as capable scientists who could achieve their inquiry goals. Rather than take over when students became frustrated, the educator asked focused questions that

could support children's Maker-based inquiries. STEM-rich Making provided the context necessary for the FASP program to support children in pushing through challenging moments and developing confidence in their abilities to solve problems.

Katie was working with two girls who struggled to light a bulb in their circuitry activity. They told Katie, "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]" and Katie said "so maybe you just need it just right! The perfect storm!" The girls looked stumped and one of them said, "I don't know…" Katie continued to encourage her with a smile, reminding her, "you're the little scientist!" and Katie recalled how the student had asked the most interesting questions when they explored taste buds in a previous activity. Then Katie asked the girls, "where do you want to put the bulb?" One girl pointed to the top of the battery and said "here" and Katie asked "do you want [the wire] to touch the bulb or the battery?" and she pointed to the different materials. The girls pondered this as Katie asked, "was it touching the wire or just the battery [when it flashed]?" The girls began fiddling with the set up, trying to touch the wires to different parts of the bulb so it would flash again. While most students had made their bulbs light, some continued to struggle alongside these girls. So Katie shared, "here's a hint: you want the electricity to go in one end and out the other [she held up a battery 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.


Girls lighting a bulb.

This vignette reflects the ways Making provided a valuable context for learning STEM, but also how important pedagogical practice was for supporting youth through challenging problems. Successfully engaging children in STEM-rich activities was particularly meaningful for the FASP program that served young girls and students of color underrepresented in STEM. 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. They were uncertain about how to establish a strong circuit and, in a room full of other children who were exclaiming "We did it!" and "Our bulb lit up!" the girls' increasing disappointment that they couldn't figure out how to make the bulb light was palpable. The educator—recognizing that the girls were on the verge of giving up and really wanted an adult to intervene and do it for them—refused to put her hands on the circuitry and, instead, began by verbally encouraging the girls to pursue their experiment. She acknowledged how the materials could be challenging to work with as a way to validate their feelings of frustration, stating that maybe they just needed the wires to line up "just right" and have the "perfect storm." When one girl replied with "I don't know…," instead of showing her how to do it, the educator reminded her that she had strong inquiry skills and connected this learning experience to previous learning that had been positive for the young girl. Katie reminded the girls that they *could* do science and that this task was not beyond them. Encouraging the spirit of inquiry through Making, Katie proceeded to ask open-ended questions that could support the girls in their experiment with the circuitry ("where do you want to put the bulb?" and "do you want to touch the bulb or the battery?"). And when she noticed other students struggling, she did not explain how to make the bulb light up, but gave students room to consider her "hint" about how electricity needed to flow from one end of the battery to the other. One can imagine that the success the girls felt after they got their bulb to light was much greater than it would have been if the teacher had simply stepped in and showed them how to do it or if the teacher had previously demonstrated how to complete circuits in front of the entire group of students. In these ways, Making advanced FASP's programmatic goals to support children's intellectual and emotional development as the girls worked through STEM challenges and the educator supported them with specific questions and prompts that could sustain their inquiry.

Characteristics of Productive Making

A 5th grade boy was struggling to get his Scribbling Machine to move. He was able to get a 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?" The boy replied in a deflated tone, "yes." Katie began to say, "so you need to put the…"

but then she stopped herself from telling him how to make his machine and instead asked, "so how are you going to get this movement [pointing to the motor] to help this cup move?" Katie observed of his machine, "it [the motor] is trying to get out!" Then the boy noted that he could "tape it" to the cup instead of just place it inside the cup. Katie replied, "that's an idea!" to which he noted, "But I tried that already." Katie's response was, "maybe it was weird the first time. Maybe this [and she held up the tape] is the magic tape you need [this time]. So maybe you need to make sure the motor is still moving when you tape it?" Then the boy noted "I tried here and right here" showing Katie where he had previously tried attaching the
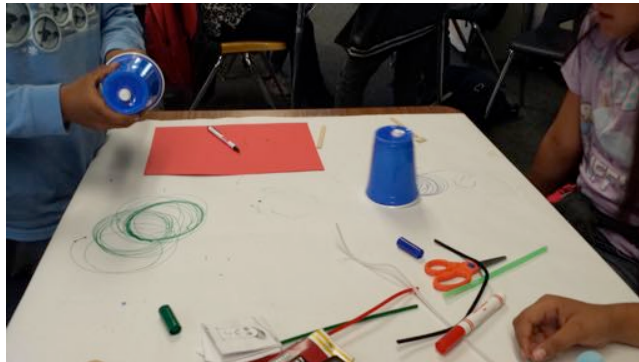
Boy experiments with placement of his Scribbling Machine's motor.

motor. Katie nodded her head 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?" After this Katie stepped away, and the boy tried taping the motor to different places 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 that inspired him to explore again.

STEM-rich Making at FASP encouraged children to pursue their own questions and ideas in ways that recognized multiple pathways in designing and creating projects. This was supported by specific facilitation moves. For example, Katie kept herself from taking over the student's project and encouraged him to consider various ways to experiment with his project design. She asked questions that addressed how form could affect function (e.g., "how are you going to get this movement to help this cup move?") as well as physical design questions ("Maybe try another position? Inside, outside…"). In this way, Katie did not offer specific answers to the boy's Making challenge that might suggest that there was only one way to solve his problem. Rather, she asked questions that opened up a variety of possibilities to make the machine move. This approach to teaching in Making contexts proved particularly important for allowing space for children to experiment, try different pathways to a solution, and try out their ideas. This productive Making context invited youth to work through challenging moments toward experiences and achievements they could be proud of.

Staff Facilitation and Professional Development

The ways that Katie supported FASP youth in STEM-rich Making—encouraging underrepresented students to see themselves as scientists by connecting to prior learning, welcoming multiple pathways toward student-driven success, and providing space for youth to pursue their own inquiry-based goals—drew directly from ideas that Paul shared during iCreate Making workshops. Paul emphasized specific facilitation moves that he deemed critical to student engagement. One key pedagogical move that he shared with educators was the importance of developing a safe space in their programs where kids could feel comfortable exploring and trying out their ideas. For example, at the start of a circuitry Making workshop, Paul stressed that using everyday materials to explore new learning around electricity could make the familiar feel strange and new. He also noted that some people might feel uncomfortable when working with circuitry because electricity can feel dangerous. Couching circuitry in Making activities that connected to what people found familiar could quell such fears, supporting new STEM learning. Acknowledging that educators had limited resources and time, he also emphasized that using everyday materials that were easily accessible not only was helpful to teachers, but also to students who could feel comfortable working with what was familiar and not overly precious. In these ways, Paul modeled teaching practices that encouraged people 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" in their projects that could yield interesting differences in results.

In order to explore this idea more deeply, educators were also introduced to the importance of connecting to students' prior learning and personal knowledge as a key pedagogical practice with Making. Paul regularly

emphasized how STEM-rich Making activities should draw on students' own actions and experiments so that new knowledge builds on what they are experiencing vs. what teachers are telling them. Making provided the context that could allow youth to connect with what they already knew or were interested in. Paul modeled this practice, drawing on the knowledge and interests that educators brought to his workshops as shown in the following vignette:

Educators were going to be making catapults and began by experimenting with shooting rubber bands at different angles. Paul approached an educator who was particularly quiet during the workshop and stayed seated at the

back of the classroom. As she tried shooting her rubber band, she observed how 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 it to basketball. The teacher continued experimenting and noted that an angle of 45 degrees allowed the rubber band to travel the farthest. Paul agreed and said, "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." And the teacher replied, "kind of like Stephen Curry last night, on his 3's" Paul smiled and nodded his head in agreement and 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." And the teacher became noticeably more engaged while nodding her head and saying "exactly." And Paul continued, "So if you were to adjust it, so go back to our variables, what if I went higher [and he angled his arms up towards the sky referring to a larger angle from the ground], but I needed it to go further [and he motioned outward with his arms, pointing away from himself], what would I do with the rubber band?" The teacher replied, "pull it back farther" and she motioned with her arms as if pulling the rubber band further and giving it more tension." Paul nodded his head and said, "there you go. So with shooting a basketball, if I'm shooting over someone but I

Teachers making catapults.

need to go more distance, then I'll need to put more force into it" and the teacher nodded her head, repeating the word "force" and saying "exactly." Later, Paul emphasized with the whole group about how it was important to make these connections to student knowledge and perspectives so that they could move from "I don't know" to "this is familiar."

While this vignette may seem like a simple moment in which basketball was connected to catapults, Paul modeled an important pedagogical practice in STEM-rich Making that encouraged learner experimentation by rooting new learning in everyday knowledge of the world. When this teacher—who had been quiet in group settings—was willing to share her observation about how basketball related to the rubber band experiments, Paul took up the opportunity to connect their Making experience to her interest in basketball. The teacher became noticeably more and more animated through the conversation in her physical engagement with the activity as well as by referencing the previous night's basketball game, suggesting a growing interest in the activity and learning at hand. Paul used the opportunity to also connect the simple rubber band experiment with STEM vocabulary and concepts around force and distance. In this way, Paul organically modeled how to build on learners' personal knowledge and interests to encourage experimentation toward new learning. The educator in this vignette also experienced how Paul's recognition of her observations about basketball could increase her engagement and lead to thinking 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 the FASP educator who made efforts to remind girls about their previous STEM experiences that could encourage new learning.

Similarly, when introducing tinkering with circuits, Paul modeled how educators could show connections to everyday life to demystify electricity. He explained the way circuits work differently in parallel vs. series and why we would need the two types by describing how you wouldn't want to have to turn on all your appliances just to use a toaster in the kitchen and by illustrating circuitry using the classroom lights. He emphasized the importance of connecting to everyday life that excited 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. If they're into power steering cars." He also used this logic for thinking about how to make electricity less scary and 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 years, why the rivers flood certain times of the year, why lightning comes. And if we demystify things and kind of make it real for us, it can really help us understand and make those connections to other places."

The workshops also emphasized how effective Making pedagogy involved a careful process of asking questions instead of simply giving learners solutions, and reflecting on learning by sharing ideas with peers. Paul modeled these pedagogical actions in order to support workshop attendees in pursuing their inquiries with Making activities, rather than directing their learning himself. This is shown in the vignette below:

Educators started to tinker with circuitry and Paul noticed some were struggling to light a bulb. So he asked if people wanted a hint. Many said "yes," so Paul drew a battery on the board and said, "so here's a battery, and on my battery you'll notice a plus and a minus. Those are called terminals. What we want to do is we want to get electricity to come out of one of the terminals and go back into the other terminal. So it's gonna come out and go in. So what you need to figure out is how to get the bulb in the way." Then he encouraged people to reflect on their different approaches to circuitry by asking various people to come up and draw their light bulb connections on the board. The following drawings were created by educators from around the room:
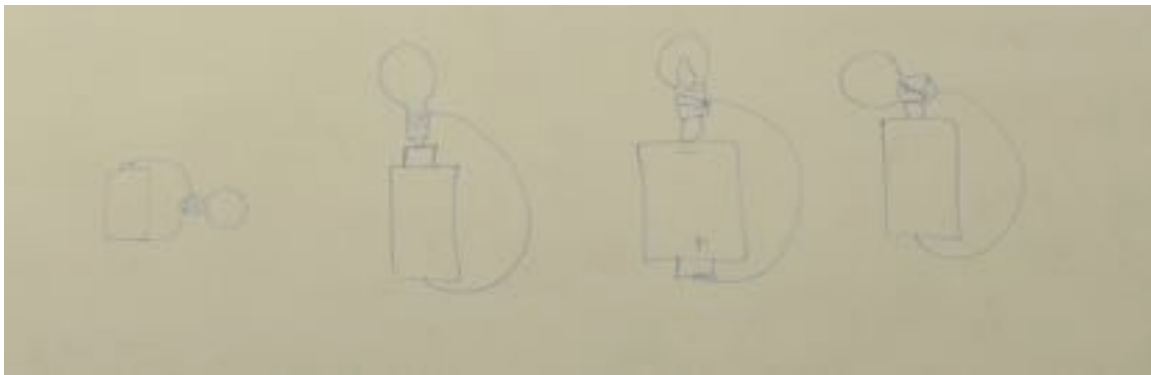
Teachers' drawings of their different approaches to lighting a bulb.

As people drew, emphasis was placed on how people could create circuits in a multitude of different ways—there
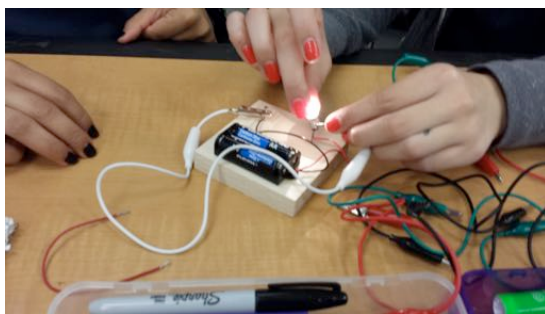
Educators experiencing Making activities.

was no single perfect way. Paul recognized that Making should allow for multiple ways of knowing and thinking, not singular solutions. Paul also emphasized that, "instead of giving students the information ahead of time, what I like to have them do is to kinda go through the exploration process and kinda see what's working. And if I have journals, I'll have them draw out the steps. Not just what worked but what didn't. So as they try something, draw a little picture and then write an explanation 'did not work.' And then what that helps them do is gets them in the habit of documenting things, but also it helps them remember 'okay, well we're going to try this, but look we did this here, and it didn't work, or we did this here." In this way,
Paul emphasized the importance of supporting reflection with this tinkering activity that could help students understand how the circuits work.

Then, keeping his hands off of Fontana After School Program educators' materials as they tried to create a circuit during his workshop, Paul asked, "How are we doing?" The two women were struggling to get their light bulb to light. Paul referenced the pictures drawn by their peers on the front board and pointed out the positive and negative charges where one end of the bulb was touching a positive and the other end was touching the wire. A woman at the table said, "So one end was touching [the battery]…" and Paul noted (without touching their set up), "so the other end has to touch the other end – but what do we do with that wire?" The women considered this question and then rearranged their set up to make the bulb light as shown in the photo above.

Importantly, Paul's hints and ways of supporting reflection in order to emphasize multiple pathways toward solving problems were taken up by FASP educators as exemplified in the vignettes of Katie above. Katie took on these pedagogical practices in her own afterschool programming, which resulted in students working through challenging moments and pursuing 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 among STEM educators. These professional development workshops provided educators with the opportunity to physically tinker, offering them a way to understand the experiences of their youth. This model proved effective for sharing pedagogical practices such as allowing Making projects to be student-driven, connecting new learning to ideas and experiences students already know, or giving youth the space to tinker by keeping hands off and asking supportive questions. Furthermore, FASP educators' implementation of activities reflected many of the pedagogical strategies shared by Paul in his workshops as they leveraged students' knowledge as assets and actively supported youth without taking over their projects.