JSO JOURNAL of STEM OUTREACH

Vol. 6, Issue 1, October 2023

Mobile Making: A Research-Based Afterschool Program Led by STEM Undergraduates Serving as Near-Peer Mentors

Edward Price, Ph.D.[1], Sinem Siyahhan, Ph.D.[1,*], James Marshall, Ph.D.[2], and Charles DeLeone[1]

[1]California State University San Marcos, San Marcos, CA and [2]San Diego State University, San Diego, CA

[*] Corresponding Author

Keywords: Informal Education, After School, STEM Education, Making, Broadening Participation, Equity

Publication Date: October 13, 2023

DOI: https://doi.org/10.15695/jstem/v6i1.13

ABSTRACT: Making is a design-based, participant-driven endeavor based on a philosophy of "learning by doing." Formal and informal educators at science museums, libraries, and universities see Making to engage youth in authentic experiences involving science and technology. However, there is a lack of ethnic, gender, and socioeconomic diversity among Makers. With the goal of broadening participation in Making, we used six research-based design principles to develop and implement an afterschool STEM-based Making program for middle school students. As part of the program, teams of diverse undergraduate science and math majors lead weekly sessions that introduce middle school students to a variety of Making activities. A two-year pilot at four middle schools involved over 200 middle school participants and 46 undergraduate facilitators. Observations, focus groups, and surveys investigated the integration of design principles and documented increases in the participants' interest and self-efficacy related to Making and STEM, as well as their perception of the relevance of STEM/Making in everyday life. This paper describes the complex interplay between design principles, program implementation and refinement, and participant outcomes, with implications for others seeking to broaden participation in Making and STEM through informal education experiences.

INTRODUCTION

Making is a design-based, participant-driven endeavor based on a philosophy of "learning by doing." Propelled by their curiosity, Makers look for new ways to solve problems and then share their ideas with others. Making is interdisciplinary, drawing on physics, computer science, engineering, math, and materials science, and employing both high- and low-tech tools. The open-ended, project-based nature of Making has caught the attention of teachers and informal educators, who see Making as a means for engaging K-12 students in science, technology, engineering, and mathematics (STEM). Making is a central activity in constructionist and progressive theories of learning, where learning occurs when a person engages in the process of creating and designing (a.k.a making) artifacts that are personally and socially relevant (Blikstein, 2013). Research suggests that there are several benefits of engaging students in Making including, but not limited to, developing problem-solving, critical thinking, communication, and collaboration skills that are highly valued in today's job market (Martin, 2015; Mersand, 2021; Kafai et al.; Searle, 2014; Vossoughi and Bevan, 2014; New York Hall of Science, 2013).

The Maker movement has increased the visibility of Making and stimulated the interest of learners of all ages in the last fifteen years through Maker Faires and Makerspaces that provide resources and space for people to design, create, and make individually and collaboratively with others. However, there are still questions about the relevance of Making outside of its upper-middle-class roots (Buechley, 2013; Tan and Barton, 2016; Vossoughi, Hooper, and Escudé, 2016), and relatedly, its promise to broaden the participation of underserved communities in STEM. Equity-related issues in Making include access to resources, pedagogical approaches, the design of learning environments, and what counts as learning (Vossoughi et al., 2016; Halverson and Sheridan, 2014). For example, while Makerspaces help engage and support participation in Making, access to these spaces may be limited by physical proximity or the cost of membership. Even if access was not an issue, it is unclear how individuals and groups, especially those from traditionally underserved audiences, view themselves as Makers or part of the larger

Making community (Halverson and Sheridan 2014; Kafai et al., 2014; Martin and Dixon, 2013). Weaving culturally responsive practices into afterschool environments is one way to bring Making, Tinkering, and Do-It-Yourself (DIY) activities to low-income youth and broaden participation in STEM more generally (Barton, Tan, and Greenberg, 2017; Vossoughi, et al., 2016).

The lack of access and diversity within Making has resulted in a desire to establish Making programs in underserved urban and rural communities (American Society for Engineering Education, 2016). Afterschool programs can play an important role, having demonstrated success in connecting girls and minorities with STEM (Afterschool Alliance, 2013; McCreedy and Dierking, 2013). The flexibility of out-of-school (OST) environments allows for stimulating and adaptive curricula that can engage underrepresented students and provide a real-world context for learning. Afterschool environments are increasingly being viewed as strategically important for bringing Making, Tinkering, and DIY activities to low-income youth (Krishnamurthi et al., 2013; Vossoughi et al., 2013; Remold et al., 2013). It is well documented that OST programs that involve partnerships between higher education institutions and community organizations are mutually beneficial and effective in meeting the local needs of providing quality afterschool experiences for youth while providing opportunities for career and personal development for university students (Bergerson et al., 2014; Hebets et al., 2020; Rethman et al., 2021). However, it is unclear how university-community partnerships can be utilized to implement afterschool programs that aim to broaden the participation of underserved communities in Making and STEM.

In this paper, we discuss the initial design and impact of our Mobile Making program that meets underserved middle school students at their school site. The Mobile Making program is an afterschool, informal, voluntary program for middle school youth. We recruit and train qualified STEM undergraduate students (called "STEM Ambassadors"), many of whom are first-generation students from the community surrounding the university, as facilitators of Maker-based STEM activities with youth. The STEM Ambassadors provide leadership and bring materials, equipment, and tools directly to the school sites. They introduce middle school students to a variety of authentic Making activities that (a) cover STEM content and (b) use low-cost materials and tools to effectively engage a diverse group of participants, during 60 to 90-minute sessions held weekly for seven to nine weeks each semester.

In what follows, we discuss the sociocultural and socio-cognitive theories of learning to ground our pedagogical approach to designing and implementing the afterschool Maker-based STEM activities and the Mobile Making program, more broadly. We then share the design principles upon which the program was built, and how we enacted these principles as part of the program's two-year pilot testing. By so doing, we provide a context for how we hoped to promote the targeted youth participant outcomes. We also hope to illustrate how the design is informed by previous research, rather than treating the program as a black box. We then share findings on the program's impact on middle school students' self-efficacy, interest, and perception of the relevance of Making and STEM. We discuss how participant outcomes relate to our design choices and inform the future iterations of the program. Finally, we conclude with the implications of our work for others seeking to broaden participation in Making and STEM through informal education experiences.

BACKGROUND

Making has historical antecedents in the tinkering and DIY movements (Vossoughi and Bevan, 2014). Its theoretical foundations include experiential education, constructionism, and critical pedagogy (Blikstein, 2013). These schools of thought suggest that deep learning takes place when learners are engaged in personally and socially meaningful projects that position them as agents of change through creating, designing, and making tangible artifacts that can be shared with others vis-a-vis the community. Learners use a variety of tools ranging from low-tech materials like cardboard to digital technologies. They engage in problem-solving as they create, test, and iterate on their designs in the process of Making. As such, Making as a pedagogy stands in sharp contrast with how students learn in many schools, especially in STEM content, where they are often asked to memorize formulas, regurgitate information, and replicate experiments. As opposed to traditional STEM activities where learners watch a demonstration or go through the steps of an experiment to observe a natural phenomenon in action (e.g. lava lamp experiment to teach kids the concept of density), maker-based STEM activities engage learners in the active design or construction of an artifact such as a balloon car or an operation game and allow learners to have creativity over how the final product looks at the end of the design process.

Research suggests that minorities and low-income students express enthusiasm for science at a young age, yet this interest often fades by the time they reach early adolescence (Grigg et al., 2006; National Center for Education Statistics, 2007). The way STEM content is taught in schools, stereotypes around who gets to do STEM, and lack of representation of this population in STEM fields are often cited as possible contributing factors for the dwindling interest of these students in STEM. Students' STEM experiences in schools are often disconnected from their interests, experiences, and learning outside of school (Basu and Barton, 2007; Bouillion and Gomez, 2001). As a result of the disconnect between the worlds of family, peers, and school, many students see little use for STEM in their lives, instead, viewing it as a subject best reserved for "experts" (Aschbacher et al., 2009; Costa, 1995). This disconnect has important implications because students' perceived relevance of science instruction, and its connection to their personal needs and goals, is an important factor in engagement, motivation, and future actions (Wolter et al., 2013).

Self-efficacy is a belief in one's capability to succeed in a specific context and is developed through mastery experiences, vicarious learning, and verbal persuasion (*ibid*, 2006). Studies have shown that minority and low-income students often have lower self-efficacy in STEM compared to their white and more affluent counterparts (Andersen, and Ward, 2014; Diekman and Benson-Greenwald, 2018). This is problematic because self-efficacy beliefs provide the foundation for motivation, interest, well-being, and personal accomplishment, and they play an especially critical role in the lives of adolescents. Self-efficacy also has a strong influence on persistence, effort, and other behaviors that are important for college and career- readiness (Bandura, 2006). Young people are also influenced by the collective efficacy of the groups to which they belong. Homes, neighborhoods, and entire communities develop a shared belief in their capabilities to attain goals and accomplish desired tasks (Pajares, 2006).

Out-of-school programs play an important role in engaging minority and low-income students in STEM. OST environments can provide real-world contexts for learning, and successfully engage girls and minorities in STEM (Afterschool Alliance, 2013; Keune et al., 2019; McCreedy and Dierking, 2013). The most effective after-school programs subscribe to a sociocultural definition of learning and participation (Honig and McDonald, 2005). Critical program features include relevant and authentic activities; opportunities for joint enterprise; supportive relationships; including youth in central decision-making roles; family engagement; and ongoing assessment and improvement (Metz et al., 2008; Dahlgren et al., 2008). Such programs can help participants develop increased interest and self-efficacy in STEM, enhance their capacities to productively participate in STEM learning activities, and acquire an understanding of the value of STEM in society (Afterschool Alliance, 2013; 2015). We further connect to the literature on OST in describing our program design principles in the next section.

PROGRAM DESCRIPTION

Design Principles. The design of the Mobile Making program is informed by research on afterschool programs and STEM learning. We identified six key principles for effective Maker-based STEM afterschool programs in underserved communities. These principles emphasize the importance of *university-community partnerships, diverse near-peer facilitators of Making activities, access to resources for Making, designing authentic Making activities, ongoing input and guidance from participants,* and *legitimacy within the community.* We hypothesized that together these design principles would ensure the program achieves its intended positive impact on youth participants such as increased self-efficacy and interest in STEM. Table 1 summarizes these principles, their basis in the literature, and their mechanisms of action.

In what follows, we discuss each design principle in detail, focusing particularly on how we enacted these principles in our program design and implementation, and how we revised our activities and approach based on feedback from our community partners, youth participants, and undergraduate facilitators. We explain the structure and processes through which we aim to achieve targeted positive program outcomes on youth participants' interest, self-efficacy, and relevance of Making and STEM.

Design Principle 1: University-Community Partnership. Aligned with our university's mission to be a community-engaged institution, our vision for the Mobile Making program is informed by our desire to serve and build stronger relationships with the communities that surround our campus. The university and its surrounding areas are ethnically and socioeconomically diverse. According to the San Diego Association of Governments, Hispanics/Latinos comprise 32% of the residents in North San Diego County. The Mobile Making pilot program operated at four local middle schools near the university in North County San Diego. The four participating middle schools serve a largely Hispanic/Latino population, with enrolments ranging from 46% to 90%. At these schools, between 45% and 90% of students qualify for free or reduced lunch.

The student body at California State University San Marcos (CSUSM) reflects the diversity of the local region; the university is designated as a Hispanic-serving Institution (HSI). Approximately 60% of graduates are the first in their immediate family to receive a bachelor's degree. North County San Diego has many technology-based firms that hire CSUSM graduates and a growing interest in STEM and Making related activities. The region's first permanent Maker-related studio opened in 2012, and the inaugural San Diego Mini Maker Faire took place in December 2013. The Open-Source Maker Lab (OSML) opened in the spring of 2013. OSML is a membership-based, high-tech digital fabrication lab located ten miles from campus.

Given these developments, local K-12 school administrators and teachers have been increasingly interested in bringing STEM and Making activities and programming to their school sites to better prepare their students for college and the workforce. However, issues of equity and access to

Table 1. *Summary of design principles and mechanisms of action.*

Design Principles	Mechanisms of Action
Cultivate **university-community partnerships** (Furco, 2010)	Collaborative, two-way partnership helps support and sustain engagement. Site personnel (K12 teachers, administrators, and afterschool coordinators) are essential to effective programs.
Utilize **diverse near-peer facilitators** (Syed et al., 2011; Zirkel, 2002; Gasbarra and Johnson, 2008, Pajares, 2006)	Peer leaders help underrepresented students and girls negotiate feelings of isolation and stereotypes. Mentors provide adolescents with a greater sense of value and help them envision a future in science or technology. Peer models are especially useful in situations in which young people have little experience with which to form a judgment of their competence.
Provide **access to resources** (U.S. Commission on Civil Rights, 2010; Gasbarra and Johnson, 2008,)	Addresses the higher likelihood that schools in poorer urban areas have inadequate curricula, under-qualified teachers, and fewer instructional materials
Employ **authentic activities** (Archer et al., 2010; Rahm et al., 2005; Peppler, 2013; Roth and Lee, 2004)	Activities that engage students in applying science and engineering practices to real-world issues can be especially impactful for underrepresented students and girls.
Solicit **ongoing input and guidance from participants** (Honig and McDonald, 2005; Lyon et al., 2012; Sefton-Green, 2013)	It is empowering for students to assume ownership of activities or projects. Students experience an increased sense of belonging when they have a voice in a project design.
Establish **legitimacy within the community** (Ferry, et al., 2000; Gilmartin, Li, and Aschbacher, 2006; Huang, et al., 2000; Lemke, 2001)	Parental involvement influences students' interest in science and their connectedness to the academic environment. Community engagement helps students see the relevancy of science in their everyday lives. Adolescents' interests, attitudes, and motivation toward science, depend on community beliefs, acceptable identities, and other consequences related to life outside school.

quality experiences around STEM and Making persist locally as well. We created the Mobile Making program to respond to the local need for successful Maker-based STEM afterschool programming and to support the participation of underserved middle school students in STEM and Making. The Mobile Making program operates out of the Center for Research and Engagement in STEM Education (CRESE) and leverages the relationships we as faculty developed with teachers and administrators in local school districts over many years.

Design Principle 2: Diverse Near-Peer Facilitators. Research suggests that having near-peer mentors who have shared experiences or similar backgrounds can be transformative for minority students (Brown, 2004). Near-peer mentors serve as role models and help students develop a sense of belonging and identity in STEM where minority students are historically underrepresented (Zaniewski and Reinholz, 2016). For our Mobile Making afterschool program, we recruited undergraduate math and science majors to facilitate the Making activities and serve as near-peer mentors to children at each school site. More than 50% of undergraduate facilitators are members of underrepresented groups (mostly Hispanic/Latino), approximately 70% are female, and most are first-generation college students. Because CSUSM attracts a high number of students from the local area, most of the undergraduate facilitators are members of the same community as the children they work with at school sites. In some cases, our undergraduate facilitators attended the same school at which they implement the Mobile Making after-school program. Having facilitators who are representative of and from the local communities distinguishes the Mobile Making afterschool program from those university-based programs where undergraduates work in underserved communities with which they have little or no prior connection.

Each undergraduate facilitator is assigned to a school site and works with approximately 15 to 25 children at that school site throughout the semester. Each school site has two undergraduate facilitators who implement the Making activities with youth. At the beginning of each semester, undergraduate facilitators are trained before their first session at a school site. During training, undergraduate facilitators learn about Making activities, Making pedagogy, classroom management, and cultural proficiency. We engage in group discussions and role play around managing challenging situations with children including lack of engagement in activities. Our findings suggest that undergraduate facilitators' success in implementing Making activities at school sites with children is dependent upon (1) having the knowledge and experience to explain and execute the Making projects; and (2) effectively communicating, teaching, and mentoring children to ensure they succeed with their projects. Therefore, in addition to the initial training, we provide continuous support to undergraduate facilitators through online chats and informal gatherings where they can ask questions and receive feedback and coaching about working with young people in after-school settings.

Design Principle 3: Access to Resources. It is now well documented that children in low-income and minority neighborhoods have fewer opportunities to engage in Making and STEM (Barton and Tan, 2018; Brahms and Crowley, 2016; Vossoughi, Hooper, and Escudé, 2016). Schools often have limited funds to purchase materials, attract less qualified teachers, and experience more teacher turnover (Biddle and Berliner, 2002). These challenges undermine the implementation and sustainability of Making activities at many schools. Further, maker spaces situated in communities often involve membership fees that make accessing resources challenging for those who cannot afford them. Makerspaces at libraries are promising, however, they continue to be limited in numbers. The Making activities we design for the afterschool program utilize low-tech tools such as cardboard and high-tech tools such as circuitry and robotics kits that undergraduate facilitators bring to each school site. In this way, we provide access to materials, equipment, and tools that are necessary to engage youth in Making and STEM. Throughout the semester, participants have multiple opportunities to work with the same materials and tools on different Making projects. The combination of low-and-high tech tools and materials also allows youth to keep the projects they worked on during the afterschool session. Not only do we provide access to materials and tools for Making at the school site, but the materials and tools we provide also travel to participants' homes with them, allowing them to continue to tinker, design, and experiment with the materials and tools beyond the afterschool program.

Design Principle 4: Authentic Activities. Designing activities for youth in an afterschool setting required balancing tensions. First, we had to design activities that could be completed within 60 to 90 minutes given the context of an afterschool program. Second, attendance can fluctuate across different sessions in an after-school context. Further, youth have a wide range of previous experiences with low and high-tech tools ranging from no experience to deep knowledge and practice. In response to these tensions, we have taken a modular approach to designing Making activities for youth rather than having them work on the same project across multiple sessions. Our design process started with a review of existing Making activities found online through the MakerEd website, the Exploratorium Tinkering Studio, Instructibles, Howtoons, and others. These included projects related to robotics, electronic textiles, solar-powered vehicles, toy hacking, and game development, which engage students in circuits, mechanics, energy, and basic coding. However, rather than simply taking the activities we found online and implementing them with youth as part of the Mobile Making program, we adapted them so that (a) they could be completed within 60 to 90 minutes time, (b) they do not require prior knowledge, understanding, or experience so that all participants, regardless of their attendance history, can complete them, and (c) they are simple but yet can be adjusted during the session to challenge participants who have advanced knowledge or understanding.

Many of the activities we found online lacked a personally or socially relevant problem context to create a need to design and learn. Learning sciences research suggests that meaningful learning and sustained engagement are more likely to take place when youth work on problems that they care about (Hidi and Renninger, 2006; Eccles and Wigfield, 2002). For example, rather than asking them to create a board game using LEDs, buzzers, and motors, which required participants to investigate and troubleshoot circuits, we framed the activity in terms of designing a board game to raise awareness of a problem in their communities. Framing activities in terms of personal or social significance allowed participants to engage in authentic activities that connected their Making to their experiences outside of the afterschool program. By positioning them as agents of change in their communities, we expect them to develop increased self-efficacy and interest in Making and STEM.

Design Principle 5: Ongoing Input and Guidance from Participants. In any program development and improvement process, feedback from participants plays a key role to ensure desired program outcomes are achieved (Metz et al., 2008). In our case, feedback from youth participants and undergraduate facilitators is used to revise the Making activities and inform our management of the Mobile Making program to ensure positive impacts on participants' self-efficacy, interest, and relevance of Making and STEM. At the end of each session, both youth participants and undergraduate facilitators complete a short questionnaire about the project or activity they completed. Youth are asked how enjoyable and challenging the activity was along with questions about how they perceived Making, while undergraduate facilitators are asked to share challenges from preparing materials to take to the afterschool session to facilitating the activity during the session.

We review the feedback on a weekly and semester basis and make adjustments accordingly. Some adjustments are simple or mundane yet critical to address before the next session, for example, ensuring there are enough supplies at the sessions. Some changes, especially around Making activities, require more thought, planning, and redesign. For example, participants expressed great interest in projects they could take home. They wanted to continue their work and share them with others (siblings, parents) outside of the after-school sessions. They were also interested in projects that incorporate choice or ownership. As a result, the second year of the pilot Mobile Making program focused on less expensive projects that participants can keep, and projects in which participants can incorporate their own personal items (e.g., bringing in a backpack or shirt to work on during an electronic textile project).

Design Principle 6: Legitimacy within the Community. We establish legitimacy within the school and the larger community in several ways. First, our Mobile Making program operates within the existing afterschool programming structure at each school site. This allows us to work closely with afterschool program providers such as Afterschool Ed-

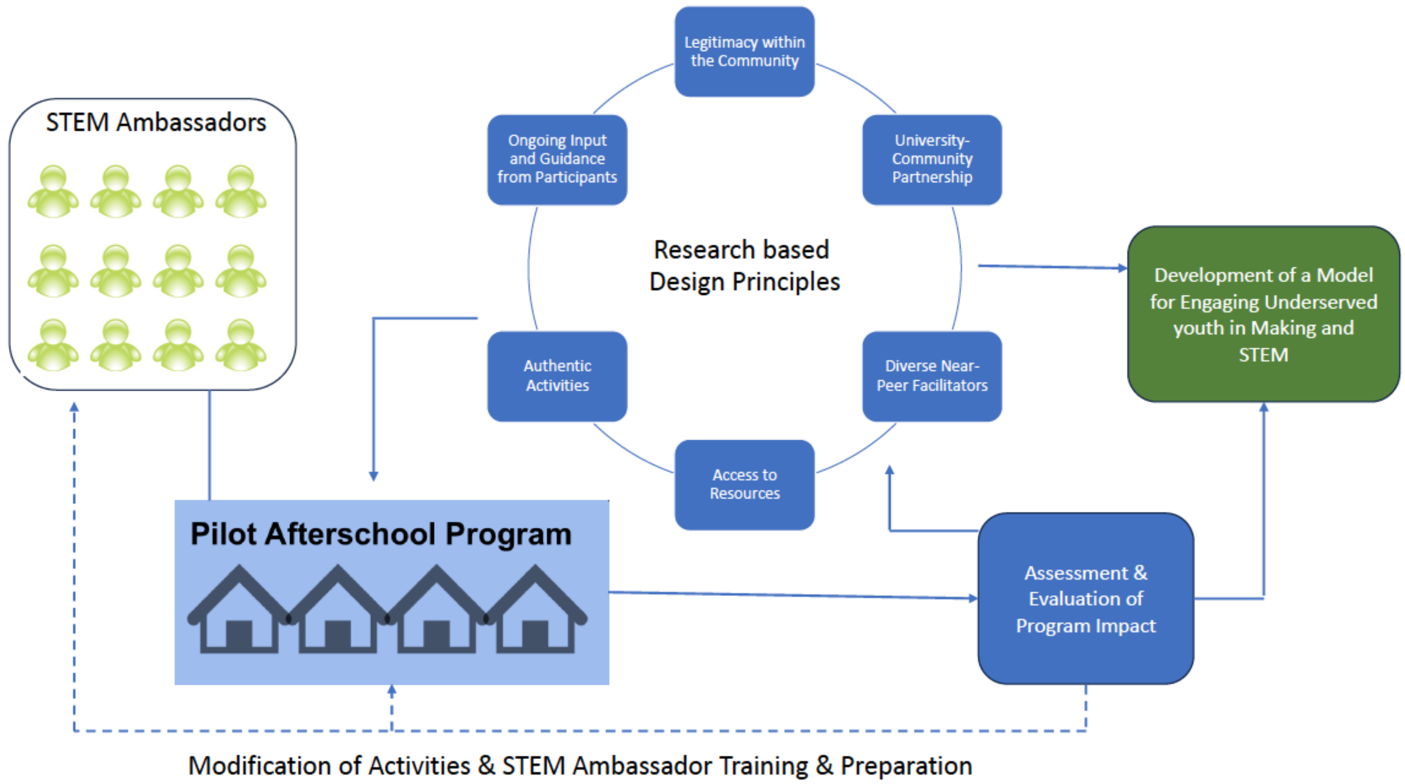

Figure 1. Project Overview and the Mobile Making Program.

ucation and Safety (ASES), Boys and Girls Club, and others as well as school principals and teachers who champion the inclusion of our program in current afterschool program offerings at the school sites. Further, school principals and teachers pay visits to our sessions and engage in informal conversations with us to explore ways to incorporate Making activities into the classroom. As such, our program is acknowledged and well-supported within the school community.

Second, we participate in and support Family Maker activities at schools during parent nights throughout the year. This allows us to connect with parents directly and engage them in Making activities alongside their children. The Family Maker activities are also facilitated by our undergraduate students. This creates opportunities for undergraduates to learn more about the students they work with and for parents to ask questions and learn more about what students are doing during our after-school sessions.

Lastly, we participate in and encourage opportunities for children's projects to be featured at school districts' annual STEM events as well as local Maker Fairs and science and engineering festivals. These efforts are designed to promote the value of Making and science within the communities while showcasing what children learn and create as part of the Mobile Making program. Further, we believe children's interests and self-efficacy will increase when they know that their work will be shared with the larger community. Not only do children feel proud to share and talk about their work but also appreciate the feedback and encouragement from the community members.

Figure 1 provides a visual representation of our project design and how the design principles inform our project activities. Figure 1 also illustrates how the outputs of our project activities are utilized to make improvements to our Mobile Making program and ultimately help us develop a model for engaging underserved youth in Making and STEM.

Making is inherently interdisciplinary, and existing Making activities cover a broad range of STEM content areas and skills (Blikstein, 2013). Each semester, we ran our Mobile Making program for nine weeks at four middle schools. Each session lasted 90 minutes. STEM Ambassadors (paid undergraduate students majoring in STEM) were hired and trained to serve as the facilitators of the activities with youth. STEM Ambassadors brought materials, equipment, and tools for the activities to the school sites and met with youth once a week for nine weeks. In each session, STEM Ambassadors introduced a Maker-based STEM activity that involved creating a design product, provided materials and tools for the activity, and supported the youth's Making process during the session to ensure the youth participants completed their designs. Examples of our Maker-based STEM projects include but are not limited to, the design of a hydraulic bridge, catapult, marble maze, and snow globe (see Figure 2).

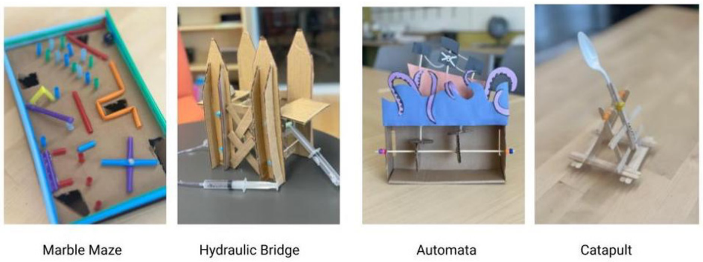

Figure 2. Examples of maker-based STEM activities.

IMPACT

In our effort to understand how the design principles we identified work together to support middle school students' self-efficacy, interest, and sense of the relevance of Making and STEM in their lives, we have taken an ecological approach to assessing the impact of the Mobile Making program on youth participants. In an ecological approach, evaluation is used to monitor short-term outcomes and inform continuous improvement of the program design. We gathered impact data while also eliciting feedback to guide program implementation. Mixed methods were used, including observations, focus groups, interviews, repeated measures surveys, and attendance rates. Specifically, we were interested in the impact of the program on youth participants' interest, self-efficacy, and sense of the relevance of Making and STEM in participants' everyday lives.

During the program's initial two-year pilot implementation period, more than 200 middle school students from four middle schools and 46 undergraduate facilitators (STEM Ambassadors) participated in the Mobile Making program. Of middle school participants, approximately 45% were female. The majority were Hispanic/Latino, representative of the school population. Table 2 summarizes the targeted participant outcomes, data sources, and analysis we conducted to measure the impact of the program on youth participant outcomes during the two-year pilot testing phase.

Below, we share the multiple sources of data we collected and how we analyzed them to measure the targeted participant outcomes, as well as the results from our two-year pilot testing. We put emphasis on both quantitative and qualitative findings equally. As such, we believe capturing and understanding how youth engage with Making and STEM activities is complex, multi-faceted, and difficult. Both quantitative and qualitative data collection and analysis can shed light on different aspects of the phenomenon, and thus when used together, can provide a more holistic picture of how the Mobile Making program supports targeted youth participant outcomes.

Sustained Interest in Making. In the post-session forms, youth participants rated their interest in the project they completed during each session on a 5-point Likert scale (1=Strongly disagree and 5=Strongly agree). The percent of youth participants responding "agree" or "strongly agree" with "the project kept me interested" was 80% in Year 1 (n=151) and 75% in Year 2 (n=171) for the total number of post-session forms received during each program year.

Additionally, we used a time series-based observation protocol to document how students spent their time in the Mobile Making program in the classroom and assess their immediate interest in the Making activities. A total of 20, 20-minute observations were conducted by our external evaluator across the four middle school sites. The observed student's activity was recorded at 30-second intervals throughout each 20-minute observation period. We recorded engagement with activity content, interaction with peers and STEM ambassadors, and the student's physical location within the classroom. We found that throughout the observation period, students remained largely "on task," with recorded observations finding them focused on their projects in 89% of the observed time intervals. Observation results also quantified the amount of support provided by STEM Ambassadors, with 26% of observations involving students who were interacting with their near-peer advisors.

Longer-term evidence of interest in Making emerged multiple times in focus group sessions conducted by our external evaluator. Focus groups were conducted with participating youth at each school site by our external evaluator. Participation was voluntary, however, on average 95% of participants present on the day of a focus group chose to participate. Groups consisted of 7 to 10 students and lasted

Table 2. *List of youth participant outcomes, data sources, and analysis.*

Youth Participant Outcomes	Data Sources	Data Analysis
Sustained Interest in Making and/or STEM	• Attendance • Post-session form at the end of each session • Observations during the program • Focus groups at the end of the program	• Descriptive statistical analysis of the post-session forms and observations (e.g. frequency and percentages) • Constant-comparative method (Strauss and Corbin, 1994) used to identify recurring themes and experiences emerged during focus groups.
Self-efficacy in Making and/or STEM	• Post-session form at the end of each session • Pre-and-post survey at the beginning and the end of the program	• Descriptive statistical analysis of the post-session forms (e.g. percentages) • Paired t-test to assess changes in self-efficacy from pre-to-post survey
Relevance of Making and/or STEM	• Post-session form • Pre-and-post survey at the beginning and the end of the program	• Descriptive statistical analysis of the post-session forms (e.g. percentages) • Paired t-test to assess changes in youth participants' perceptions of relevance from pre-to-post survey

Table 3. *Self-Efficacy assessment questions pre-to-post comparison, by the magnitude of difference.*

Survey Items	Pretest (n=37)		Posttest (n=37)		Post – Pre Difference
	Mean	SD	Mean	SD	
I am good at following directions	4.32	.67	4.30	.77	-.03
I like a challenge	4.16	1.01	4.19	1.15	.03
I am good at talking about my ideas with other people	4.08	.83	4.14	1.06	.05
I like to figure things out	4.30	.81	4.41	.93	.11
I am good at making things	4.32	.67	4.43	.77	.11
I am good at showing other people how to do things	3.89	.76	4.08	.87	.19
I am good at doing things by myself	4.08	1.02	4.28	.94	.19
I am good at solving problems	4.03	.80	4.24	1.06	.22
I am a good leader	3.86	.89	4.08	1.04	.22
I am good at listening to other people's ideas	4.03	.76	4.35	.67	.32
I am good at working with other people	4.03	1.11	4.38	.76	.35*
I like to explain how something works	3.84	.93	4.22	1.13	.38*

**statistically significant, p < .05.*

between 20 to 25 minutes. Results were analyzed using a constant comparative method to identify recurring themes and experiences.

Overall, students described the importance of sharing their work with others, often a parent or a sibling. Ambassadors echoed this sentiment, describing how students were adamant about taking their projects home to share with their parents. At times, when this wasn't possible due to the cost of the project parts, students expressed disappointment. On the design principle inventory, 78% of youth participants said it was 'very important' or 'critically important' to have opportunities for their parents to see the maker projects they completed (n=49). Focus group interaction with the student participants also suggested that some students developed a sustained interest in Making. One student described taking his work home, deconstructing it, and then reconstructing the project on his own. Another student described taking the project home and working with her brother to dis- and reassemble the project. Other students shared how they worked with siblings or parents to make things using parts they had around the house. Overall, we observed that students took ownership of the projects and generally desired to share the results with important people in their lives. In some cases, participants requested additional opportunities to do so.

Self-efficacy in Making. In the post-session forms, youth participants rated how successful they felt completing the project during each session on a 5-point Likert scale (1=Strongly disagree and 5=Strongly agree). For the total number of post-session forms received during each program year, the percent 'agreeing' or 'strongly agreeing' with "I felt successful after doing this project" was 68% in Year 1 and 79% in Year 2.

Additionally, a comparison of pre-and-post-survey administered before and after the program was used to assess potential changes in youth participants' self-efficacy. Items that targeted self-efficacy followed the recommendations outlined in Bandura (2006), which suggests that scales of perceived self-efficacy must be "tailored to the particular domain of functioning that is the object of interest or else risks ambiguity about exactly what is being measured." Using a five-point Likert scale, students rated their agreement with 13 statements designed to specifically target self-efficacy in Making (see Table 3). Students' post-survey responses were higher for 12 of the 13 statements, with statistically significant gains for youth participants' self-efficacy in working with other people and explaining how things work ($p<0.05$)

Relevance of Making and STEM. Finally, we investigated students' recognition of how Making and/or STEM is relevant to their everyday lives. On the post-session forms, 41% (year 1, n=151) and 52% (year 2, n=171) of youth participants agreed or strongly agreed that "the project helped me apply Making to my everyday life", 48% (year 1) and 64% (year 2) agreed or strongly agreed that they learned something during the session that they can use in school, and 55% (year 1) and 69% (year 2) agreed or strongly agreed that the project "helped me understand how science is important in the world around me".

Students' perceptions of the relevance of science were measured on the pre-and-post survey administered at the beginning and the end of the program using a modified version of the Changes in Attitudes about the Relevancy of Science (CARS) instrument (Siegel and Ranney, 2003). Like the self-efficacy scale, the relevance instrument included Making-specific items and more general STEM-related items. The area of greatest impact, based on pre-to-post-survey comparisons, was student interest in a career in science. Mean responses shifted from a baseline measure of 3.80 to 4.26 at the program's conclusion (as measured on a five-point agreement scale). A paired t-test analysis identified the difference as statistically significant ($p < .05$). Here, 15 of 35 (42.8%) students who offered matched responses to this question indicated increased agreement with the statement on the post-survey, relative to their original responses (see Table 4).

In addition to the positive, statistically significant growth in science careers, significant differences were also recorded for relevance-related questions about the importance of science in the community and the use of science in everyday

Table 4. *Relevance assessment questions pre-to-post comparison, by magnitude of difference.*

Survey Items	Pretest (n=37)		Posttest (n=37)		Post – Pre Difference
	Mean	SD	Mean	SD	
Knowing technology is important for success in college	4.41	.70	4.41	.78	0.00
Knowing technology is important for success in life after college	4.47	.61	4.47	.75	0.00
Knowing science is important for success in college	4.37	.69	4.51	.74	0.14
I use my knowledge of technology in my everyday life	4.11	.80	4.26	.85	0.14
People in my community think technology is important	4.06	.84	4.20	.90	0.14
I am interested in a career involving some aspect of technology	4.11	.83	4.26	1.01	0.14
Knowing science is important for success in life after college	4.17	.82	4.34	.87	0.17
I use my knowledge of science in my everyday life	3.68	.72	4.03	.83	0.35*
People in my community think science is important	3.57	.92	3.94	.87	0.37*
I am interested in a career involving some aspect of science	3.80	.96	4.26	.92	0.46*

*statistically significant, $p < .05$.

life (paired t-test, $p < .05$). Like self-efficacy findings, mean responses to post-assessment questions were higher, relative to pre-assessment ratings. This was true for all but two relevance ratings, which remained constant from pre-to-post.

DISCUSSION

Although there has been growing excitement and efforts to engage youth in Making both nationally and locally in North County San Diego where we are located, educators and researchers have yet to realize ways to broaden participation of underrepresented K-12 students and underserved communities in Making and STEM, more broadly. The results shared in this paper suggest that an afterschool Making program that builds on university-community partnership and recruits STEM undergraduate students to serve as near-peer mentors who bring Making materials and tools to school sites can effectively engage diverse youth participants in Making experiences and sustain their interest over time.
The six design principles we discuss in this paper not only guided the initial program development but also provided a lens through which we interpret the challenges and findings while we engaged in the process of iterative refinement of the program. The design principle calling for a university-community partnership was foundational to the program. The university provided near-peer leaders and is a natural hub for Maker-based STEM activity design, logistics, and evaluation. While we have no evidence to the contrary, our conjecture is that it would be more challenging to support all the other design principles (such as near-peer mentors) at non-college/university sites.

Barriers to reaching underserved students were effectively reduced by locating the program at schools. Likewise, the design principle calling for near-peer facilitators is supported by both qualitative and quantitative results demonstrating the high-value participants placed on near-peer leaders. Arguably, the involvement of near peers from STEM majors helped middle school students connect to their community and envision science in contexts beyond their schools. Our findings also support the design principle concerning authentic activities. Authentic, participant-driven activity is often presented as an intrinsic feature of Making but substantiating this—especially in underrepresented populations—is important. Evaluation results show that students value the activities and rated them as being relevant. Students were on task almost 89% of the time, suggesting strongly that the activities were compelling. Eliciting ongoing input and guidance from participants plays a crucial role in the success of the program. The near-peer facilitators were trained to consciously attend to the student's Making experience and make modifications to the activities during implementation. Likewise, student responses to post-session forms and undergraduate facilitator debriefing helped iteratively improve the projects over time.

Over a two-year period, we have documented a positive program impact on middle school students' self-efficacy, interest, and perception of the relevance of Making and STEM in their lives. The pre-and-post surveys administered at the beginning and end of the program suggest that youth participants see the relevance of their Making activities and learning at the sessions to school, home, and the community at large. The pre-and-post assessments suggest that the program helped youth participants see science as particularly relevant to their lives. It is perhaps because many of our maker-based STEM activities use low-tech tools like cardboard, glue guns, and simple circuitry as opposed to high-tech tools like coding, 3D modeling, etc. In addition to the use of everyday items, participants were able to connect with college-going young adults (STEM Ambassadors) who were mostly from similar communities and backgrounds. Receiving motivation, encouragement, and connection with the STEM Ambassadors may have helped youth participants see science as relevant to people from their community, and, by extension, themselves.

Together, our findings suggest the effectiveness of our model of program development, implementation, and refinement. Many universities are in or near underserved communities. The design principles and program model may provide a template for university-school partnerships that wish to expand Making opportunities for middle school students. At the same time, more work is needed to distill the unique contribution of each design principle and what aspects of the design principles can be modified and adapted to different school sites, and what aspects stay the same as we scale our program within our region. Additional questions remain for future work: Are the design principles we identified relevant to the afterschool Making program for upper elementary students? Are they relevant to underserved rural communities and other after-school settings (e.g., libraries, museums)? While this paper focuses on youth participants, the roles and outcomes of the undergraduate facilitators can be addressed in future work, including questions such as: Is recruiting non-STEM near-peer facilitators as effective as recruiting STEM near-peer facilitators? What supports would STEM and non-STEM undergraduate students need to effectively support Making activities with youth? Can we achieve positive youth participant outcomes across different after-school settings and different undergraduate facilitator populations?

CONCLUSIONS

Making is an exciting, authentic way to engage learners in STEM. However, there is a lack of ethnic, gender, and socioeconomic diversity among Makers. The Mobile Making program is designed on research-based principles for engaging underserved communities. Undergraduate facilitators, math and science majors, who serve as near-peer mentors, are key to the success of the program. In the past two years, over 200 youth engaged in Making through afterschool programs at four nearby middle schools with diverse student populations, using activities compatible with the format and time constraints in afterschool settings. We have documented positive impacts on student participants' interest levels, perceived relevance, and self-efficacy specific to Making. We have shown the program model's effectiveness and the value of research-based design principles. Our work is currently being expanded into additional after-school programs across the region. Continuing inquiry will involve how to scale and sustain the Mobile Making program in underserved communities and for underserved K-12 students.

AUTHOR INFORMATION

Corresponding Author

Dr. Sinem Siyahhan. Email: ssiyahhan@csusm.edu

Author Contributions

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript.

ACKNOWLEDGMENTS

The authors thank Debbie DeRoma for her contribution to the Mobile Making program.

FUNDING SOURCE

This research is supported by funds from the National Science Foundation (Award #1423612).

ABBREVIATIONS

ASES: Afterschool Education and Safety; CARS: Changes in Attitudes about the Relevancy of Science; CRESE: Center for Research and Engagement in STEM Education; CSUSM: California State University San Marcos; DIY: Do-It-Yourself; HIS: Hispanic-Serving Institution; OSML: Open-Source Maker Lab; OST: Out-of-School; STEM: Science, Technology, Engineering, and Mathematics

REFERENCES

Afterschool Alliance. (2013). Defining Youth Outcomes for STEM Learning in Afterschool. Washington D.C.

Afterschool Alliance. (2015). Afterschool programs: Inspiring students with a connected learning approach. Washington D.C.

American Society for Engineering Education. (2016). Envisioning the future of the maker movement: Summit report (Summit Report). Washington, D.C.

Andersen, L., and Ward, T. J. (2014). Expectancy-value models for the STEM persistence plans of ninth-grade, high-ability students: A comparison between Black, Hispanic, and White students. Science Education, 98(2), 216-242.

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., and Wong, B. (2010). "Doing" science versus "being" a scientist: Examining 10/11-year-old schoolchildren's constructions of science through the lens of identity. Science Education, 94(4), 617-639.

Aschbacher, P. R., Li, E., and Roth, E. J. (2009). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. Journal of Research in Science Teaching, 47(5), 564-582.

Bandura, A. (2006). Adolescent development from an agentic perspective. In F. Pajares and T. Urdan (Eds.), Self-efficacy beliefs of adolescents, (pp. 1-43). Greenwich, CT: Information Age Publishing.

Barton, A., Tan, E., and Greenberg, D. (2017). The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. Teachers College Record, 119(6), 1-44.

Barton, A., and Tan, E. (2018). A longitudinal study of equity-oriented STEM-rich making among youth from historically marginalized communities. American Educational Research Journal, 0002831218758668.

Basu, S. J., and Barton, A. C. (2007). Developing a sustained interest in science among urban minority youth. Journal of Research in Science Teaching, 44(3), 466–489.

Bergerson, A. A., Hotchkins, B. K., and Furse, C. (2014). Outreach and identity development: New perspectives on college student persistence. Journal of College Student Retention: Research, Theory and Practice, 16(2), 165-185.

Biddle, B., and Berliner, D. C. (2002). Unequal school. Educational Leadership, 59(8), 48-59.

Blikstein, Paulo. (2013). "Digital Fabrication and 'Making' in Education: The Democratization of Invention." in J. Walter-Herrmann and C. Buching (eds), FabLabs: Of machines, makers and inventors Bielefeld: Transcript Publishers.

Bouillion, L. M., and Gomez, L. M. (2001). Connecting school and community with science learning: real world problems and school–community partnerships as contextual scaffolds. Journal of Research in Science Teaching, 38(8), 878–898.

Brahms, L., and Crowley, K. (2016). Learning to make in the museum: The role of maker educators. In Makeology (pp. 15-29). Routledge.

Brown, B. A. (2004). Discursive identity: Assimilation into the culture of science and its implications for minority students. Journal of Research in Science Teaching, 41(8), 810–834.

Buechley, L. (2013). A critical look at making. Keynote address presented at the 3rd Fablearn Conference, Stanford University.

Costa, V. B. (1995). When science is "another world": Relationships between worlds of family, friends, school, and science. Science Education, 79(3), 313–333.

Dahlgren, C., Noam, G., and Larson, J. (2008). Findings for year one data for the Informal Learning in Science Afterschool Study (ILSA). Retrieved from http://www.informal-science.org/informal-learning-and-science-afterschool-ilsa-survey-data

Diekman, A. B., and Benson-Greenwald, T. M. (2018). Fixing STEM workforce and teacher shortages: How goal congruity can inform individuals and institutions. Journal Policy Insights from the Behavioral and Brain Sciences, 5(1), 11-18.

Eccles, J. S., and Wigfield, A. (2002). Motivational beliefs, values, and goals. Annual Review of Psychology, 53(1), 109-132.

Ferry, T. R., Fouad, N. A., and Smith, P. L. (2000). The role of family context in a social cognitive model for career-related choice behavior: A math and science perspective. Journal of Vocational Behavior, 57, 348-364.

Furco, A. (2010). The engaged campus: toward a comprehensive approach to public engagement. British Journal of Educational Studies, 58(4), 375-390.

Gasbarra, P., and Johnson, J. (2008). Out before the game begins: Hispanic leaders talk about what's needed to bring more Hispanic youngsters into science, technology and math professions. Retrieved from https://www.publicagenda.org/files/outbefore.PDF

Gilmartin, S. K., Li, E., and Aschbacher, P. (2006). The relationship between interest in physical science/engineering, science class experiences, and family contexts: Variations by gender and race/ ethnicity among secondary students. Journal of Women and Minorities in Science and Engineering, 12(2–3), 179–207.

Greene, J. C. (2006). Toward a methodology of mixed methods social inquiry. Research in the Schools, 13(1), 93-98.

Grigg, W. S., Lauko, M. A., and Brockway, D. M. (2006). The nation's report card: Science 2005 (NCES 2006–466). Washington, DC. Retrieved from: https://nces.ed.gov/nationsreportcard/pdf/studies/2007482.pdf

Halverson, E.R., and Sheridan, K. (2014). The maker movement in education. Harvard Educational Review 84(4), 495-504.

Hebets, E. A., Hill, P. W., Matthews, A., Phillips, K., Weller, S., Whitney, C. S., and Corey, T.B. (2020). Using a college curriculum to integrate informal science learning opportunities for university and middle school students. Journal of STEM Outreach, 3(2).

Hidi, S., and Renninger, K.A. (2006). The four-phase model of interest development. Educational Psychologist, 41(2).

Honig, M. I., and McDonald, M. A. (2005). From promise to participation: Afterschool programs through the lens of socio-cultural learning theory. Afterschool Matters Occasional Paper Series. Retrieved from http://robertbownefoundation.org/pdf_files/2005_afterschoolmatters_fall.pdf

Huang, D., Gribbons, B., Kim, K. S., Lee, C., and Baker, E. L. (2000). A decade of results: The impact of the LA's BEST after school enrichment initiative on subsequent student achievement and performance. Los Angeles: National Center for Research on Evaluation, Standards, and Student Testing (CRESST), University of California–Los Angeles. Retrieved from: http://www.lasbest.org/imo/media/doc/Keeping_Kids_in_School.pdf

Kafai, Y., Fields, D., and Searle, K. (2014). Electronic textiles as disruptive designs: Supporting and challenging maker activities in schools. Harvard Educational Review, 84(4), 532-556.

Keune, A., Peppler, K. A., and Wohlwend, K. E. (2019). Recognition in makerspaces: Supporting opportunities for women to "make" a STEM career. Computers in Human Behavior, 99, 368-380.

Krishnamurthi, A., Bevan, B., Rinehart, J., and Coulon, V. (2013). What after-school STEM does best: How stakeholders describe youth learning outcomes. After-school Matters, 18, 42–49.

Lemke, J. (2001). Articulating communities: Sociocultural perspectives on science education. Journal of Research on Science Teaching, 38(3), 296-313.

Lyon, G. H., Jafri, J., and St. Louis, K. (2012). Beyond the pipeline: STEM pathways for youth development. Afterschool Matters, 16, 48-57.

Martin, L., and Dixon, C. (2013, June). Youth conceptions of making and the Maker Movement. In Interaction Design and Children Conference, New York.

Martin, L. (2015). The promise of the maker movement for education. Journal of Pre-College Engineering Education Research (J-PEER), 5(1), 4.

McCreedy, D., and Dierking, L. D. (2013). Cascading Influences: Long term impacts of informal STEM experiences for girls. Retrieved from http://www.fi.edu/girls/cascading-influences.pdf

Mersand, S. (2021). The state of makerspace research: A review of the literature. TechTrends, 65(2), 174-186.

Metz, R. A., Goldsmith, J., and Arbreton, A.J.A. (2008). Putting it all together: Guiding principles for quality after-school programs serving preteens. Philadelphia: Public/Private Ventures Retrieved from: http://www.californiaafterschool.org/articles/Preteens.pdf

National Center for Education Statistics. (2007). Mapping 2005 state proficiency standards onto the NAEP scales (NCES 2007-482). Washington, DC. Retrieved from : https://nces.ed.gov/nationsreportcard/pdf/studies/2007482.pdf

New York Hall of Science. (2013). Making meaning (M2). New York: New York Hall of Science. Retrieved from http://nysci.org/m2/

Pajares, F. (2006). Self-efficacy during childhood and adolescence: Implications for teachers and parents. In F. Pajares and T. Urdan (Eds.), Self-efficacy beliefs of adolescents (pp. 339–367). Greenwich, CT: Information Age Publishing.

Peppler, K. A. (2013). STEAM-powered computing education: using e-textiles to integrate the Arts and STEM. IEEE Computer 46(9), 38-43.

Rahm, J., Martel-Reny, M. P., and Moore, J. C. (2005). The role of afterschool and community science programs in the lives of urban youth. School Science and Mathematics, 105(6), 283-291.

Remold, R., Verdugo, R., and Michalchik, V. (2013). California tinkering afterschool network pilot year evaluation report. Menlo Park, CA: SRI International. Retrieved from: https://www.sri.com/work/publications/california-tinkering-afterschool-network

Rethman, C., Perry, J., Donaldson, J. P., Choi, D., and Erukhimova, T. (2021). Impact of informal physics programs on university student development: Creating a physicist. Physical Review Physics Education Research, 17(2).

Roth, W-M., and Lee, S. (2004). Science education as/for participation in the community. Science Education, 88(2), 263-291.

Sefton-Green, J. (2013). Learning at not-school: A review of study, theory, and advocacy for education in non-formal settings. Cambridge, MA: MIT Press.

Siegel, M.A., and Ranney, M.A. (2003). Developing the Changes in Attitude about the Relevance of Science (CARS) questionnaire and assessing two high school science classes. Journal of Research in Science Teaching, 40(8), 757-775.

Strauss, A., and Corbin, J. (1994). Grounded theory methodology: An overview.

Syed, M., Azmitia, M., and Cooper, C. R. (2011). Identity and academic success among underrepresented ethnic minorities: An interdisciplinary review and integration. Journal of Social Issues, 67(3), 442-468.

Tan, E., and Barton, A. C. (2016). Hacking a path in and through STEM: Unpacking the STEM identity work of historically underrepresented youth in STEM. In 12th International Conference of the Learning Sciences, ICLS 2016: Transforming Learning, Empowering Learners, Proceedings (Vol. 1, pp. 418-425). International Society of the Learning Sciences (ISLS).

U.S. Commission on Civil Rights. (2010). Encouraging minority students to pursue science, technology, engineering and math careers. A briefing before the United States Commission on Civil Rights held in Washington, D.C. Briefing report. Washington, DC: Author. Retrieved from http://www.eric.ed.gov/PDFS/ED524622.pdf

Vossoughi, S., Escudé, M., Kong, F., and Hooper, P. (2013). Tinkering, learning and equity in the after-school setting. Paper presented at the FabLearn Conference, Palo Alto, CA. Retrieved from: http://fablearn.stanford.edu/2013/wp-content/uploads/Tinkering-Learning-Equity-in-the-After-school-Setting.pdf

Vossoughi, S., and Bevan, B. (2014). Making and tinkering: A review of the literature. National Research Council Committee on Out of School Time STEM. Washington, DC: National Research Council, 1-55.

Vossoughi, S., Hooper P. K., and Escudé, M. (2016). Making through the lens of culture and power: Toward transformative visions for educational equity. Harvard Educational Review, 86(2), 206-232.

Wolter, B. H., Lundeberg, M. A., and Bergland, M. (2013). What makes science relevant?: Student perceptions of multimedia case learning in ecology and health. Journal of STEM Education: Innovations and Research, 14(1), 26-35.

Zaniewski, A. M., and Reinholz, D. (2016). Increasing STEM success: A near-peer mentoring program in the physical sciences. International Journal of STEM Education, 3(1), 1-12.

Zirkel, S. (2002). Is there a place for me? Role models and achievement among White students and students of color. Teachers' College Record, 104, 357-376.