Advances in Engineering Education

FALL 2019

# A Mobile Workshop Model for Equitable Making with High School Aged Youth

LEE MARTIN
University of California, Davis

AND

COLIN DIXON
Concord Consortium
Emeryville, CA

## ABSTRACT

There is growing interest in the engineering education community in *making* and the Maker Movement as a context for young people to learn and develop interest around design and early engineering competencies. Although some researchers argue that making has the potential to serve a liberating and anti-oppressive function in education, there are deep and abiding concerns that making as it exists today is not serving the goals of equity, but is in fact reproducing patterns of inequality in access and participation. In this paper, we consider an educational innovation we designed to create a more equitable maker learning experience for high school aged youth. We designed our innovation around a core pedagogical commitment to meeting youth “where they are”. We mean this in three senses: First, we mean this literally/geographically, as youth need physical access to resources to learn. We addressed this goal by creating a mobile makerspace. Second, we mean this cognitively, as new knowledge must be built on existing knowledge. We addressed this goal by creating flexible project structures with “just-in-time” teaching. Third, we mean this affectively, so that we meet students as *who* they are. We addressed this goal primarily by giving youth the freedom to make choices about their project work, in what they worked on, in how they wanted it to look, and in who their audience or client for the work would be. The paper describes the design of the mobile workshop and the pedagogical approach and offers two cases of educational programs implementing these models, one from an out-of-school context and one from an in-school context.

**Keywords:** Design; Project based learning; High school

## INTRODUCTION

There is growing interest in the engineering education community in *making* and the Maker Movement as a context for young people to learn and develop interest around design and early engineering competencies. Making can be defined as “a class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented toward making a ‘product’ of some sort that can be used, interacted with, or demonstrated” (Martin, 2015, p. 31). The idea that making is a germane activity for learning connects to claims by Papert (1993) that students learn best when they are able to build and share physical creations. Blikstein (2008) extends this idea to suggest that making provides young people with powerful tools of production for realizing their ideas. Others have argued that making has the potential to foster creativity and innovation while broadening access to and participation in STEM fields (Vossoughi & Bevan, 2014).

Excitement for making in education spans a variety of contexts. In K12 education, Quinn and Bell (2013) argue that making is well-aligned with the new Next Generation Science Standards, which introduce national engineering standards to K12 contexts for the first time (Carr, Bennett, & Strobel, 2012). In museums, making is associated with engagement, intentionality, innovation, and solidarity (Bevan, Gutwill, Petrich, & Wilkinson, 2015). In community contexts, maker spaces can be contexts for the development of resourcefulness and connectedness to the community (Sheridan & Konopasky, 2016), as well as the development of adaptive expertise in design (Martin & Dixon, 2016). In universities, makerspaces are being designed to give engineering students opportunities to invent, design, and build early in their educational careers, rather than waiting years for a capstone project (Forest et al., 2014). The Obama administration championed the Maker Movement as an agent of change both for K12 education and for the national economy (Kalil, 2013).

In this paper, we describe our efforts to support making among high school aged youth as a pathway to greater access to, and expertise within, engineering and design. Our goal was to create a highly flexible learning environment that was responsive to students’ interests, ideas, and needs. Specifically, we investigated the extent to which our educational efforts supported youth learning across three critical areas: design work (what evidence was there for the learning of specific design skills), identity development (evidence for shifts in identity toward engineering and STEM), and equity of outcomes (were all students able to participate fully).

We begin by articulating our conceptual framework for how we think about equitable maker pedagogy and how these manifest as high-level pedagogical principles. We then turn to more concrete information. First, we discuss the physical infrastructure that supports our work: a mobile maker space that we designed and built. Next, we discuss two learning environments we created to work with young people. For each, we highlight a qualitative case of a student or pair of students and the project they worked on. We then offer a summary qualitative evaluation of the overall effectiveness of these educational interventions.

## CONCEPTUAL FRAMEWORK FOR EQUITABLE MAKER PEDAGOGY

Despite some enthusiasm for the idea making can empower all children (Dougherty, 2013), there are abiding concerns that making as it exists today is not serving the goals of equity, but is in fact reproducing patterns of inequality in access and participation. For example, Buechley (2013) reviewed depictions of makers and maker projects in the popular maker magazine *Make* and found that 85% of covers featured white men and boys, and that most featured traditionally gendered projects of vehicles and robots. Brahms and Crowley (2016) found that 89% of authors of Make magazine articles in their sample were men, and only 2% of articles were written by a woman in a STEM field. Chachra (2015) makes the case that the veneration of making products, over and about non-maker activities like caring for others, is rooted in sexist ideologies. Vossoughi, Hooper, and Escudé (2016) argue that, in the face of these corporate, normative, and ultimately discriminatory practices, educators interested in making cannot accept the status quo, but must explicitly engage in equity-oriented design.

Our efforts to design an effective and equitable learning environment are informed by a core pedagogical commitment to meeting youth "where they are". We mean this in three senses, which we summarize in Table 1 and describe in greater detail below.

### Literal / Geographical

The first sense is literal or geographical. Although we know of no systematic review of "digital divide" issues in access to makerspaces (cf. Gonzales, 2016), in our own region many youth have

***Table 1. Our Pedagogical Principles.***

| Pedagogical Principle | Rationale | Implementation |
|---|---|---|
| Meet students where they are (geographically) | Youth need physical access to resources to learn | Mobile maker space |
| Meet students where they are (cognitively) | Constructivism: new knowledge is always built from existing knowledge | Collaborate with youth to unearth existing interests, practices, and competencies. Support youth in choosing projects. Allow for shifts over time, and offer just-in-time support. |
| Meet students as *who* they are (identity) | Identity development often precedes cognitive development | Support youth autonomy. Allow youth to be themselves and begin with existing interests and practices. |

limited or no access to digital fabrication tools characteristic of the maker movement. We wanted to be able to set up a workshop in the schools and/or community centers where students are already working. We addressed this goal by creating a mobile makerspace, which we describe in greater detail below. We note that mobility comes at a cost – a mobile workshop will never be as big or as well-equipped as a stationary workshop – but it offers flexibility in arranging the space to meet the needs and capabilities of the local learning environment.

**Cognitive**

The second sense in which we want our learning environment to "meet students where they are" is cognitive, in their knowledge and skills. This sense aligns with the core tenant of constructivism – all learning builds from existing knowledge, and as such, effective learning environments take students' existing knowledge as the starting point (Bransford, Brown, & Cocking, 1999; Piaget, 1950). It also fits with a core commitment of the maker movement, that making is about figuring out "what you can do with what you know" (Dougherty, 2013, p. 9). Concretely, we addressed this goal by combining an emphasis on student autonomy with "just-in-time" teaching. Rather than using a set of fixed projects, we allowed students choice in what they worked on and, most important, flexibility to change their project goals and processes as time passed. By building these "degrees of freedom" into expectations for the experience, we allowed youth to move up and down levels up complexity and technical sophistication in their project work in order to arrive at work that was situated at an appropriate level of difficulty in their zone of proximal development (Vygotsky, 1978).

We also believe that this commitment aligns with an asset-based approach to education. Such an approach emphasizes the assets – such as knowledge, skills, and community resources – that students bring with them, rather than hunting for deficits. Because making can involve unfamiliar and expensive tools, some views of maker education can invite a flawed narrative that low income and working class communities need educators to bring them the creative practices of making. On the contrary, Schwartz and Gutierrez (2015, p. 577) argue that "inventing, making, tinkering, [and] designing are indigenous practices" within low income and working class communities. Rather than asking how we can bring making to these communities, an asset-based view urges us to expand our understanding of engineering and design to leverage existing competencies within communities (Blikstein, 2013).

**Identity**

Finally, we want to meet students as *who* they are. This commitment is well-aligned with a cognitive asset view, but focuses more on the cultural and identity relevant assets that students bring with them. We follow Gutiérrez and Rogoff (2003) and their discussion of *repertoires of practice*, which they define as "the ways of engaging in activities stemming from observing and otherwise participating in cultural practices" (p. 22). Rather than taking the practices of the dominant group as normative, and viewing any deviation from that as deficient, a *repertoires of practice* perspective notes that all people are skilled in the cultural practices they have experienced, and coming to know and understand these practices allows educators to build from students' strengths as learners. This view also aligns with a *funds of knowledge* approach, which looks to the vast but often overlooked resources of knowledge and skill that exist in all communities (Moll, Amanti, Neff, & Gonzalez, 1992), as well as Ladson-Billings' (1992) *culturally relevant pedagogy* perspective, where teachers engage in the "kind of teaching that is designed not merely to fit the school culture to the students' culture but also to use student culture as the basis for helping students understand themselves and others, structure interactions, and conceptualize knowledge" (p. 314).

We see affective needs and issues of identity as primary to participation and learning (Tonso, 2014). Indeed, a broad body of research on learning in informal environments shows that students' development in out-of-school contexts almost always begins with interest and identification prior to development of rich knowledge and skill (for a review, see National Research Council, 2009). Vossoughi et al. (2016) argue that this is an epistemological shift: rather than taking engineering as primary, and asking how we can get students interested in that field, we can instead take their existing interests and identities as epistemologically primary. Then we ask, how does engineering fit into existing interests and ways of knowing and doing?

We addressed this goal primarily by giving youth the freedom to make choices about their project work, in what they worked on, in how they wanted it to look, and in who their audience or client for the work would be. We also have found that a spirit of playful lightheartedness can also encourage youth to feel comfortable being themselves in the maker space. But we note that building from students' interests and expertise is non-trivial: classrooms are not always safe places for identity work (Aikenhead, 1996; Calabrese Barton, 2003), and progress can require substantial iteration over time (Martin, Dixon, & Betser, 2018).

## DESIGN OF THE MOBILE MAKER SPACE

Our goal was to support making of physical things, and thus making for us was inextricably caught up in the need for appropriate tools and materials. In meetings on maker education, we have often heard educators asking about how to obtain funding and which tools are the most important. We hear two common responses. One is advice on fundraising, which often directs educators to interested corporate sponsors. For schools and community institutions with the cultural capital necessary to write and obtain grants, this can be a highly effective route, but for others it can seem out of reach.

The second response is that high tech tools and expensive materials are not necessary for making, and that the mindset behind making is much more important. Indeed, some of the most highly respected work in maker education focuses on the creative use of low cost, every-day, and even reclaimed materials (Bevan et al., 2015). Although there is value is emphasizing what can be done with low cost and easily available materials, we believe that deemphasizing the importance of tools and materials is only a partial answer. Depending on the context, the opportunity to gain skills and knowledge of tools, particularly the digital tools that are commonplace in and characteristic of the maker movement, can be a valuable attraction and a valued outcome, one that should not be limited to children from higher income areas. Another partial solution is to focus exclusively on one digital toolset, such as 3D printing, in order to keep costs down. Again, this can have value, but it limits the ability of a space to function as an all-purpose workshop, where technologies, old and new, can be creatively recombined in pursuit of novel projects. Such combinations are a hallmark of many maker projects, such as those that combine sewing with electronics, or traditional woodworking with 3D design techniques. It is also a reason that many makerspaces aim, in the model of Gershenfeld's (2008) foundational vision, to provide a complete set of tools for building "almost anything".

Furthermore, given the limitations of cost, it is at present difficult to imagine a model where every school has its own dedicated makerspace. This creates the problem of where to place makerspaces, as any choice involves tradeoffs in who will be best served by the space, with important equity implications.

We addressed the issues of cost and location by creating a mobile workshop. Our efforts were conducted in the context of an NSF CAREER award to the first author focused on studying the maker movement as a context for the development of adaptive expertise in engineering and design – the ability to flexibly solve novel problems that arise in project work, and to learn new things as needed (Hatano & Ouro, 2003). Additional support came from a grant from Intel. An explicit goal of the project is to broaden participation in making and the maker movement, and as such it was critical to serve diverse students. The best way to do this, we believed, was to be able to bring tools, materials, and activities to the local contexts where the young people we hoped to serve already lived and studied. From this basic need, from conversations with many advisors, and from our core pedagogical commitments, we decided to build a mobile maker space.

Because the use of a mobile maker space was central to our educational efforts, we describe it in some detail here. Our goal was to create a space that would support young people in creating maker projects of their own choosing. We wanted our space to be as open-ended as possible, in the model of a workshop or makerspace. This goal was itself a significant design constraint.

### Vehicle

We found a used vehicle that was available within our organization – a Dodge Sprinter with extended bed and high ceiling (see Figure 1). It came to us equipped with an E-track anchoring system


***Figure 1. The mobile maker space.***

along the walls, which we opportunistically designed around. It also has a powered lift gate, which has been useful for moving heavy equipment in and out of the van.

**Carts under Workbenches**

A mobile space can go one of two directions. One model is to build a *workshop on wheels*, where the main use case is people working inside the vehicle. This approach allows for the workshop to be self-contained. It requires a larger vehicle, and limits the number of people who can work in the space to just a handful. Power, light, and ventilation are important factors as well. A second model is to use the vehicle solely as a *means of transport* for tools and materials that will be used in a different, existing workspace. A smaller vehicle is possible, as equipment can be packed tightly, with no need for space inside for people to work. Equipment and materials must be packed in ways that are easy to transport in and out.

We chose to work toward both of these goals, optimizing neither, but compromising on a hybrid model – a functioning workshop on wheels that could easily be deployed into a larger space (Figure 2 shows a partial view of the space).

To help us to split the difference between these goals, we devised a cart-under-bench system. Tools and materials are organized thematically on carts (see below). Each cart fits underneath a workbench inside the mobile workspace (see Figure 3). Our carts have some fixed shelves and some sliding shelves, to increase accessibility of bins while in the van (see Figure 4).

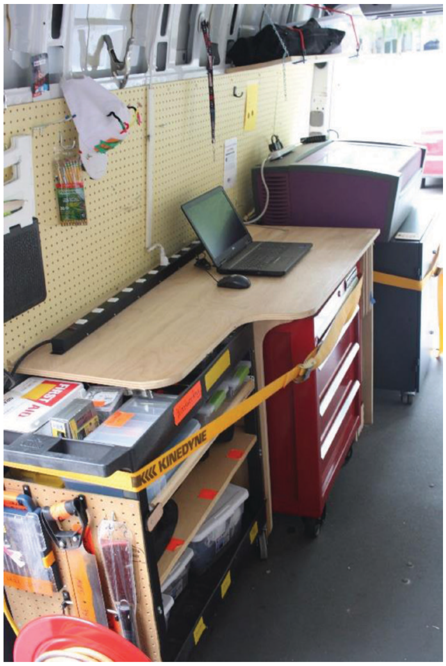


*Figure 2. The interior of the mobile maker space.*


*Figure 3. Carts fit under workbenches.*

*Figure 4. Some shelves slide forward to ease access while in the van. Slides can be locked during transport.*

**Tool Sets**

Tools and materials are stored in bins whenever possible. Bins and larger items are labeled and color coded, so that they can be returned to the appropriate cart (and the appropriate spot on that cart). This system is still a work in progress.

Figure 5 gives a top-down view of the workshop space. We have nine groupings of tools, which we outline in Table 2. We selected these through a series of compromises: between supporting a variety of ways of making and limited space; between high tech and low tech making; between traditionally

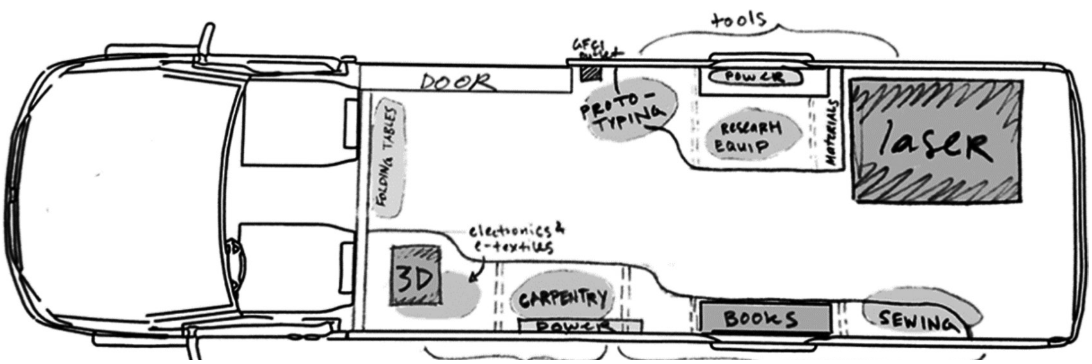


*Figure 5. Top-down view of workshop.*

*Table 2. List of tools by category.*

| Sewing ~$800 | Electronics ~$600 | Woodworking ~$600 |
|---|---|---|
| Sewing machines<br>Iron<br>Ironing board<br>Bin with various types and colors of thread<br>Compartment bin with buttons, pins, needs, seam rippers, etc. | Arduino<br>Breadboard supplies<br>Basic sensors and motors<br>Wire, resistors, LEDs, etc.<br>Multimeter<br>Soldering equipment: iron, fume extractor, solder, hands free stands, etc.<br>E-textiles supplies | Power drill<br>Powered jigsaw<br>Hand saws<br>Assorted fasteners<br>Clamps<br>Hacksaw<br>Hammer<br>Assorted screwdrivers<br>Assorted pliers |
| **Safety ~$500** | **Prototyping ~$150** | **Measurement ~$500** |
| Safety glasses<br>Work gloves<br>Nitrile gloves<br>Dust masks<br>First aid kit<br>Hair bands<br>Fire extinguisher | Paper<br>Markers<br>Pens and pencils<br>Popsicle sticks and straws<br>Post it notes<br>Hot glue guns<br>Other glue<br>Wire and pipe cleaners<br>Assorted tape | Digital calipers<br>Digital hanging scale<br>Rulers<br>Tape measures<br>Carpentry squares<br>Compass<br>Cameras |
| **3D Printing ~$2,200** | **Laser Cutter ~$12,000** | **Other ~$6000** |
| 3D Printer<br>Calibration tools<br>Extra filament | Laser cutter<br>Cleaning tools<br>Sample materials | Laptops<br>Reference books |

male and female toolsets; between safety and power; between assembly tools and thinking tools; and between depth and breadth within toolsets. We do not see these toolsets as final or definitive, but rather as a tested and workable "draft" worth sharing with others. We also designed the space to look "homemade" and approachable, with simple carpentry and off-the-shelf components throughout. Partly, this looks was born of the necessity of a limited budget, but it also fits with our desire to model approachable design within the reach of the high school aged youth we work with. In service of transparency, we offer an approximate budget for our workshop space in Table 2. Most of the initial expenses were incurred in 2015, so prices reflect 2015 dollars. In addition to the toolsets listed below, we spent about $1,500 on carts, lighting and electrical, and lumber for workbenches.

## TWO EDUCATIONAL ENDEAVORS

In order to illustrate how our approach works in practice, we now describe two instances of our work with youth. We note that, because our goal was to create flexible learning environments that were responsive to students' knowledge, interests, and identities, it would be a mistake to take these examples as rigid models of how to perform maker pedagogy. These accounts are somewhat sparse, both because of constraints of space and because of our desire to focus on higher-level principles, rather than site-specific details, but we hope they give a sense of the spirit of our work and the efficacy of our approach. We describe each program, the participants, and the activities, and then describe a particular project to give a better sense of the nature of the work. Interested readers can see Martin et al. (2018) for more information on our in-school program as an example of design research, along with more detail on how our approach evolved over time than is possible to provide here. For each program, we offer a brief qualitative evaluation of our efforts.

**An Out-of-School Summer Program Focused on Making and Citizen Science**

We partnered with an organization dedicated to conducting *citizen science* (Shirk et al., 2012) with youth from underserved communities in Oakland. The youth were involved in a month-long project to use experimental air quality monitoring equipment to assess and report on particulate matter levels in their neighborhood and in the local transit system. Participants were 7 youth, ages 14–17 – 5 girls and 2 boys; 4 Black, 2 Asian, 1 Latino – and an adult instructor and two university undergraduate mentors. Sessions were held once a week in the afternoon (approximately 12:30–4:00), for four weeks.

We contributed to this collaborative project by teaching digital design, basic programming, and electronics. We also coached youth participants in thinking about how to effectively advocate for change within their communities. Youth began by thinking about the air quality data they had collected, why the data were important, and who they wanted to share their data with. Across a series of these goal setting exercises, they prototyped, built, and tested one design.

**Pedagogy and Activities**

Students worked in small groups with the goal of creating a device that could display real-time air quality data. Students were working toward a common goal, but their devices varied substantially. We provided a range of materials to the group, allowing final products to vary widely, from a heart shaped pillow, to a “smog detector” box made of clear acrylic, to Aafiya’s wooden tree bookmark, described in more detail below. We explicitly invited youth to take up a design goal of “making the invisible visible,” which included not only what they were learning about the air, but also included expressing aspects of themselves that people might not see or know. Here we made a connection to the *identity* sense of meeting students where they are.

We worked to integrate technical skill development with students’ interests and identities. For example, as a beginning design exercise, we asked students to name a place they spent time and a characteristic that others did not know about it, then to design a small laser-cut object to express this. We also used short group exercises, individual reflection, and one-on-one support to help youth think about what kinds of styles and materials that they personally cared about and that would be familiar to the audiences they were trying to reach. In this way, student work came to reflect not only personal interests, but particular communities they wanted to connect with more deeply. This practice reflected our view of identity as socially situated and connected across contexts.

Like much citizen science work, the project with which we partnered was place-specific, involving investigation of sites familiar to the students. Here we saw a connection to the *literal/geographic* sense of meeting students where they were. Although the group met during the summer and had some flexibility to use the public transit system, they functioned on a small budget and did not have the ability to travel to a makerspace. These constraints made it important to bring fabrication and design equipment to the location where the students and the purpose of their work was based.

The group's activities were housed in the offices of a small environmental justice non-profit. For the workshops, we used the rolling carts to bring electronics and prototyping equipment into the organization's meeting room, but kept the laser cutter in the van. This flexibility meant that the students could remain connected to a space and to mentors that were already familiar, but still work with novel technologies like the laser cutter that the space could not accommodate.

To structure work in the program, we organized youth into small groups of two or three. This allowed students to focus on parts of the process according to interest and prior experience. Here, we were explicitly hoping to connect to the *cognitive* sense of meeting students where they are, allowing students to begin from their existing areas of knowledge and skill. Some students, for example, focused on programming and electronics, while others focused on concepts and design. We did not assign roles, but encouraged youth to take the lead in areas where they felt comfortable, to learn from their partners, and to take risks together when encountering tools or concepts novel to everyone. Accepting different roles and starting points for the projects also meant accepting different end points, not only in terms of aesthetics and design, but also in terms of level of sophistication and stage of production.

Although we had to introduce new technologies and concepts on a tight timeline, we minimized formal instruction, choosing instead to let the needs of each project drive what needed to be learned. We planned for just-in-time teaching of technical skills, but soon found that we also needed to provide just-in-time teaching for social processes, such as identifying interests and audiences, talking through profiles of potential users and goals for communication, and critique. We went back and forth between individual work that gave participants time to think personally about their own experiences and priorities, and group discussion in which youth and facilitators could build on ideas or reframe questions and tasks.

In this process, we worked to ensure that many forms of knowledge and practice were valued, emphasizing that effectiveness of the devices being created hinged not only on whether they functioned technically, but also on whether designs drew on knowledge of community and scientific matter, on creativity with design, and on carefulness of craft. By scaffolding the design of objects, we facilitated a bridge between scientific, quantitative reasoning and more social, expressive work. These objects made concrete the students' growing, but often tacit, knowledge of what the air quality numbers mean and why they were important. By creating this link, we began with issues the youth were already learning – and already concerned about – and demonstrated multiple forms and purposes for STEM tools and practices.

## CASE: AAFIYA'S BOOKMARK

To ground our discussion of this learning environment, we offer a brief qualitative case. Aafiya, a young Black woman heading into 10th grade, was an avid reader. She liked to read on the train and knew from the group's research that air quality was particularly bad within the local public transit system. She decided that one way to reach an audience would be to make a large bookmark that would display real-time air quality information. She could use it when riding and reading on a train and, in doing so, inform fellow riders. She began by identifying, though brainstorming and reflection, a community she was a part of that could be an audience for her project: young readers and transit riders. She then used guided questions and peer feedback to analyze and design the appearance of her project to be appealing to her audience. She first chose an image of the city's lake and skyline, but changed in her second prototype to Oakland's popular oak tree icon. Using a paper prototype as a base, she designed and tested a circuit for the indicator lights. Simultaneously, she created a digital file and laser-cut a wood prototype, which she used to solicit peer feedback. These steps were technically sophisticated, requiring Aafiya to learn vector-based design software, programming of Arduino microprocessors, and construction of basic circuits.

Aafiya refined both prototypes (paper and digital) before combining them into a single design. Working with undergraduate mentors, she integrated a microprocessor into the circuit that accepted input from the air quality sensor and translated it to the indicator lights she had designed: green for good, yellow for medium, and red for poor quality air. Finally, she tested it on the transit system. Figure 6 shows Aafiya's completed project.

Despite Aafiya's success, the program did face challenges. The fast timeline meant that not all students were able to finish prototypes and surface interests and design that motivated them. Although the air quality equipment on which data visualization was based was open-source and relatively low cost for scientific equipment, it was still too expensive to allow each student to keep a complete device (they were able to keep their physical prototypes). This limitation meant that youth were unable to continue work beyond the program time and space.

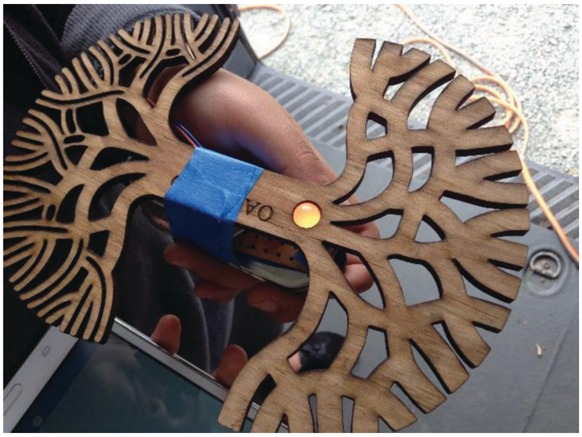

***Figure 6. Aafiya's bookmark: a device that could be used by people riding on a train to display air quality data.***

**Evaluation**

For each program, we conducted qualitative evaluation to assess the success in three critical areas: design work (what evidence was there for the learning of specific design skills), identity development (evidence for shifts in identity toward engineering and STEM), and equity of outcomes (were all students able to participate fully). We documented learner processes and products through video, field notes, and short interviews conducted at the end of work sessions. Given the open-ended nature of the activities, we hesitated to use pre-defined benchmarks against which to measure learner success, choosing instead to analyze for and report out what we saw students accomplish in their work with the mobile lab and where we saw gaps in our support.

***Design skills***

Youth developed some competence in vector-based digital design, learned the first steps of basic computer programming (learning about basic structures, loops, and syntax through Arduino's programming language), learned to construct simple circuits integrated with a microprocessor, and had the chance to build with the laser cutter. All of these experiences were new to the students, barring two students who had some experience with programming.

***Identity development***

We saw many places where the open-ended, student-driven nature of the program allowed students to connect their personal identities with project work. Being able to design backpack charms, bookmarks, and pillows, and to integrate meaningful symbols – Warriors logo, leaves, hearts, Oakland skyline, Oakland logo – seemed to invite the whole person into the group's activities in ways that scientific work in the classroom often does not. Artifacts produced in training sessions also meant that students could share their experiences – with science and design – with friends and family. Students often used social media (Instagram and Snapchat) to share pictures of the laser cutter and their projects, and a number of students produced small projects for family members.

#### ***Equity of outcomes***

In this program, students with no or very little experience with digital fabrication technologies were able to use them expressively to meaningful ends. Students leveraged new skills in service of community purposes. One indicator of success was the emergence of Aafiya as a leader in the group's activities. With her bookmark prototype a standout in the group, Aafiya was able to take on a technical and public role in the group. After the program, at least three students took advantage of the opportunity to continue their work with partner organizations.

## AN IN-SCHOOL MAKER WORKSHOP

For this program, we partnered with a public charter school to offer a 9 week maker program for interested youth, who took a class for elective credit. The school has a distinctive model where students typically spend two days per week off-site at a school-sponsored internship in the local community. For the duration of the study, students spent one day per week with us, in lieu of one of their two regular internship days. Each session lasted from 10am to 2pm, and there were nine sessions spread across nine weeks at the school. In addition, we arranged for interested students to travel to and present their completed projects at Maker Faire Bay Area, a large exposition of maker-oriented projects in the San Francisco Bay Area.

Fifteen youth participated: 7 girls, 7 boys, and 1 genderfluid individual, 5 were Black, 3 were Latino/a, 3 were White, and 4 were multiracial.

### Pedagogy and Activities

During week 1, we worked to build rapport with students and help them feel comfortable in the space by leading them through a small, initial project: making a small wooden box or a fabric bag. Beginning in week 2, we gave students the design goal of designing and making a project of their choice. As noted above, our decision to grant students autonomy over project choice was grounded in the desire to let them build from their existing areas of expertise, meeting them where they are *cognitively*, as well as their interests and aesthetics, connecting to their existing and hoped for *identities*.

We led students through brainstorming and other ideation activities, along with internet research, to generate candidate project ideas, then aided them in a process of group formation around project ideas. Projects included an illuminated, laser-etched photo; a 3D printed and LED illuminated superhero prop; a laser-cut music box; and a robot nightlight, described in more detail below. From week 3 onward, the primary activity was open workshop time. This open time was supported by several activities designed to support our pedagogical goals.

To support students' learning of tools, skills, and design techniques, we provided just-in-time instruction on topics as needed, such how to use a drill or vector design software. Because our goals for students' project outcomes were flexible, we were able to begin with our educated hunches around what students knew and were able to do, and adjust flexibly and responsively to the needs of students. When we saw a number of students interested in a topic, such as using LEDs or 3D printing, we offered mini-workshops to give students experience and confidence in those toolsets. These ideational and technical supports continued, but faded, over the following weeks to give students time and space to develop their project work. We also allowed students to choose and modify their project goals as they moved along. This flexibility allowed students to scale the complexity of work up or down as needed, for example, as they discovered the challenges of building from wood or discovered an interest in working LEDs. We believe that this helped us, as mentors and teachers, to keep students within the *zone of proximal development* (Vygotsky, 1978), where learning is neither too easy nor too hard.

We also engaged in activities to support identity development. First, as noted above, we gave students substantial choice over the topics and details of their projects, inviting them to make the projects personally meaningful. Ideation activities prompted them to think of the communities they cared about and how their designs could work within those communities. Second, we strived to soften the hierarchical divides between us – researchers from the university who had ownership over equipment and activities – and the students. We did so through several avenues: we participated fully in warm-up activities like "circle time" where we shared how we were feeling, our goals for the day, and so forth, and we worked on our own maker projects alongside students, asking for their input on design decisions and allowing them to see us make mistakes and show our own uncertainly.

Finally, we note that use of a mobile maker space allowed us to partner with a high school that served a diverse population of students and that did not otherwise have access to the maker tools that we were able to provide. Moreover, our cart model allowed us to deploy our workshop into a multipurpose room in the school. This approach allowed students to begin their work in a familiar space and eliminated transportation needs for students and their families. Here we see the connection to the *literal/geographical* sense of meeting students where they are.

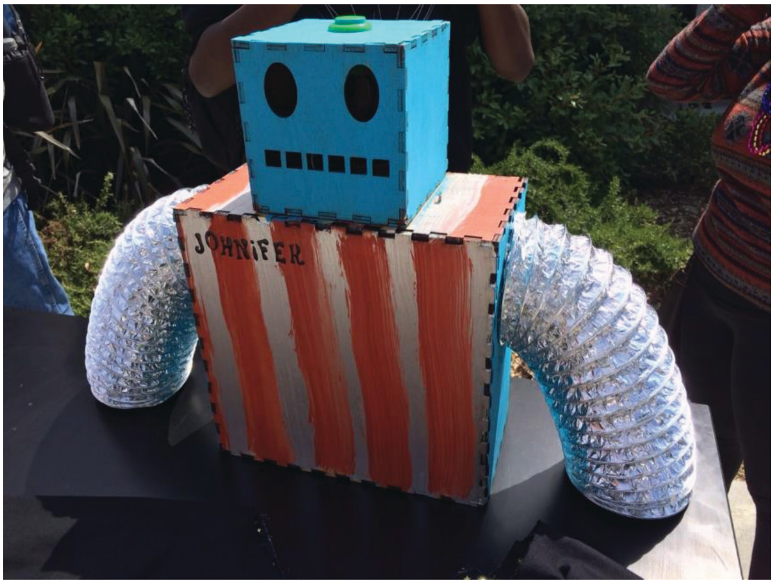


***Figure 7. The robot Johnifer, as it existed at the end of project time.***

**CASE: A ROBOT NIGHTLIGHT**

To ground our discussion of this learning environment, we offer a second brief qualitative case. Here, we consider Marquise and Cyrus, two African American ninth grade boys. They were close friends, and their initial project idea was to create a flying robot that could shoot marshmallows. This plan was scaled back in a variety of ways as they changed their sense of the difficulty of the task and their priorities. The final project was a robot-like body made primarily of wood, with a head that would light up when a button was pressed (see Figure 7). After completing the maker class, Marquise independently painted the robot and painted his preferred nickname for the robot, Johnifer (a combination of Johnathan and Christopher, he told us) on its chest.

At the end of the course, we interviewed students and asked if the maker class had changed their sense of what they are capable of. Marquise answered as follows:

> *"Yeah, for sure. Cause, like, I wouldn't have really thought that I could make stuff like this, I for surely didn't think I was going to make a robot. I thought I was going to make like maybe a box with some cool, like a chest or something you could put something in, like nothing, nothing really cool or [where] buttons work and stuff like that. But once I found I can, you know, that really changes the things I can do. So now I know I can learn, more, easily, or, not easily but, you know. Like I can learn more stuff, in, time."*

Although we do not want to overgeneralize, we note with interest that he claimed that the learning experience showed him that he can learn, not easily, but "more stuff … in time." We take that to mean that he gained not only particular competencies in making things, but also a sense of the efficacy of effort toward learning in this space, toward the goal of making things.

We also asked Cyrus if the maker class experience changed his sense of what he was capable of. He replied, "Well, usually I honestly don't-. Every time I make something I mess up, I'll be like, 'Alright, I'm never doing this again.' Like I try it, I mess up, and you know what, forget it, I quit. But like I just learned to just stick with something all the way through, try a little harder. It shows result[s]."

Cyrus's claim here is that the experience helped to develop persistence, broadly. He elaborated on this by giving an example from school, where he persisted on a difficult presentation assignment that normally would have prompted to quit:

> *"I was doing it, I kept getting stuck, you know. So I just took a break really fast because my brain was fried from irritation and stress. And you know, I finished it, and I'm glad I did, and at first I was like, 'Look, dude [to his partner], you're going to have to do it.' But you know, I actually managed to pull through on that because I hate doing bibliographies. So it was just like kind of a skill I picked up during the program."*

Again, we are cautious of overgeneralizing, but it is striking that Cyrus identified a global change in his ability to persist through difficulty, and that he attributed it to his experience in the maker class.

**Evaluation**

During last session at the school, but prior to exhibiting their projects, we gave students a brief, three question interview about their experience and their learning, as shown in Table 3. The numbers

***Table 3. Frequencies of response to the question, "After working in Maker Club, how have the following changed for you?" for each category.***

| | Decreased a lot | Decreased a little | Stayed about the same | Increased a little | Increased a lot |
|---|---|---|---|---|---|
| Your interest in designing and making things | 0 | 0 | 0 | 9 | 5 |
| Confidence in your ability to design and make things | 0 | 0 | 1 | 2 | 11 |
| Your knowledge of how to design and make things | 0 | 0 | 0 | 2 | 12 |

in the cells show the frequency of response in each of the categories across the fourteen students who completed the survey (one student was absent).

As the pattern of results in the table shows, students reported that they gained in interest, and to a greater extent, confidence and knowledge in making things. We see these data as an indication that students felt that the maker class was a positive experience, that they learned from it, and that they left more capable than when they began.

***Design skills***

Students developed a variety of high-tech and low tech skills. They learned to measure, to sketch, to create 2D and 3D digital designs, to work with a laser cutter and 3D printer, to create a simple computer program, to sew, and to create simple circuits, to name just a few. No one student developed all of these skills, and some students certainly learned more than others, but every student did develop new skills, and the range of skills seen across the whole group was impressive. In addition, several students mentioned in their interview that they learned to work collaboratively with others in ways they had not done before.

We see this skill development as a straightforward but notable achievement in this space. Not only did students engage in learning these skills, they were able to apply them to project work in meaningful ways. Every group developed a completed project or working prototype of some sort, and several students presented their work at an in-school exhibition or at Maker Faire in the San Francisco Bay Area.

***Identity development***

In interviews, many students reported a changed sense of their capabilities for designing and making, as seen in Marquise and Cyrus's stories. Many students described their accomplishments paradoxically: in one sense, they did not get as far as they had initially hoped, because making things was harder than they realized, but in another sense, they made more progress than expected, because they had not realized what they were capable of as makers. We take these findings as evidence that students grew in their sense of themselves as learners capable of engaging in design, learning new skills, and making things.

***Equity of outcomes***

As in the out-of-school program, students with little or no prior experience with these toolsets were able to use them to create personally meaningful projects. Students were able to work collaboratively to develop project ideas, refine them over several weeks, build and test prototypes, and create completed projects that they found satisfying. Most had little experience with these kinds of activities, yet the pedagogical context invited them to engage across a wide range of topical interests and experience levels.

## DISCUSSION AND CONCLUSION

In this paper, we present our efforts to create an equity-oriented maker experience for young people. Our approach is built upon our pedagogical commitment to meet youth where they are geographically, cognitively, and in terms of their identities. These commitments allowed us to support learning that begins with existing knowledge, interests, curiosities, and capabilities, and moves toward the exploration and development of these learning dimensions. We built a mobile makerspace as a flexible means to help us achieve our pedagogical ends. The two educational endeavors we report here offer a proof of concept for the efficacy of this approach for supporting student development and learning.

The primary contribution of this work is a sociotechnical model for bringing equity-oriented maker activities to diverse youth. The infrastructure and the pedagogy go hand in hand, as a mobile and flexible space allows for pedagogy that adapts to student needs. We described our mobile space in some detail, as it was a site of much learning for our team. We believe that mobile spaces are particularly well-suited to organizations, like libraries, community organizations, K12 school districts, and community college districts, that serve multiple sites, and who are unable or hesitant to provide the funding and space to create a full, permanent workshop space at every site they serve. However, the mobility of the space is secondary to the need for high quality pedagogy that puts students, holistically conceived, at the center of their own learning trajectories. We present the plans and principles here not as a rigid prescription, but as considerations for educators bringing making, mobile or not, to young people of any age, gender, race, or background.

## ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. EEC-1351605. Additional support was provided by a grant from the Intel Corporation. We would also like to thank Sagit Betser, Lenora Bruce, Damian Chapman, Christopher Chu, Kevin Cuff, Sherry Hsi, Aditya Johri, Rianna Keegan, Eugene Korsunskiy, Katie Krummeck, Ruby Sandoval, and Vince Wolfe.

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## AUTHORS

**Lee Martin** is an associate professor in the School of Education at the University of California, Davis. His research looks across in-school and out-of-school settings to investigate the varied ways that people assemble social, material, and intellectual resources to help them to meet their goals. He studies participation in making and the maker movement as activities that may help youth become more flexible and adaptive in their thinking and problem solving. In addition, he examines processes of identity development and sense of connection to STEM fields. His research group, Beta Lab, built a mobile maker studio to facilitate their work in schools and community centers. They also work to create new thinking tools to foster noticing, reflection, ideation, and collaboration.

**Colin Dixon** is a researcher and educator at the Concord Consortium. Previously, Colin was a member of the Beta Lab and the Center for Community and Citizen Science at the University of California, Davis. He has researched the development of STEM practices and agency among young people creating things to use and share with the world. He has written about equity and identity in making and engineering, the role of community in science learning, and how youth leverage their interests and experiences within STEM education. Colin works to build and research tools and learning environments that foster learning wherever it happens—in and out of schools—and that merge new technologies into more traditional tools and communities of practice, from arts to advocacy, bike mechanics to scientific research. He has worked in schools and community-based settings, doing both research and teaching. He is interested in how youth develop expertise across settings and in ways that are meaningful to them, their families, and their communities.