Being and Becoming Scientists

Design-Based STEM Programming for Girls

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"I *am* a scientist. I'm not *like* a scientist." We were excited to hear this response from one of the girls who participated in our afterschool program focused on science, technology, engineering, and mathematics (STEM). The STEMinist Program was a research-practice collaboration between university researchers and an afterschool program for female students in grades 4 to 6. This article describes how the program's ongoing design transformations increased girls' understanding of and interest in STEM. Design-based framing (Barab & Squire, 2009) enabled ongoing adjustments to the program while also identifying best practices for afterschool STEM learning. To understand the program's progression and outcomes, we examined the features of the learning environment and the relationships among design components by analyzing qualitative data collected before, during, and after program implementation. Participants' perceptions of science and scientists helped us understand the impact of the program and ways to improve it.

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Afterschool STEM Learning

The past decade has brought increased focus on STEM learning (Bell, Lewenstein, Shouse, & Feder, 2009; NGSS Lead States, 2013; U.S. Department of Education, 2015). The growth of STEM-related industries and the power associated with STEM fields make access to STEM careers an equity issue (Buechley, 2016). Despite gains in educational achievement, women and individuals from nondominant cultures remain underrepresented in STEM majors and careers (National Science Foundation, 2017). Afterschool programs offer a promising context for engaging diverse students: African American and Latinx children attend afterschool programs at rates twice that of White students (Afterschool Alliance, 2015). STEM programs at youth-centered sites capitalize on the resources of spaces children find welcoming and accessible. The natural curricular flexibility of afterschool programs enables immersive exploration and experimentation in STEM as well as authentic opportunities for building skills and developing relationships helpful to STEM careers (Afterschool Alliance, 2015; Krishnamurthi, Ballard, & Noam, 2014). Afterschool science programs naturally blur disciplinary boundaries and incorporate diverse ways of knowing (Calabrese Barton, Birmingham, Sato, Tan, & Calabrese Barton, 2013). These factors can be leveraged to broaden young people's definition of *science* and to foster "productive hybrid STEM identity work for underrepresented youth" (Calabrese Barton, Tan, & Greenberg, 2017, p. 21). Science education in youth-centered sites can value the cultures of underrepresented students while encouraging them to explore new science-related interests and identities (Calabrese Barton & Tan, 2010).

Despite widespread acceptance of the benefits of afterschool STEM, more research is needed on how program factors affect student engagement and learning (Laursen, Thiry, Archie, & Crane, 2013). Coburn and Penuel (2016) call for more studies on program processes, collaboration strategies, and productive responses to challenges. Our research-practice partnership addresses the call for responsive program development to extend and improve STEM programming for diverse learners.

Design-Based Implementation Research

Design-based implementation research is a relatively new methodology positioned at the intersection of educational practice and theory. This model of learning and innovation both informs local practice and provides insight into complex issues with broad applications (Anderson & Shattuck, 2012; Barab & Squire, 2009; Design-Based Research Collective, 2003). In design-based implementation research, exploration and analysis are conducted in "messy situations that characterize real-life learning" (Collins, Joseph, & Bielaczyc, 2004, p. 20). Program design is flexible and ongoing; it engages both researchers and practitioners (Collins et al., 2004; Fishman, Penuel, Allen, Cheng, & Sabelli, 2013). Development and research are usually conducted in tandem over a long time frame with iterative cycles of design, application, analysis, and redesign (Design-Based Research Collective, 2003; Wang & Hannafin, 2005). A key feature is collaboration among researchers, practitioners, and participants; findings should be applicable and accessible to practitioners (Anderson & Shattuck, 2012; Wang & Hannafin, 2005). Participants are not passive subjects but active contributors who inform ongoing design, implementation, and analysis (Barab & Squire, 2009). The unique advantage of design-based implementation research is that "practitioners and researchers work together to produce meaningful change in contexts of practice" (Design-Based Research Collective, 2003, p. 6).

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According to Fishman and colleagues (2013), the underlying purpose of design-based implementation research is to connect research and practice in a way that is "mutually transformative" (p. 138). Though this framework is relatively new in educational research, it integrates several modes of research and theoretical foundations. For example, various aspects align with principles for evaluation research and efficacy studies and with community-based research (Fishman et al., 2013). Design-based implementation researchers have also drawn from developmental psychology and cognitive science to examine how students solve problems, make decisions, appropriate tools, and develop conceptual understanding (Bell, 2004). In the field of cultural psychology, researchers have used design-based implementation research to examine sustainability and encourage generative learning environments and outcomes (Bell, 2004).

The STEMinist Program and Its Inclusive Curriculum

Professors and graduate students from a university in southern California collaborated with local Girls Inc. leaders to develop and implement the STEMinist Program. All participants were girls ages 9 to 11; 56 percent self-identified as Latina. The program included activities both at the afterschool site and at the university.

We shaped the learning environment, the ways participants interacted, and the types of tasks assigned in alignment with culturally inclusive values.

The STEMinist Program built on lessons learned from an earlier collaboration with a different afterschool organization. In this pilot program, students read about young scientists and participated in hands-on science and engineering activities. Following the pilot program, the university researchers partnered with Girls Inc., whose leaders wanted students to think of themselves as members of a STEM community. We therefore added interviews with female scientists at the university to this new STEMinist Program. All girls visited six labs, and each small group of four girls was responsible for interviewing and writing about two scientists for a book the girls created together. Participants also read about famous women scientists, created art for their books, and presented their work at a final showcase (Arya & McBeath, 2017). The format was similar for Year 2, but the focus shifted from STEM to STEAM (adding arts). Participants interviewed women in diverse disciplines including media arts and theater as well as engineering, technology, and computer science.

Our design-based implementation research covered two years of the STEMinist Program. During the first year, 25 girls in grades 4 through 6 met once a week for two academic quarters, January through June. Most weeks, the girls were bussed to the university. For the second year, we lengthened the program to cover a full academic year, changed our focus to innovators, and made other changes described below under Lessons Learned.

In designing the program, we drew on feminist research on incorporating diverse ways of knowing, making science relevant to real-life issues, avoiding deficit language, and valuing diverse and intersecting identities (Brickhouse, 2001; Brotman & Moore, 2008). We shaped the learning environment, the ways participants interacted, and the types of tasks assigned in alignment with culturally inclusive values. These "embodied elements of the design" (Sandoval, 2014, p. 22) included making the work hands-on, multidisciplinary, and community-oriented, as well as relying on multiple forms of mentorship (Brotman & Moore, 2008; Munley & Rossiter, 2013; Rahm & Gonsalves, 2012; Riedinger & Taylor, 2016). For example, the STEMinist curriculum was *hands-on* and *multidisciplinary* because participants engaged in investigations in university labs and interviewed scientists in geography, neuroscience, marine biology, bioengineering, computer science, and math. They also participated in hands-on, multidisciplinary non-STEM activities, writing biographical profiles and creating art displays as part of their book about the women scientists. The program design was *collaborative* and structured around a *community* of peers, undergraduate mentors, and scientists. Activities were conducted in groups of four peers with two undergraduate mentors; each group contributed to the shared goal of publishing a book. Female undergraduate facilitators and professors also acted as *mentors* and role models, sharing about their lives and offering guidance.

Data Collection and Analysis

Following guidelines for design-based implementation research (Design-Based Research Collective, 2003), we collected multiple types of data: pre- and post-participation qualitative reading inventories, surveys, focus group interviews, video and audio recordings of instruction and student interactions, session observations, field notes from the undergraduate facilitators, student work, and weekly lesson plans. We also interviewed individual participants, both before and after the program, about their perceptions of STEM practices and of themselves in relation to those practices, basing the interview protocol on the Views of Nature of Science assessment for elementary students (Council of State Science Supervisors, 2017).

This paper includes analysis based on data from one focus group of nine students at the beginning of the pilot year, one focus group of seven students after the pilot year, three focus groups totaling eight participants after Year 1, and 22 pre-post individual interviews from Year 1. The research group—four undergraduate students, a coordinating graduate student, and two professors—met weekly to discuss our experiences and observations, which informed changes to the program design and data collection. Including perspectives from multiple data sources helped us tackle the challenge of implementing a successful program in an ever-changing, multifaceted environment while maintaining "empirical control" (Sandoval & Bell, 2004).

We began qualitative data analysis by constructing representations of the timeline and weekly activities for each year of the program, as recommended by Green, Skukauskaite, and Baker (2012). In keeping with the design-based implementation research framework (Sandoval & Bell, 2004), we examined program processes and products to understand the effect of design decisions and program components. Finally, we examined the designed learning environment through conjecture mapping, an analytic technique that articulates design features, how they relate to each other, and how they influence program outcomes (Sandoval, 2014).

Next we transcribed the pre- and post-participation individual interviews and the focus group interviews conducted after the pilot year and after the first year of the STEMinist Program. In the group interviews, participants discussed their perceptions of science generally and of the book project in particular; we also asked about key activities such as interacting with scientists, reading, and public speaking. We then coded both sets of interviews. Structural codes (Saldaña, 2009) about perceptions of science, such as *science vs. other subjects, imagination in science,* and *children as scientists*, were determined in advance based on the Views of Nature of Science questions (Council of State Science Supervisors, 2017). Other thematic codes, such as *future goals, productive failure in science, scientist self, familiarity with scientists*, and *science as a process*, emerged as we examined the data. Observed patterns were refined into themes in discussions among research team members.

In reporting below on the girls' responses in interviews and focus groups, we use pseudonyms the girls selected themselves.

Lessons Learned

The changes we made between the pilot year and the second year of the STEMinist Program enabled us to see whether these changes made a difference in promoting literacy skills and increased interest in STEM. These changes guided our ideas about best practices for afterschool programs that combine science with reading, writing, and art. Feedback from partnering practitioners and participants highlighted the four key design principles outlined in Table 1. Following Sandoval's (2014) process for conjecture mapping, the table shows the relationships between design principles and their associated practices and outcomes.

Integrating Disciplines of Practice

From the beginning, the STEMinist Program presented hands-on, multidisciplinary opportunities for learning science and language arts. Although we targeted interest and confidence in STEM, we also wanted students to grow as readers, writers, and critical thinkers. Multidisciplinary projects were ideal for engaging diverse learners. However, creating a cohesive curriculum demanded extensive planning and development.

Table 1. STEMinist Program Design Principles and Outcomes

Design Principle	Associated Practices	Outcomes
Integrating disciplines of practice	Activities that focus on communicating new knowledge (e.g., creating an interview protocol)	Improved reading and writing; improved science content retention
Presenting science as pushing through difficulty	Discussions about everyday science; engaging in productive failure (e.g., multiple trials in science labs)	Richer understanding of science in practice and as a discipline
Positioning participants as being and becoming scientists	Discussions about who participates in science; constructing narratives of scientists (e.g., interview questions emphasizing early interests)	Identification with scientists; recognition by self and others that one is a scientist or is capable in STEM
Engaging in shared experiences	Shared discussions about scientists; group collaboration (e.g., co-writing essays about scientists)	Ability to communicate confidently in multiple contexts

During the pilot study, science educators and writing instructors worked separately to complement each other's lessons; however, their instructional visions and timelines were not always aligned. To address this lack of cohesion, we decided to integrate science and literacy more fully. For the first year of the STEMinist Program, we changed the format to culminate in publication of a book about women who worked in STEM at the university, thus authentically integrating science with art and writing in a shared goal. Although program sessions were roughly divided into reading, science, and writing sessions, they were all connected to this final goal. For example, students discussed their readings about famous scientists before visiting scientists on campus. The readings thus served as "mentor texts" (Gallagher, 2011), providing examples to help the girls interview the scientists and then write up their findings for the book. Later activities continued to integrate writing with science. For example, groups used mental maps to represent the core research theme and supporting ideas for each scientist. They used these maps to select silhouette images for their artwork and key ideas for their biographical profiles.

The girls recognized the mutually reinforcing roles of the science, literacy, and art components. In a focus group, participants Poppy and Brianna suggested that writing or art was as important as the scientist visits. Panda responded, "Interviewing scientists was all the information, and this book is an informational text." The interviews and science activities provided the content, while writing and art were the modes of communication. Diana believed that these forms of communication were complementary, explaining in a focus group that the illustrations helped explain and clarify the scientists' work. In addition to valuing these components, students developed more sophisticated understandings of both science and writing. In exit interviews, they reported that the program was hard work, but that they were now more proficient writers and better understood science. Poppy said, "I wrote most of [my group's profile] because the person who was in charge made us do a lot of work. It really helped though…. It helped me to write better." Glory agreed that the project was challenging but rewarding: "It was hard work, but it was really fun, and we got to learn a lot about science in the process." She called the project "inspiring … interesting and very cool."

We did not anticipate how important the discussions about dealing with failure and setbacks would be for STEMinist participants. For example, visiting a lab where the MRI machine was not functioning made an impression on the group.

Presenting Science as Pushing Through Difficulty

As we designed and redesigned the program, we determined that the girls found science more approachable when they perceived it as something everyday people do, when they could see it as messy and failure-prone but rewarding if they put in enough time and effort. The pilot program centered on multidisciplinary STEM activities, but we did not typically discuss scientific processes or make explicit references to iterative development or productive failure. In designing the first year of the STEMinists Program, we focused on deepening understanding of science as a dynamic process of exploration and knowledge building. We hypothesized that the girls would learn about authentic science practices through their discussions with scientists in addition to participation in hands-on science activities.

We did not anticipate how important the discussions about dealing with failure and setbacks would be for STEMinist participants. For example, visiting a lab where the MRI machine was not functioning made an impression on the group. In her exit interview, Melanie commented, "Sometimes science doesn't always work, or machines shut down, and you don't know why. I learned that part of being a scientist requires you to keep trying even when things don't work." Brianna echoed this sentiment in her exit interview:

> You like to try new things, and you don't give up if something goes wrong, because science doesn't always go the right way. And I'm guessing the scientists who are here, if they mess up, they retry it. They don't just throw it away and say, "I give up."

Similarly, Odalis said in a focus group that hearing about scientists' doubts and struggles in addition to their accomplishments "made me more interested in their stories."

In their biographies, the girls described their scientists' successes despite challenges or discrimination as "very inspiring" and "truly one of a kind." Members of one group wrote that, when confronted by self-doubt or others' reservations, their scientist "stays headstrong and convinces people she can do things." Another group wrote that the scientist "just kept working hard, and she accomplished every goal she dreamed of." A third wrote that the scientist "overcame all her doubts, poof, gone!"

The stories about the scientists overcoming barriers inspired the girls to speak about resisting gender stereotypes at the final showcase event. Pink commented, "Some people think girls can't do what boys can do, and I think that they are wrong. We need to stop that kind of thinking. Girls can do anything they put their mind to." Similarly, Lexi reported, "Being in the [project] gave me the chance to see a lot of women in science who don't always get a lot of attention for what they do.... Seeing women in science makes me feel stronger."

During the second year of the STEMinist Program, we further emphasized this idea of science as a long-term process of daily exploration and of pushing through difficulty. Instead of reading about famous scientists, participants focused on young innovators in science and engineering and on their processes for developing ideas and creating knowledge. For example, they learned about Becky Schroeder, who at 10 years old invented a glow-in-the-dark clipboard, and Alina Morse, a seven-year-old who created healthy candy designed to clean teeth.

This change was also motivated by the fact that many of the girls were unfamiliar with engineering. Before the first year of the program, only 25 percent of girls said they had heard of engineers. After the program, 52 percent said they had heard of engineers, even though two of the women the girls wrote about were engineers. In addition to bringing more attention to engineering in the second year of the program, we recruited innovators in diverse disciplines including media arts, theater and dance, technology, and computer science.

Positioning Participants as Being and Becoming Scientists

A major program component across all iterations was reading and writing about STEM in action. We used the stories of featured scientists and innovators to connect participants with the daily work of these professionals and the ways in which their work resembled participants' own thinking and learning. This narrative exploration included reading biographies of famous scientists or of lesser-known young innovators, writing stories about scientists' or designers' innovations, interviewing women in STEAM fields, and discussing what it means to be a scientist or researcher.

At the beginning of the pilot year, eight of the nine participants in a focus group agreed that only adults could innovate and that everything had already been invented (Arya et al., 2017). To counteract this notion, we had participants read stories about young inventors, connect these stories to their own family histories and personal experiences, and create their own inventions. By the end of the year, the students demonstrated confidence in and ownership of their designs; however, they did not refer to themselves as innovators or scientists. Program staff and instructors tended to call participants "leaders" or "makers" rather than using such science-related designations as "engineers," "scientists," or "researchers."

Applying these findings during the first year of STEMinists, we shifted to describe participants as future scientists. The girls read about famous female scientists, including Patricia Bath and Rachel Carson. Then they met and interviewed scientists on the university campus. Most of the girls were interested in the stories of the famous scientists but did not particularly relate to them. In contrast, the girls cherished the scientist visits. They asked questions about the scientists' previous experiences and personal lives in addition to their current research. Poppy, like many others, felt the most important thing she learned was "what the scientists do in their lives," according to her exit interview response.

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Participants reacted in different ways to the scientists' stories: Some felt inspired or supported, some were curious about previously unfamiliar fields, and others were relieved that they did not yet have to decide about becoming scientists. Many girls felt the program provided information on STEM careers and offered options. In a focus group, C. J. said, "If we want to do something in the future, we actually know a little bit about it." Diana added that she felt more like a scientist after meeting the university scientists: "What they're showing us, you might become one." Students also learned that becoming a scientist is a process and not necessarily a decision a person makes as a child. Cassie said in her exit interview, "A lot of people think all scientists grow up wanting to become a scientist. That is not true." She gave the specific example that one of the scientists "wanted to be an actress when she was little, but now she's a mathematician. There's a big difference between the two." She concluded, "I learned that anybody could be a scientist, even me." Learning about the scientists' lives helped the girls see a STEM career as a possible trajectory and feel more confident in their ability to become scientists.

However, in focusing on adult scientists and their trajectories, we missed the chance to help participants consider how they were currently engaging with the world as scientists. Our field notes refer to a day when the girls were reviewing their interview notes. The lead professor referred to them as "researchers." One girl exclaimed, "Wait, we're researchers? Cool!" From that point on, we were more deliberate about how we described what the girls were doing. We called them "researchers," engaged them in our own research by asking them to choose their pseudonyms for our reports, and discussed what it means to be researchers reporting on findings. In the end-of-project interviews, over 75 percent of the girls stated that they were like scientists. When asked in focus groups how they were like scientists, participants listed such similarities as "thinking a lot," or being "strong, smart, and bold." Several girls even questioned the comparison, saying that they *were* scientists rather than *like* scientists. The following excerpt from a focus group interview shows how the girls argued that they were scientists because they engaged in the practices of scientists.

Facilitator: In what ways do you think you are like a scientist?
Poppy: We studied.
Panda: I *am* a scientist, I'm not *like* a scientist.
Facilitator: Okay, in what ways *are* you a scientist? Studying? What else?
Panda: I make discoveries and teach myself things.
Poppy: I look like them!
Facilitator: Discoveries, teaching—Did you say you look like them? What do you mean by that? I think that's interesting.
Poppy: Yeah, I look like them.
Panda: Anybody looks like a scientist because everybody is a scientist!
…
Facilitator: So based on everything you guys know, what do you think it means to be a scientist?
Poppy: It means to become smarter than you already are.
Facilitator: So learning new things?
Poppy: More! As much as you can.
Panda: Making discoveries for the world. Everything is science technically. I mean like, how did those beams get held up? How is that paint white? And how would these bulbs work—How do these lights turn on? How is that clock working? How is that something doing that?
Poppy: How are we alive?
Facilitator: That's true, scientists ask and answer all those questions.

In this discussion, participants argued that science is relevant to everyday life and that anybody can be a scientist. Such discussions helped us realize the importance of positioning children as both current and future scientists. The ways we referred to the girls and how they referred to each other, as well as how they viewed and discussed the scientists, influenced the ways the girls viewed themselves and how others viewed them. Therefore, in the second year we more deliberately framed their activities as the work of scientists, engineers, and makers, while continuing to present the diverse trajectories of adult scientists. Additionally, we returned to the pilot year readings about everyday innovators and young inventors, rather than famous scientists, as a way of focusing on the agency of young people.

The ways we referred to the girls and how they referred to each other, as well as how they viewed and discussed the scientists, influenced the ways the girls viewed themselves and how others viewed them.

Engaging Participants in Shared Experiences

Across the pilot program and the two years of STEMinist, we changed the ways in which activities were structured. In the pilot year, participants typically engaged in activities as a whole group, splitting off occasionally as individuals or pairs for specific tasks. This pilot group accumulated many shared experiences and thus grew very close; however, at times it was difficult to keep the whole group on task or accountable to weekly goals. In the first year of the STEMinist Program, we organized the girls into groups of four, each with two undergraduate facilitators. Although the girls appeared to enjoy the format and succeeded in creating a meaningful product, they did not form as cohesive a group as did the girls in the pilot program. Afterschool program staff asked for more team bonding in the next iteration.

Though we wanted to enable the cohesion of the large group, we also wanted to keep the advantages of small groups. Participant comments suggested that the small groups helped the girls feel comfortable voicing their opinions. During a focus group interview after Year 1, Diana said, "With our own little group, not a huge group, you don't dis-include [exclude] people…. You explain yourself more." Odalis agreed, "It's easier in small groups." Our next iteration in Year 2 thus included reading and writing activities in small groups along with introductory whole-group activities: Participants toured the campus, interviewed each other about their interests and experiences, and worked together on engineering design challenges. Additionally, we decreased the number of adults interviewed so that the whole group could interview all six innovators in six weeks rather than splitting up to interview six of 12 scientists as in Year 1. The Year 2 format allowed participants and undergraduate facilitators to develop a shared foundation they could use in creating their stories about the innovators and in reflecting on their experiences.

Becoming STEMinists

The STEMinist Program was designed to help girls understand science and engineering both as sets of practices and as knowledge-building disciplines. We also wanted to enable girls to identify with STEM professionals and to share their experiences publicly in creative ways. With each iteration, we maintained similar aims but altered the design and context to address challenges. The multidisciplinary project of creating a book about STEM interviewees was effective in engaging our diverse learners, but it demanded significant planning and development. The success of the program depended on four design principles: integrating disciplines of practice, presenting science as pushing through difficulty, positioning participants as being and becoming scientists, and engaging participants in shared experiences. These design principles affected both processes and outcomes related to the girls' interest and competence in STEM.

However, our findings involve a relatively small number of participants. We analyzed pre- and post-participation data only for the pilot year and Year 1, with preliminary analysis of Year 2 results. Future comparative analyses incorporating pre-post interviews for Year 2 will strengthen conclusions about the program's outcomes and identity implications. Additionally, this paper is merely one contribution to the discussion about design transformations in science-focused research-practice partnerships. Future studies focused on longitudinal and large-scale design efforts with cross-site comparisons can add to the field's knowledge.

Despite the limitations, our study can help other university educators and researchers see how to address design challenges in partner afterschool STEM programs. Coburn and Penuel (2016) emphasize the importance of this type of work, stating that "at present, there is little basis for recommending some partnership designs or particular strategies to address challenges over others" (p. 51). Our university-afterschool partnership is ongoing; it therefore will provide an opportunity to build on previous work to create a theory of action for afterschool programs that seek to combine science with reading, writing, and art. Multidisciplinary programs have shown promise in recruiting and retaining participants from groups underrepresented in STEM because they incorporate diverse ways of knowing and broaden the definition of science (Calabrese Barton et al., 2017). Furthermore, our research reveals the promise of practices that present the stories of scientists to show that science is accessible and relevant. We hope our findings will help practitioners and researchers to design and implement effective multidisciplinary science content and reach diverse learners.

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