CONNECTED STEM LEARNING IN RESEARCH & PRACTICE

Edited By
Beth Murphy, PhD
Katherine Roberts

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National Science Teaching Association

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NSTA WEB SEMINARS

Case Studies from Connected Science Learning

Developing Critical Consciousness in Middle-School Science Through Engineering for Sustainable Communities

In this web seminar, the presenters share how an Engineering for Sustainable Communities approach in the middle grades can foster critical consciousness and support strong connections between classrooms and communities. The presenters show how critical consciousness, when integrated with learning the content and practices of STEM, is an effective way for orienting students to how and why learning STEM matters in everyday life and hoped-for futures.

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Archive available at https://my.nsta.org/resource/126194

Case Studies from Connected Science Learning

Transformative Science Learning through Museum-School Collaboration

Strategic partnerships that bring together schools and other organizations–such as museums–have the potential to transform learning in ways that neither partner can accomplish alone. This web seminar explores the process, products, and outcomes of such collaborations and provides inspiration and insight for launching similar partnerships. Two different examples of how schools and museums can work together are explored.

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Archive available at https://my.nsta.org/resource/125354

INTRODUCTION

In the summer of 2020, NSTA received the exciting news that it had received a grant from the National Science Foundation to engage in a project to help advance the field of connected STEM learning. The goal of this project was to publish resources in *Connected Science Learning (CSL)* that would support STEM educators in applying the latest research to the design and delivery of connected STEM learning experiences. This report is a result of this work.

To accomplish the project goal, *CSL* first convened a study group to identify key themes for manuscript submissions aligned with *CSL*'s purpose and goals. The journal focuses on intersections in the STEM learning ecosystem: intersections between in- and out-of-school, informal and formal learning, schools and other organizations, different fields of study, research and practice, learning and life. In other words, *CSL* focuses on publishing articles that

- bridge the gap between in- and out-of-school STEM learning,
- demonstrate practice informs research and research informs practice,
- are grounded in cross-sector collaboration that transcend traditional boundaries,
- incorporate transdisciplinary approaches and integration between and beyond STEM fields and learning settings, and
- focus on preK–12 youth and those who support them (e.g., educators, education leaders, and instructional designers; STEM professionals, mentors, and role models; caregivers and community members).

Subsequently, the study group reviewed abstracts to select invited authors and later also engaged in the peer review process alongside a team of existing reviewers. In this report you will find 13 articles—8 of which resulted directly from this work and 5 that were previously published in the journal but strongly align with the identified themes and explore the following questions:

- What do thriving STEM learning ecosystems look like? What characteristics, values, and cultural practices define them and lead to their success?
- How can STEM be a catalyst for empowering young people to take action, inspire change, and design solutions to real community problems in their schools, neighborhoods, and beyond?
- What do connected STEM learning experiences look like? In what ways do they transcend traditional boundaries?
- How can informal and formal STEM organizations and educators work together to improve teaching and learning in and out of school? What can they learn from each other?
- What are some successful models for collaboration between STEM education providers and families for achieving shared goals?
- What are some innovations in online learning? How can online learning be used to complement classroom learning, increase access to resources and information, engage students in research, and provide innovative and impactful learning experiences that may not otherwise be possible?

Please note that this report provides only a sampling of the exceptional articles that have been featured in *CSL* since its inception in 2016. We invite you to regularly explore *Connected Science Learning*—both the current issue and archives—at *https://www.nsta.org/connected-science-learning*.

In closing, I want to thank the project team for their teamwork in implementing this project and the study group participants for their support in advancing the field of connected STEM learning. To the readers of *Connected Science Learning* and this report, thank you for all that you do to research, evaluate, design, and deliver high-quality, connected STEM learning experiences. Onward!

Beth Murphy, PhD (bmurphy@nsta.org), *is field editor for* Connected Science Learning, *director of education at Science from Scientists, and an independent STEM education consultant with expertise in fostering collaboration between organizations and schools, providing professional learning experiences for educators, and implementing program evaluation that supports practitioners to do their best work.*

EQUITY AND CONNECTION IN STEM LEARNING ECOSYSTEMS

INTRODUCTION

What Is a STEM Learning Ecosystem? Lessons From the Natural World

BY BETH MURPHY, Field Editor, *Connected Science Learning*

According to the National Research Council, a learning ecosystem is defined as "the dynamic interaction among individual learners, diverse settings where learning occurs, and the community and culture in which they are embedded" (NRC 2015, p. 5).

That's a good start, but how can we make a STEM learning ecosystem feel more tangible? To answer this, I find myself looking to the natural world. When students learn about natural ecosystems in school, they're taught to think about structure and function—the complex network and interactions between living organisms and nonliving physical conditions, how energy is transferred, and how resources are used. The go-to picture in my head is from a workshop I once chaperoned at the local zoo for my daughter's fifth-grade class. The workshop led students to explore the interconnectedness of living and nonliving factors in a prairie ecosystem common to our state and then predict what might happen to that system in the face of change. The model of the ecosystem students built—using photo cards and wires with alligator clips—helped them understand how a single change in an ecosystem can have significant and cascading effects, the impacts of which will vary depending on that ecosystem's health and resilience.

How far can we push this natural ecosystem analogy to explore the dynamics of a designed ecosystem, such as one focused on STEM learning? The answer, I believe, is quite far—and one I can only begin to explore here.

I was excited to find that education researchers have done a lot of thinking on this topic. For example, Unpacking the Learning Ecosystem Framework: Lessons From the Adaptive Management of Biological Ecosystems (2019) explores the paradigm shift required if we are to truly adopt systems thinking as an approach to understand and improve how learning happens. One takeaway from this work is that the problems that need addressing in learning ecosystems are complex, rather than complicated—and this distinction is critical to informing how we act. The difference is that complicated problems are hard—but not impossible—to solve with established algorithms. Complex problems, on the other hand, have too many unknowns, interrelationships, and conditions to be solvable via a standardized process. A solution that works in one place doesn't necessarily apply in another, nor continue to be effective upon scaling. The authors argue that "we ought to accept local variation and pursue adaptive strategies" that recognize that scaling is also "about a shift in perspective, rather than just a shift in size."

Let's face it, simply replicating and scaling STEM programs and interventions that are successful in one setting hasn't yet led to hoped-for outcomes. Maybe this is because we've been approaching problems that need the most attention as complicated, rather than complex. This is perhaps why—despite efforts over many years—gaps in access, opportunity, and achievement in STEM are so persistent. Even so, I'm hopeful about what's possible if we embrace the complexity of STEM learning ecosystems and as a result define and solve problems in new, responsive ways.

REFERENCES

Hecht, M., and K. Crowley. 2019. Unpacking the learning ecosystems framework: Lessons from the adaptive management of biological ecosystems. Journal of the Learning Sciences 29 (2): 264–284. DOI 10.1080/10508406.2019.1693381.

National Research Council. 2015. Identifying and Supporting Productive STEM Programs in Out-of-School Settings. Committee on Successful Out-of-School STEM Learning. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

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Thriving STEM Learning Ecosystems—for All?

BY LYNN D. DIERKING, JOHN H. FALK, NETA SHABY, AND NANCY L. STAUS

Many researchers use "ecological" perspectives to frame their learning studies, which is the idea that a STEM learning ecosystem contains varied resources—both in and out of school (Falk et. al 2015; Staus et al. 2020; Traphagen and Traill 2014)—and youth construct unique STEM interest and participation pathways (SIPPs) as they traverse the ecosystem. Research suggests that rather than typical influences (i.e., grades and courses taken in school), factors such as interest, identity, and participation in out-of-school, informal/free-choice learning activities during the middle-school years—as well as social and cultural capital factors (income, education, and geographical access to resources)—are collectively the best predictors of future engagement and participation in STEM (McCreedy and Dierking 2013; Fortus 2014; Maltese, Meilki, and Wiebke 2014). As a result, many researchers, educators, and policymakers have begun to advocate for an ecosystem approach to STEM learning: an approach that supports STEM interest and participation across the day and settings, both in school and outside school (Dierking and Falk 2003; NRC 2015; Traphagen and Trail 2014).

A six-year US–National Science Foundation (NSF) project, *SYNERGIES: Customizing Interventions to Sustain Youth STEM Interest and Participation Pathways* investigated the STEM Interest and Participation Pathways (SIPPs) of multiple youth (11–14 years old) within the *same* low-income, urban community over time (days, months, and years), both in school and during out-of-school (OOS) informal/freechoice learning time. Quantitative findings from the analysis of the STEM Interest and Participation Pathway survey questionnaire administered once a year include a factor analysis study (Falk et al. 2015; Staus et al. 2020a; Staus et al. 2020b) and latent profile and transition analyses. These studies show that, in aggregate, youth pathways were influenced by complex factors; in particular, youth persisted in and sustained STEM interest if they had family support for "their" interest and engaged in OOS activities.

In a qualitative component of the research, we tracked three participating youth, Charlie, Steve, and Stella (pseudonyms that students created), who at the start of the study were interested in STEM (Shaby et al. 2021). We interviewed each of them over two to three years as they moved through the learning ecosystem to "see" in an in-depth manner whether their interests persisted and were sustained. These data demonstrate how three individual youth living in the same community were influenced by

- significant others in their lives;
- the social capital (resources derived from group membership, relationships, and networks of support) and cultural capital (resources such as knowledge, skills and education) of their families;
- their perceptions of, and experiences with the learning resources; and
- the nature of their specific interests.

This study highlighted the opportunities and obstacles each youth faced in pursuing their STEM interests, as well as factors influencing the further development of and persistence in the interest. Even though the three youth live in the same learning ecosystem and attended the same middle school and afterschool program, the mere presence of STEM learning resources did not guarantee that each youth was aware of the resources or if they were aware of the learning resources that they felt the resources were available and accessible to them. Finances (economic capital), geography, available transportation options, and other social or cultural capital resources all were factors. Each of the pathways were exceedingly unique and from the perspective of each youth the ecosystem *was* different.

This article attempts to deepen and extend the qualitative findings of the three youths' SIPPs by moving beyond their three unique pathways, which are difficult to generalize to the overall STEM learning ecosystem. We also strive to define the characteristics essential in addressing fundamental questions such as whether the ecosystem is thriving; if it is, who does it work for, and if it is not thriving, what is the reason? We argue that the ecological sciences have applied systematic approaches and empirical methods to study ecosystems, while educational research and applications have primarily used the ecosystem concept as a descriptive metaphor, which is only helpful to a degree (Hecht and Crowley 2020; Falk, Dierking, and Staus 2020). We make the case that researchers and educators using the ecosystem model for learning contexts could significantly benefit from adapting the analytical and application approaches pioneered within the ecological sciences that have enabled the development of adaptive management strategies such as those used in ecosystem restoration and recovery efforts.

Like ecologists, we defined a *STEM learning ecosystem* in a very specific way, focusing on three qualities of thriving ecosystems: (1) productivity; (2) durability; and (3) resilience (see Falk, Dierkingand Staus 2020). Also, as with living things in natural ecosystems, we assumed that learners perceived the learning opportunities in their ecosystem in varied ways for different reasons. Thus, although all youth ostensibly live within the same learning ecosystem (one that contains comparable resources and opportunities), reality is likely not this straightforward. The mere presence of STEM learning resources in a community does not guarantee that learners are aware of them; if they are aware, they feel resources are available and accessible to them because of either finances, geography, transportation, or other social/cultural capital reasons. In addition, not all learning ecosystems contain the same number or variety of STEM offerings, depending upon systemic factors such as the ecosystem's size, affiuence, or location (e.g., rural/urban). It is our hope that this approach will help inform the management and adaptability of entire learning ecosystems.

Youth work with circuits during 4-H Science Club in the SUN afterschool program.

Case Study Findings Through an Ecosystem Lens

Over the three years we tracked Charlie, Steve, and Stella, we wanted to understand what the STEM learning ecosystem "looked like" for each of them and what supported or hindered their strong interest in STEM, with the broader goal of understanding their individual journeys and better understanding critical elements of a thriving STEM learning ecosystem. Here we provide highlights of the findings from this perspective; for a detailed description of the methods and each youth's pathway, refer to Shaby et al. (2021).

Charlie

Charlie takes a path through uncharted territory, with few skilled guides and visible signposts to help connect his interest to visible and accessible resources in the learning ecosystem. Charlie is very interested initially in what he refers to as "coding." He enrolled in a free Schools Uniting Neighborhoods (SUN) afterschool program held at the middle school. One class he took was Pixel Arts, in which he learned how to design web-based games; one of the class sessions focused on coding, but he also learned about and used Twine, an open-source tool for telling interactive, nonlinear stories for a game. Although coding is not required in Twine, one can extend stories with additional coding languages (e.g., JavaScript). Charlie enjoyed storytelling and began writing at home. His parents and peers were supportive, reading his work and providing feedback. At this same time, Charlie was trying to learn JavaScript because he was interested in "coding" and so he could he write more complex, extended stories. Unfortunately, JavaScript was not taught in the Pixel Arts afterschool program or in school.

Charlie tried to find resources to teach himself JavaScript, but he was only able to identify resources that required payment. His parents offered general encouragement for his writing and offered feedback, but seemed to lack the social capital necessary to effectively guide him. He also received mixed messages from them about being on the computer too much. Like many youths from underrepresented communities, he was in uncharted territory with few guides and a lack of social capital to make his resource search effective. Although he remained interested in coding, he was unable to pursue this interest as much as he would have liked: He could no longer take computer science classes at school, there was no afterschool program at the high school, and his home computer was broken. He participated in what was "in front of him" while in middle school and during the afterschool program in which he participated, but he was unable to successfully navigate greater opportunities in the extended ecosystem because of financial and social capital reasons. During the three years we interacted with Charlie, he never got his computer fixed and his family moved in with his grandparents.

Fortunately, when Charlie entered high school, he became interested in video and took two elective courses, Advanced Video and Newsroom. Charlie's teacher noticed his piqued interest and offered him a job using the video class equipment to record school board meetings. This permitted Charlie to continue his interest in storytelling—in this case, visual storytelling. He now had an effective guide in his teacher, who helped him economically by offering him a job. It is possible that Charlie's interests all along were more in storytelling than technology, computers, and coding—an emerging line of practice (Azevedo 2011) that he and his family (and even the supportive teacher) may not have entirely understood. Despite his strong desire to learn about programming generally, and coding in particular, Charlie may have had difficulty identifying and locating relevant resources and opportunities in the ecosystem because he lacked the adult support to help him determine exactly what his interests were. These constraints in the structure of the ecosystem itself, and Charlie's inability to access additional resources related to computers and coding (and perhaps storytelling), decreased his participation in such activities, making it challenging for his interest to persist. Charlie had consistently taken advantage of opportunities in the ecosystem readily available to him, but his choices were limited both in and outside of school due to his and his family's limited financial and social capital. The ability for youth to fully identify their interests and find resources within the ecosystem is critical to their pathways and persistence in a specific STEM area. Fortunately, he had a high school teacher who noticed his interest and was an effective guide in helping him pursue opportunities in video production.

Steve

Steve takes a path that at times is difficult to recognize, until guides connect with his interest and assist him in realizing that the ecosystem includes more visible and accessible learning resources. When we first met Steve, he was totally infatuated with ants; however, he quickly exhausted his ability to pursue this interest, in part because of the lack of social capital that his guides (in this case his extended family) had related to his topic of interest. Although family members tried to capture ants for him, collectively they were unable to help him find additional resources, hindering his interest pathway.

Beyond his and his family's lack of social capital, there was another critical reason that Steve's initial path seemed difficult to recognize. Both Steve's specific interest in ants—and his more general interest in entomology—are exceedingly specific interests with very few visible resources or guides available in the Parkrose STEM learning ecosystem, either in school or outside school. School provided little support, so he primarily pursued this interest at home, via the internet, and on his own by observing captured ants and trying to build a colony. If his parents had additional social capital, they might have taken Steve to the local public library or to observe an ant swarming after a nuptial flight in Central Oregon; they might have also perused the Portland State University faculty directory to see if there was a local expert on ants or entomology, but seemingly they did not understand that these options were available.

However, Steve—still a resilient STEM-interested youth—began pursuing an alternate interest he had in computer science, perhaps related to his extended family (two of his uncles work in Silicon Valley). This was a STEM area in which his extended family had social capital and one in which both in-school and out-of-school learning resources existed; collectively these resources allowed Steve to successfully pursue this interest.

There was also one other critical reason why Steve was able to progress in this interest. When Steve first identified this "new" interest, his parents gave him a great deal of support, another form of social capital. This was not because they necessarily shared his interest, but because of the lived experience of their extended family, they could see that their son might be able to make a good living in this area; an important issue for them. Thus, his parents were motivated to support his interest. Even though Steve still struggled to find opportunities to push his coding knowledge and skills to ever-higher levels, he felt like he got more support for this area of interest than he did for his interest in ants. The support offered by his extended family—on a topic in which they have social and cultural capital—allowed them to effectively guide Steve through the ecosystem. This influenced his ability to participate in activities related to his interest, which facilitated his persistence.

Stella

Stella takes a well-lit path, with visible signposts and skilled guides, as well as connections between her interests and available learning resources. Early on Stella expressed a strong interest in astronomy and made broad use of the Parkrose and extended Portland STEM learning ecosystem to pursue this interest. Initially her expressed interest was in astrophysics, until she appreciated how much math was required; she switched to astrobiology after taking a biology course in high school. During her middle school years, she participated in the SUN afterschool program, an amateur astronomy club, and an astronomy-focused Girl Scout troop. Her parents, who also were interested in astronomy, not only helped initiate her interest but also had the social capital to connect her to relevant resources. This alignment between her and her parents' interests served as a mutually reinforcing motivation.

Unlike Steve's interest in ants, Stella's interest in astronomy also was more readily fulfilled as there were numerous out-of-school astronomy resources in Parkrose and the greater Portland community. These resources were effectively signposted in a way that Stella and her parental guides could readily access; if they were outside Parkrose, Stella's parents drove her to them. It is unlikely that these resources were all free and there was no indication that the cost of her interest was an issue for the family financially. In fact, at her last interview, she was pleased to share that her parents had bought her a new telescope for her birthday (that she asked for), in addition to the two other telescopes the family already owned and the one she made at Girl Scouts.

There also was a serendipitous event during the study, a complete solar eclipse, which further reinforced Stella's interests and her parents' involvement in supporting the interest. It is critical to note that while high school offered Stella more choice and opportunities to explore her astronomy interest, she began to push back a bit about being identified only as a STEM-interested youth. She talked about her "new" interests in performance (she joined the drama class, band, and choir). Although Stella was proud of "branching out," she still strongly claimed at her last interview that she planned to do something STEM-related in the future, although she did not know in what area. Research findings indicated that Stella's pathway—including her persistence in STEM overall and in astronomy specifically, as well as a clearly developing STEM identity—was quite unique among most Parkrose youth at this age.

Discussion

These cases offer useful insights into how three specific youth perceived the resources available to them in a STEM learning ecosystem, highlighting the affordances and constraints each faced in pursuit of their interests, as well as the curious role of serendipity. Importantly, each youth's interest in STEM persisted over the three years we followed them, although not always in the same specific areas of focus. Collectively, the STEM Interest and Participation Pathways (SIPPs) of these youth uniquely demonstrate the critical importance of understanding the nature of the *ecosystem* itself and its characteristics, including *its structure* and the *availability and access to learning resources* (with access defined primarily by a youth's family social, cultural, and financial capital). Also important was whether *resources* to support specific interests, activities, or practices *were numerous and signposted* in ways that made them visible and relatively easy to access and use.

However, to apply these ideas more generally to learning ecosystems writ large, it is critically important to transcend the individual pathways so that we can actively and intentionally create and tweak ecosystems in ways that increase the number of children who have access to quality STEM learning early on; find it interesting; and then begin a supported, connected, and valued journey toward a life that includes STEM. As outlined by Falk, Dierking and Staus (2021), it is helpful to frame these findings using the three qualities of healthy, thriving biological ecosystems: (1) productivity, (2) durability, and (3) resilience. It is important to point out that although we will discuss these three dimensions as separate entities, this is not the case at all; it is difficult to categorize the characteristics and processes we observed in the three youth SIPPs (as well as in our entire sample), into just one of the three dimensions (see Figure 1). Collectively, these three qualities contribute to a healthy and thriving ecosystem.

There were additional structural issues in the ecosystem that strongly influenced youth STEM interest and participation pathways. In terms of formal schooling, no youth reported that science and math classes at the middle school (ages 12–14) were important in either triggering or sustaining specific STEM interest. By contrast, high school (ages 15–16) classes were consistently identified as important resources for supporting STEM interest. It is fair to generalize that there are many more ecosystem opportunities at the high school level since youth have more choice and control over courses that align with their interests and aspirations. Like Bricker and Bell (2014), we found that offerings in middle school seemed to potentially constrain the maintenance of STEM interest.

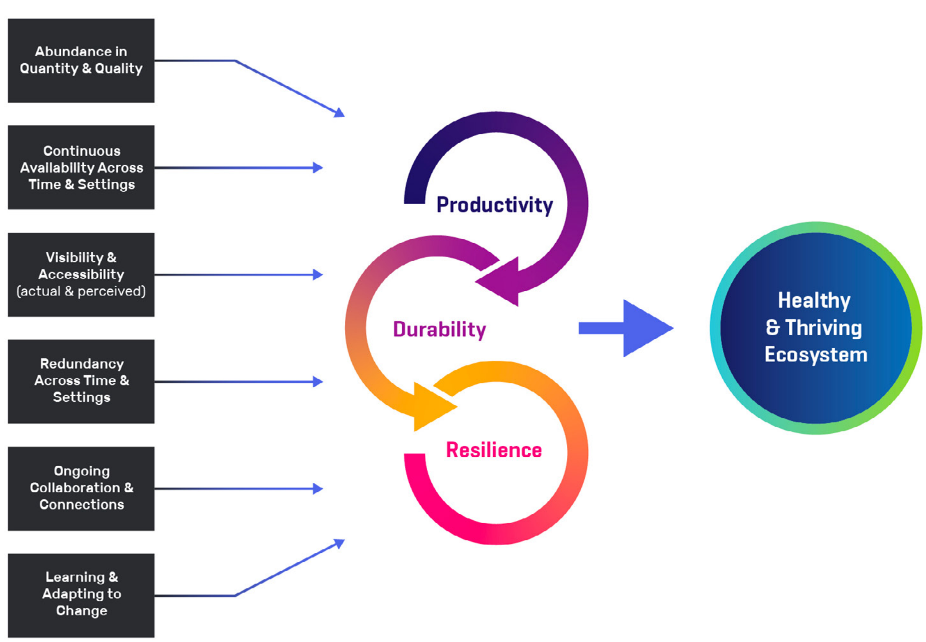
These structural issues were also a factor with the out-of-school learning resources in the ecosystem. Programs such as afterschool, weekend, and summer opportunities are now appreciated as important in supporting STEM engagement, learning, interest, and motivation, particularly among low-income youth and youth of color (McCreedy and Dierking 2013; Bevan et al. 2010; Clark 1990; NRC 2009 2015; Stocklmayer, Rennie, and Gilbert 2010). Although all youth in this study

Productivity

Understanding what, and how much an ecosystem "produces" is critical to understanding a system. The biological study of ecosystems was revolutionized by the consistent use and quantification of productivity measures such as energy (McIntosh 1985). Within a learning ecosystem, productivity is a function of its structure and the visibility, availability, and access learners have to its resources; the three youth SIPPs presented here demonstrate the varying interaction with these resources that can occur within the same ecosystem. Specifically, youth pathways were significantly influenced by the quantity and characteristics of in-school and out-of-school resources and activities related to their interests that were available within a variety of learning settings and contexts during middle school and high school years.

FIGURE 1

Characteristics and processes of learning resources that affect ecosystem productivity, durability, and resilience and collectively contribute to the maintenance of a healthy and thriving ecosystem.



participated in afterschool programs during middle school, the programs provided varying and mostly incomplete levels of support for interests. A further constraint was that these programs were only available for one month in the summer and most did not continue into high school. Summertime was consistently a STEM learning "desert" in this ecosystem, despite our efforts to support family STEM engagement during these months. Thus, although out-of-school resources were important, they suffered from similar structural issues to those identified in the middle school. As a result, collectively, the ecosystem was not sufficiently productive to consistently sustain specific STEM interests over time at this critical age.

Durability

Healthy natural ecosystems are characterized by considerable durability that arises from long-term intersecting relationships between and among resources. Therefore, measuring ecosystem durability requires that the entire system be studied as a whole, rather than merely as individual or isolated parts of the system. Learning ecosystems are durable and persistent only to the degree that they support access and participation across settings and social arrangements over long periods of time. One important aspect of durability is redundancy; in learning ecosystems, complexity develops as the number, richness, and diversity of learning resources increase; for example, individuals can learn about geology, both in school and through out-of-school opportunities such as afterschool programs, special interest clubs, websites, online resources, etc.

As highlighted in this study, social and cultural capital (as well as effective guides) play important roles in helping youth pursue long-term interests. This study supports the idea that in a healthy learning ecosystem youth have opportunities to identify and use appropriate learning resources across settings and over time (durability) that extend their interest. The mere availability of learning resources, productivity, is insufficient by itself to establish a healthy and thriving ecosystem. As suggested above, the capacities afforded by durability also need to be present so youth can locate and use the "next" resource that will help them continue to pursue their interest.

The ability of a youth in this ecosystem to continue to pursue their interests was greatly influenced by both youth and their families' social and cultural capital, which influenced their ability to find and leverage potential resources. The role of familial social, cultural, and financial capital was observed in all three cases most often when it was missing. We found that Steve exhausted his ability to pursue his interest in ants in part because of his parents and extended family's lack of social or cultural capital related to his specific interest but also their understanding of the overall STEM learning ecosystem, its learning resources, and how to access them. Financial constraints also emerged as a limitation for some youth's ability to pursue their interests.

The reverse was also true. Stella's parents possessed ample quantities of social, cultural, and financial capital (including understanding how to access the resources), so there were seemingly endless possibilities to pursue her STEM interests with no apparent geographical or financial constraints. Stella's perceived ecosystem was more extensive than that of the other two youth, in part because her parents could locate and access a wide variety of often geographically dispersed resources.

One other family-related issue of critical importance often not considered in the literature—likely because it can be sensitive—relates to whether the family values support a child's interest. Important to youth at this point in their development, particularly youth from underrepresented communities, is that they feel their family supports their interest (Wang 2020). Value placed on making a good living—combined with the social capital of knowing people who work and succeed in a variety of STEM occupations, including as technologists and other support roles within the scientific enterprise—can make a tremendous difference.

Parkrose youth from the SUN afterschool MESA Club explain their Robotics design to a referee at a city-wide competition.

Resilience

To be resilient, the species and communities within an ecosystem (in our case, in-school and out-of-school learning resources, the educators offering them, and the learners and families engaging with them) must be able to buffer disturbance, reorganize and renew, and learn to adapt and transform in response to change (Lavorel et al. 2015). We all observed this starkly with the advent of COVID-19, as both in-school and OOS educators scrambled to learn from and adapt to these new realities. Also, as is true of biological ecosystems (e.g., Mahonge 2010), the more complex and highly integrated a learning ecosystem, the healthier and more resilient it can be.

New research into climate adaptation in biological systems has identified three primary mechanisms and traits that support the resilience of ecosystems and facilitate their capacity to adapt: structural diversity, the role of keystone species, and connectivity. In a biological system, this may be maintaining perennial vegetation to reduce the risk of future desertification; preserving intact, diverse, connected forest stands; or focusing on greater management of fire-sensitive species. We can view the resilience of a learning ecosystem similarly. For example, resilience increases when educational organizations and resources foster substantial collaboration and connections (i.e., synergies within and between themselves). It is also critical that the ecosystem includes key learning resources to support specific interests, activities, or practices that are perceived as abundant, visible, and accessible. In some cases, specific youth interests were not supported by the ecosystem under study, either because resources were not diverse enough or were not effectively signposted in ways that made them relatively easy to identify, access, and use.

Youth used digital resources (e.g., YouTube videos) to pursue interests, but even this resource appeared to be insufficient for sustaining engagement in the absence of other supports in the ecosystem. The topic of the interest also made a difference; there were more resources and opportunities aligned with some specific areas than others, which in turn influenced outcomes. For example, as discussed earlier, there were far fewer clearly visible resources about ants in this ecosystem than there were about astronomy.

Although youth could pursue an existing interest or an interest could be triggered, it was clear that if youth had less social, cultural, or financial capital, it often influenced their ability to effectively navigate the ecosystem, and thus they found it challenging to locate learning resources that could sustain their interest. As has been discussed in the out-of-school, informal, and free-choice STEM learning arenas, a healthy, resilient learning ecosystem contains many diverse resources and opportunities in school and out of school that have the potential to excite youth—and possibly even adults and families—about a topic. We found that the STEM learning ecosystem under study was less rich and diverse in terms of resources and effective signposting, making it difficult for some youth to be inspired and sustain an interest (Staus, Falk, and Dierking, forthcoming).

Recommendations

Based on the findings and their interpretation, here are some recommendations for building a productive, durable, and resilient learning ecosystem healthy enough to support and sustain youth's interest and participation in STEM, both in adolescence and beyond:

Productive Ecosystems

1. Ensure quantity and quality of both in-school and out-of-school resources and activities available to youth, ideally with designed ways for youth to access the next experience, along with intentional planning and collaboration between and among in-school (middle and high school) and out-of-school resources. Remember that availability and accessibility require both awareness that a resource exists, as well as the means and opportunity to use it.

2. Ensure that there are diverse afterschool, weekend, and summer opportunities for youth and their families to participate in that offer individualized pursuit of interests, fostering both beginning interest, as well as nurturing and sustaining interests over time. Build these offerings based on the interests of youth. (See earlier SYNERGIES papers describing STEM Interest and Participation Pathway survey findings and applications.)

Durable Ecosystems

1. Since learning ecosystems are healthier as the number, richness, and diversity of learning resources increase, build redundancy into the ecosystem's available resources.

2. Durable ecosystems also support access and participation that goes beyond the quantity and quality of available resources. Equally, if not more important, are issues of accessibility, both identifying the availability of resources across settings and understanding how to use them. Involving parents and significant adults of youth—particularly those from underrepresented groups—in positive, engaging, and fun activities with their children using learning resources throughout the community is one strategy to accomplishing

this goal. Also, it is essential to design workshops for parents and significant adults of youth that help them understand the importance of their children's interests, build *their* social and cultural capital, and gain knowledge about offerings within the ecosystem and how to access them.

3. Help educators (in school and out of school), parents, and other significant adults understand the importance of supporting youth's interests and provide them with pointers for serving as effective guides. Encouragement is a form of social and cultural capital that is underused. Offering youth extracurricular activities and jobs, as well as being a resource for helping them plan their future learning are particular examples for how to provide this support and encouragement.

Resilient Ecosystems

1. Ensure that resources to support specific interests, activities, and practices are numerous and signposted in ways that make them relatively easy to access and use within the learning ecosystem. This is particularly the case for specialized topics. Build in scaffolding that supports and sustains youth interest beyond the initial trigger and excitement.
2. Resilience increases when educational organizations and resources foster substantial collaboration and connections (i.e., synergies within and between themselves).
3. It is also critical that the ecosystem includes key learning resources to support specific interests, activities, or practices that are perceived as abundant, visible, and accessible. Help youth know what the "next" resource might be to move them along their STEM interest pathway.

Summary

We have argued throughout this article that researchers and educators using an ecosystem model in learning contexts could benefit from adapting ecological analytical and application approaches to develop adaptive management strategies, like those used in biological ecosystem restoration efforts.

Complex ecosystems like the Parkrose STEM learning ecosystem are dynamic, both at the individual level of learners and at the overall ecosystem level. Ideally, the goal is to create and foster a community-wide effort to build a productive, durable, and resilient STEM learning ecosystem healthy enough to support and sustain youth's interest and participation in STEM, both in adolescence and beyond.

Youth's beginning storyboard for a web-based game about organic food in Pixel Arts at the SUN afterschool program.

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REFERENCES

Azevedo, F.S. 2011. Lines of practice: A practice-centered theory of interest relationships. *Cognition and Instruction* 29 (2): 147–184.

Bevan, B., J. Dillon, G.E. Hein, M. Macdonald, V. Michalchik, D. Miller, D. Root, L. Rudder, M. Xanthoudaki, and S. Yoon. 2010. *Making science matter: Collaborations between informal science education organizations and schools*. Technical Report. Washington, DC: Center for Advancement of Informal Science Education.

Bricker, L.A. and P. Bell. 2014. "What comes to mind when you think of science? The Perfumery!": Documenting sciencerelated cultural learning pathways across contexts and timescales. *Journal of Research in Science Teaching* 51 (3): 260-285.

Cresswell I.D., and H. Murphy. 2016. *Biodiversity: Factors affecting resilience capacity. In: Australia state of the environment* 2016, Australian Government Department of the Environment and Energy, Canberra. https://soe.environment.gov.au/theme/biodiversity/topic/2016/factors–affecting-resilience-capacity, DOI 10.4226/94/58b65ac828812

Clark, R.M. 1990. Why disadvantaged students succeed: What happens outside school is critical. *Public Welfare* (Spring): 17-23.

Dierking, L.D., and J.H. Falk. 2003. Optimizing out-of-school time: The role of free-choice learning. *New Directions for Youth Development* 97 (Spring): 75-88.

Dierking, L.D., and J.H. Falk. 2016. 2020 Vision: Envisioning a new generation of STEM learning research in (Eds.) L.D. Dierking and J.H. Falk. Cultural Studies in Science Education. 11(1): 1–10. DOI: 10.1007/s11422-015-9713-5.

Falk, J.H., and L.D. Dierking. 2018. *Learning from museums*. Lanham, MD: Rowman and Littlefield.

Falk, J.H., and L.D. Dierking. Forthcoming. On-ramps to nowhere: Are free-choice science learning institutions/organizations fulfilling their goals? In *Amplifying Informal Science Learning* eds. J. Diamond and S. Rosenfeld. New York: Routledge.

Falk, J.H., L.D. Dierking, and N.L. Staus. 2020. The use of ecological concepts in the social sciences: Measuring the productivity, durability and resilience of learning ecosystems. *Ecology and Conservation Science* 1 (3): 555563. DOI: 10.19080/ECOA.2020.01.555563

Falk, J.H., L.D. Dierking, N. Staus, W. Penuel, J. Wyld, and D. Bailey. 2015. Understanding youth STEM interest and participation pathways within a community: The SYNERGIES project. *International Journal of Science Education, Part B* 6 (4).

Falk, J.H., L.D. Dierking, N.L. Staus, J.N. Wyld, D.L. Bailey, and W.R. Penuel. 2016. The *Synergies* research-practice partnership project: a *2020 Vision* case study. *Cultural Studies in Science Education* 11 (1): 195-212. DOI: 10.1007/s11422015–9716–2.

Fortus, D. and D. Vedder-Weiss. 2014. Measuring students' continuing motivation for science learning. *Journal of Research in Science Teaching* 51: 497-522. https://doi.org/10.1002/tea.21136.

Hecht, M., and K. Crowley. 2020. Unpacking the learning ecosystems framework: Lessons from the adaptive management of biological ecosystems. *Journal of the Learning Sciences* 29 (2): 264-284. https://doi.org/10.1080/10508406.2019.1693381.

Lavorel, S., M.J. Colloff, S. McIntyre, M.D. Doherty, H.T. Murphy, D.J. Metcalfe, M. Dunlop, R.J. Williams, R.M. Wise, and K.J. Williams. 2015. Ecological mechanisms underpinning climate adaptation services. *Global Change Biology* 21 (1): 12-31. https://doi.org/10.1111/gcb.12689

Maltese, A.V., C.S. Melki, and H.L. Wiebke. 2014. The nature of experiences responsible for the generation and maintenance of interest in STEM. *Science Education* 98 (6): 937-962.

McCreedy, D., and L.D. Dierking. 2013. Cascading influences: Long-term impacts of informal STEM programs for girls.Philadelphia, PA: Franklin Institute Science Museum Press.

National Research Council. 2009. *People, places and design: Learning science in informal environments*. Washington, DC: National Academies Press.

National Research Council. 2015. *Identifying and supporting productive STEM programs in out-of-school settings*. Washington, DC: National Academies Press.

Shaby, N., N.L. Staus, L.D. Dierking, and J.H. Falk. 2021. Pathways of interest and participation: How STEM-interested youth navigate a learning ecosystem. *Science Education.* 105 (4): 628-652.

Staus, N.L., K. Lesseig, R. Lamb, J.H. Falkand, and L. Dierking. 2020a. Validation of a measure of STEM interest for adolescents. *International Journal of Science and Mathematics Education* 18 (2): 279-293.

Staus, N.L., J.H. Falk, W. Penuel, L. Dierking, J. Wyld, and D. Bailey. 2020b. Interested, disinterested, or undecided: Exploring STEM interest pathways in a low-income urban community. *EURASIA Journal of Mathematics, Science and Technology Education* 16 (6): em1853.

Stocklmayer, S.M., L.J. Rennie, and J.K. Gilbert. 2010. The roles of the formal and informal sectors in the provision of effective science education. *Studies in Science Education* 46 (1): 1-44.

Traphagen, K., and S. Traill. 2014. *How cross-sector collaborations are advancing STEM learning*. Technical Report. Los Altos, CA: Noyce Foundation.

Wang, X. 2020. *On my own: The challenge and promise of building equitable STEM transfer pathways*. Boston: Harvard Education Press.

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2

YOUTH AND COMMUNITIES TAKING ACTION THROUGH STEM

INTRODUCTION

What's STEM Got To Do With It?

BY BETH MURPHY, Field Editor, *Connected Science Learning*

What's the goal of education? Career preparation is surely a part, but there's certainly more to it than that. While the purpose of schooling is a topic worthy of discussion and debate, you'll likely find a reasonable degree of agreement regarding the importance of teaching young people the skills and knowledge necessary for things like informed decision making, productive contributions to society, and civic engagement.

What does this have to do with science education? The purpose of K–12 science education is broader than preparing students for postsecondary learning and STEM-related careers. After all, we want every young person to become an adult capable of using scientific knowledge and skills to guide how they gather information, make decisions, and take action in their everyday lives. Scientific thinking and knowledge can and should be tools everyone has the confidence and capabilities to use.

So, then, how do we as educators help to make this a reality? Perhaps you've read articles about or seen for yourself what young people can make happen when they see science as personally relevant and are inspired and empowered to advocate and act because of it. This chapter features strategies for engaging young people to use STEM to make a difference in their communities—whether it is in their classroom, neighborhood, city, or the world—and examples of how they are doing it!

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Commitments for Connected STEM

Spanning Disciplines, Generations, and Anchor Institutions for Humane Science

BY KATIE HEADRICK TAYLOR

"I wonder whether your moral and spiritual progress has been commensurate with your scientific progress." — Martin Luther King Jr.'s "Paul's Letter to American Christians," delivered at Dexter Avenue Baptist Church, Montgomery, Alabama, on 4 November 1956

In response to Martin Luther King Jr.'s provocation, how do educators ensure that students' learning about the moral imperatives of society remain in sync with understanding scientific innovation? What are new models of *connected STEM* that clearly value the moral and social development of young people? How do these new models create and reinforce human connection across various heterogeneities of knowledge, culture, and practice (e.g., Rosebery et al. 2010)?

In this article, I propose three major design principles—or commitments—in creating educational environments for connected STEM learning that scale across diverse student populations and bridge formal and informal learning contexts. The first principle is that a definition of connected STEM should not be limited to spanning knowledge and practices from multiple STEM disciplines or contexts, but should intentionally span humanities practices and related orientations to inquiry Second the design of STEM learning environments should work to span generations of learners so that problems the effort addresses are approached historically as well as innovatively. The third design consideration (related to the intergenerational nature of participating learners and teachers) is to involve *and connect* stakeholders and representatives from important anchor institutions revered by the community (e.g., public libraries, local colleges, the mayor's office, public schools, places of worship). If facilitators, paraeducators, and learners cannot physically move across these institutions to do the collective work, then participants should develop lasting connections to and across these places from being a part of the work.

In summary, *connected STEM* in our designed learning environments should span

- STEM and humanities disciplines,
- generations of learners, and
- anchor institutions.

Enacting these commitments foregrounds and supports the ethical and moral obligations learners have to each other, to their communities, and toward larger social issues, ensuring that connected STEM works on problems that matter for people's lives.

Examples of STEM Engagement

To support these points, I draw upon two sources of empirical material. The first source is an interview with a developmental neuroscientist working as lead scientist at a biomedical startup. The interview was part of a larger effort to understand *how* the work of STEM professionals is "connected," and what connection looks like at the scale of routine professional practice in a lab. The focal scientist, Dr. Stewart, was chosen because he reported pursuing a STEM profession for moral reasons (rather than financial or other objectives): to improve people's well-being and quality of life through therapeutic intervention.

The second empirical source is a recent community-based design study (Bang et al. 2016) I led called *Off the Map* that occurred in a nonmetropolitan area of the southeastern United States. The project brought together public high school students and teachers, software designers, librarians, local historians, GIS specialists, college professors, and members of the mayor's office to create and disseminate a digital walking tour of the town's forgotten histories. Following recommendations from Roschelle et al. (2000), *Off the Map* embedded the use of technology as a learning tool within a larger movement of community reform.

Looking comparatively across these two examples of STEM engagement demonstrates that *connected STEM* undergirds both professional practice and designed learning opportunities for young people, but more importantly foregrounds social connection and ethics in the *doing of STEM*. Comparing STEM professional practice to that of designed educational experiences for young people to learn STEM accomplishes two goals:

1. The comparison invites a range of possible STEM endeavors into the same conversation, drawing a link between what young people are doing and what they could become, and
2. Identifies similar implicit and explicit values and ethical projects across different STEM learning contexts (e.g., Hall and Stevens 1994).

Looking at professional practices helps educational designers decide which ethical orientations we hope to reproduce and those we want to newly promote for more just, morally driven STEM work. How might we better prepare young people to approach STEM professions as a way to enact their moral obligations and ambitions and what current examples do we have of those enacting ethical aims in their professional worlds?

Redefining Connected STEM to Span the Humanities

In thinking expansively about connected STEM, I found useful the notion of "integrated STEM." Nadleson and Seifert (2017) define *integrated STEM* as "involv[ing] conditions that require the application of knowledge and practices from multiple STEM disciplines to learn about or solve transdisciplinary problems" (p. 221). The issue or problem guides the learning process rather than the "have a hammer, everything is a nail" approach. However, actual transdisciplinary problems—wicked, real-world problems—do not adhere to *STEM* boundaries either. Such problems require that we think further beyond STEM disciplines to span knowledge and practices from the humanities.

How It Looks in Professional Practice

The daily work of Stewart, lead scientist at a biomedical start-up, illustrates how knowledge and practices from STEM and the humanities are endemic to his problem-solving processes in his laboratory. With a PhD in developmental neuroscience, Stewart chose this professional path as a means of improving the overall quality of people's lives through STEM. Therefore, he reported surprise at discovering that visual design is one of the most essential skills in his professional work, skills that he never *formally* learned. A typical day or week for Stewart involves communicating with investors, lawyers, and managers (all non-scientists) using scientific processes and generated data visualizations he creates. His understanding of visual design must be sophisticated enough to *shift* to the relative expertise of these various audience members (e.g., investors need to see the rate of growth, lawyers need to see risk, managers need to see logistics). Stewart anticipates the professional vision people bring to an interaction with a process or product (Goodwin and Goodwin 1997), using it as a resource for his visual designs. Stewart reported that using the same visualizations across these stakeholders is not an option, something he was reprimanded for early on in his tenure at the company. But with so much practice, Stewart's elevated sense of gestalt—his perception of the overall elements working together in the design—made him the go-to person for producing or editing visualizations in the company. Stewart feels satisfaction in this role, commenting that this function in his scientific job seamlessly connects to his at-home art-making projects and practices; he paints portraits and nature scenes in his garage studio when not at work.

How We Designed for It

In *Off the Map,* a community-based design study, a team of educators (e.g., public high school teachers, librarians, community historians) used STEM to solve an issue that plagues most U.S. communities: histories belonging to People of Color were whitewashed or altogether buried over time (a process in which public schools have been complicit, see Taylor 2018). But if residents of a place desire to understand how their home communities developed over time, then they must learn the histories of Black, Indigenous, and other BIPOC stakeholders.

The team of educators, high school students, and representatives from the local mayor's office designed a solution to excavate those stories: a mobile app that pinged residents or visitors with excavated stories while on the move (Marin et al. 2021). Learning and taking up practices from humanities, especially history, were critical for students to understand how the digital application should be designed and coded, and how it should function for residents/users. Further, students needed archival research and oral history interview strategies to generate the content of the mobile app. While building the technical components of the app were not trivial, the more challenging aspect of software development arose when team members had to "translate" the complexities of historical accounts to the forms familiar in mobile apps. Stories—perhaps better characterized as "yarns"—told by elders became a brief text description, one or two images, and a point on a map. Eventually, coders of the app added audio capabilities so that users could hear excerpts of elders' stories. Students agreed, however, that the available digital modalities were a poor representation of their conversations with older folks. At times, this incommensurability demonstrated how *un*-practiced we are at supporting teams of learners to work across STEM and humanities disciplines (e.g., Stevens et al. 2005), or how we think of these disciplinary mismatches as opportunities for better educational designs. As the project wrapped up, it became clear to the team that the technical form beat out historical complexities, leaving most of us unsatisfied with the overall outcome of the digital, mobile app.

The mayor of a small town in the southeastern United States talks with public high school students and teachers about processes of community development. Students hold various mobile devices to collect visual and audio records.

Synthesis

Practices from the arts and history are two examples in which disciplinary knowledge from the humanities made addressing a particular problem possible. Looking across a range of STEM endeavors— from professional practice to educational interventions with youth—we sometimes see seamless integration of STEM and humanities catalyzed by the identification of a problem to be solved first. This starting point is, of course, different from deciding what practices or orientations learners need to know and then attempting to retrofit real-world problems to those targeted practices.

For Stewart and the *Off the Map* team, getting people's attention and changing their minds was of utmost importance. Then, they asked, what familiar practices can we borrow from disciplines to do that work? Looking at his images and figures, I often forgot that the *content* of Stewart's visualization was complex scientific phenomena because his graphics were so stunning. In *Off the Map* the content was historical data made to fit within a more straightforward wireframe, or web format (though no less easy to construct). In this way, disciplinary boundaries blur in describing the outcome. It is in the backward mapping of the *process* where we see that different ways of looking and working, borrowed from distinct disciplines, added up to a product intended to improve the well-being of its users.

Integrated STEM as Working Across Generations

Just as authentic problems do not adhere to disciplinary boundaries, neither do they segregate by age. School is one of few contexts most of us encounter where age segregation is the norm. Families, libraries, museums, places of work, churches, and most out-of-school time STEM programs consider multi-age learning configurations as an asset (Hatton Yeo and Ohsako 2000). Following this logic, the design of learning environments in and out of schools should work to span generations of learners (e.g., Tzou et al. 2019) so that problems the effort addresses are approached historically as well as innovatively.

How It Looks in Professional Practice

Stewart's work as a mid-career scientist is to innovate within the drug development process. Yet, at every team meeting a "longer view" on the development process is represented by late-career scientists. These "old-timers [more experienced scientists and external advisors to the company] know what should come next without even looking at it," Stewart said. This familiarity with the overall process saves Stewart and the company precious time in avoiding common pitfalls and queuing-up acceptable next steps in drug discovery. Stewart also describes "newcomers" as scientists recently coming out of different doctoral programs and being intimately familiar with recent publications and developments from their respective institutions. Newcomers make important connections to other parts of the field so that Stewart's lab is not operating within a vacuum. (See Lave and Wenger 2002 for an extensive analysis of the role of newcomers and old-timers in communities of practice.)

How We Designed for It

I saw similar advantages of intentional generation-spanning in *Off the Map.* The success of our project hinged upon the integration of retirees in the community. Several high school students involved in the project were interested in representing the changing role of their school in the community (from a Freedman's Institute to a polytechnic school to a public high school) in the app; old-timers *embodied* some of these transitions, having been students there decades ago and living through some of the institutional transitions. Though retirees had exceptional historical and professional knowledge from a variety of disciplines, they also had other invaluable and uncommon resources (at least compared to teens young parents and working professionals): time and long-standing far-reaching community connections. Like in Stewart's lab, old-timers helped the younger generation of innovators (i.e., high school students designing the mobile app) anticipate roadblocks and would then connect students to other people in the area who might be useful in solving an emergent issue. While these interactions were helpful in the moment, several students made lasting relationships with older community members, and reciprocally, retirees described feeling useful to and knowledgeable about the overall objectives of the project. In many ways, these working relationships temporally spanned academic and professional trajectories and contextualized for high school students the objectives of the project. Students heard much about the *transformation of participation* (Rogoff 1994) of old-timers who were students at their high school, had graduated, gone to college, become successful professionals, and then retired, still contributing and committed to their shared community.

Students, teachers, and members of the historical society join in the public library conference room to discuss the potential form and function of the mobile app, viewable on the projector.

Synthesis

Designing STEM learning environments to connect and *integrate* knowledge and wisdom from across generations might be considered a form of *relational pedagogy* (e.g., Herrenkohl et al. 2019); relationships anchor the work and allow learning and teaching to thrive. Importantly, this form of relational pedagogy (i.e., working across generations of expertise) provides a long view on the process and product, collaboratively questing for innovative solutions with an awareness of redundancies, missteps, and potential next steps. At a personal level, learners and teachers—younger and older—grow their networks potentially beyond the life cycle of the collective project. (An example of this network growth is a high school student in *Off the Map* who contemplated an undergrad degree at the University of Washington because of side conversations with the author about existing programs.) Young people in particular, working with elders, confront a living example of learning, growing, and investing in the community. This version of thriving is perhaps different from other narratives of success young people receive in small towns, such as narratives that focus on upward mobility via moving to the big city and leaving your roots behind.

Integrated STEM as Spanning Anchor Institutions

The third design consideration, related to the intergenerational nature of invited learners (and teachers), is to involve stakeholders and representatives from important anchor institutions revered by the community (e.g., public libraries, local colleges, the mayor's office, public schools, and places of worship; see Barron et al. 2013). Working across these partnerships is not only necessary to accomplish meaningful work, but also builds a social and potentially physical infrastructure to support future projects where ideas, people, and resources can move more easily (e.g., Penuel 2019; Pinkard 2019).

How It Looks in Professional Practice

Science projects in the professional sector increasingly function across geographically distributed teams, pulling in expertise and assets from around the globe. In Stewart's workday, the scientific work is distributed globally, resulting in cultural, linguistic, and temporal spreading (McDonough et al. 2001). With work occurring at two major research universities, clinical trials in Europe, and drug chemistry occurring in Southeast Asia, this startup thrives on national and international collaboration, but also the lowest bidder. While this form of spanning "anchor institutions" is not entirely feasible when designing learning environments, young learners should understand that today, scientific collaboration is often a team of global players. In Stewart's lab, the nature of work does *not* map onto highly individualized metrics of "success" like tests in school. Are people's lives improved by the product? If so, the work that Stewart produced contributed to that success, but it is not his alone.

How We Designed for It

The local public library—a kind of crossroads for many, especially rural, communities (Reid and Howard 2016)—housed the bulk of the in-person work for *Off the Map*. A revered local institution, the library in this nonmetropoli-

Students, teachers, members of the historical society, and residents discuss the role of the public school in desegregating the area. Students considered this conversation for app content.

An Off the Map participant gathers feedback on the mobile app from a community member.

tan setting gathers people from far-reaching rural spots in the county, the very young to the very old, and people from various racial and cultural groups that the public schools segregate (i.e., white students make up the vast majority of one of the two high schools in the area). Various community groups borrow space during the week to hold meetings and events. Workspace is dedicated to school-age children for homework help and Wi-Fi hotspots. This public library also affords a robust technical infrastructure with dedicated staff to troubleshoot computer and internet-based is-sues destined to arise Given this setup the public library already spans and brings together other anchor institutions revered by the community. The seed library, podcast, tax consultations, writing workshops, and almost nightly lectures on a host of topics ensure that people from across backgrounds and interest intersect through these library services.

In coming together for *Off the Map*, team members were exposed to various ways other communities of practice consider and work on a problem. High school students designing the app worked with the town's GIS specialist to gather geolocated data layers. An intern from the local newspaper worked with software designers to tell the story of the app. Local historians and librarians worked with school teachers to share available resources for building locally based curricula. Professors at the local liberal arts college worked alongside high school teachers to compare instructional practices.

Synthesis

The network of sites connected via *Off the Map* was much more limited in scope than something like the HIVE Network in New York City (e.g., Ching 2015) or how Stewart's lab functions internationally. However, spanning anchor institutions in nonmetropolitan and rural settings is an essential part of modeling for young learners the nature of connected and *integrated* STEM practice (e.g., Bell 2012) that we see in professional settings. Additionally, a foundational component of the *Off the Map* curriculum was for young people to research through text and artifact-based methods various key institutions in the area *and* physically visit them with a community elder. In these site visits, both young and older participants saw the familiar in new ways based on people's questions, reactions, new information, and the mediation of the mobile app (Bell et al. 2019).

Project team members quickly learned that the learning and teaching processes of *Off the Map* were intensely negotiated and sometimes contested, with different stakeholders at times pulling toward their objectives or relinquishing control (e.g., Barton 2003). Such negotiation is endemic in the cultural, linguistic, and temporal distribution of Stewart's work in the lab. Like Stewart has learned and continues to practice, young people in *Off the Map* learned the delicate interactional work of *relational attunement* (Taylor 2020): how people understand and fine-tune aspects of their work by considering the different perspectives and values of their collaborators. But within this negotiated terrain of knowledge practices, spanning essential anchor institutions created "access to and valued possibilities for participation in practices at a broader scale" (Hall and Jurow 2015, p. 173). The landscape of possibilities—for learning, for work, for participation—expanded even within a small town in the southeastern United States.

Conclusion

What are current examples of connected STEM learning environments that intentionally advance the moral and social development of people (across the lifespan) alongside scientific innovation? How do we make STEM knowledge production *about* being and living together better, in more just ways with all forms of life rather than toward the accumulation of capital? Looking at professional practices—and people motivated by moral obligations to humanity—helps educational designers decide what ethical orientations we hope to reproduce and those we want to newly promote for more just, morally driven STEM work. I have offered three commitments for connected STEM, though there are more, radical notions of how our learning environments should prioritize upending structures of inequality, racial injustice, and human supremacy (e.g., Bang 2020). How would this re-prioritization shift Dr. Stewart's lab work or the app development in *Off the Map*? Working across difference is a starting point and then making movements toward knowledgeably enacting equitable change is the objective.

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REFERENCES

Bang, M. 2020. Learning on the move toward just, sustainable, and culturally thriving futures. *Cognition and Instruction* 38 (3): 434–444.

Bang, M., L. Faber, J. Gurneau, A. Marin, and C. Soto. 2016. Community-based design research: Learning across generations and strategic transformations of institutional relations toward axiological innovations. *Mind, Culture, and Activity* 23 (1): 28–41.

Barron, B., S. Wise, and C.K. Martin. 2013. Creating within and across life spaces: The role of a computer clubhouse in a child's learning ecology. In *LOST Opportunities.* Explorations of Educational Purpose, vol 23, eds. B. Bevan, P. Bell, R. Stevens, and A. Razfar, 99–118. Springer, Dordrecht.

Barton, A. C. 2003. Kobe's story: Doing science as contested terrain. *International Journal of Qualitative Studies in Education* 16 (4): 533–552.

Bell, A., K.H. Taylor, E. Riesland, and M. Hays. 2019. Learning to see the familiar: Technological assemblages in a higher education (non) classroom setting. *British Journal of Educational Technology* 50 (4): 1573–1588.

Bell, P., C. Tzou, L. Bricker, and A.D. Baines. 2012. Learning in diversities of structures of social practice: Accounting for how, why and where people learn science. *Human Development* 55 (5–6): 269–284.

Ching, D., R. Santo, C. Hoadley, and K. Peppler. 2015. On-ramps, lane changes, detours and destinations: Building connected learning pathways in Hive NYC through brokering future learning opportunities. *Document retrieved from: http://hivenyc.org*.

Goodwin, C., and M.H. Goodwin. 1997. Contested vision: The discursive constitution of Rodney King. In *The construction of professional discourse*, eds. B.-L. Gunnarsson, P. Linel, and B. Nordberg, 292–316. London: Longman.

Hall, R., and A.S. Jurow. 2015. Changing concepts in activity: Descriptive and design studies of consequential learning in conceptual practices. *Educational Psychologist* 50 (3): 173–189. doi:10.1080/00461520.2015.1075403

Hall, R., and R. Stevens. 1994. Making space: A comparison of mathematical work in school and professional design practices. *The Sociological Review* 42 (S1): 118–145.

Hatton Yeo, A., and T. Ohsako. 2000. *Intergenerational programmes public policy and research implications. An international perspective*. UNESCO.

Herrenkohl, L.R., J. Lee, F. Kong, S. Nakamura, K. Imani, K. Nasu, … and N.P. Eslami. 2019. Learning in community for STEM undergraduates: Connecting a learning sciences and a learning humanities approach in higher education. *Cognition and Instruction* 37 (3): 327–348.

Lave, J., and E. Wenger. 2002. Legitimate peripheral participation in communities of practice. In *Distributed Learning, Social and Cultural Approaches to Practice*, eds. M.R. Lea and K. Nicholl. London: Routledge Falmer.

McDonough, E.F., K.B. Kahn, and G. Barczak. 2001. An investigation of the use of global, virtual, and colocated new product development teams. *Journal of Product Innovation Management* 18 (2): 110–120.

Penuel, W.R. 2019. Infrastructuring as a practice of design-based research for supporting and studying equitable implementation and sustainability of innovations. *Journal of the Learning Sciences* 28 (4–5): 659–677.

Pinkard, N. 2019. Freedom of movement: Defining, researching, and designing the components of a healthy learning ecosystem. *Human Development* 62 (1–2): 40–65.

Reid, H., and V. Howard. 2016. Connecting with community: The importance of community engagement in rural public library systems. *Public Library Quarterly* 35 (3): 188–202.

Rogoff, B. 1994. Developing understanding of the idea of communities of learners. *Mind, Culture, and Activity* 1 (4): 209–229.

Roschelle, J., R. Pea, C. Hoadley, D. Gordin, and B. Means. 2000. Changing how and what children learn in school with computer-based technologies. *The Future of Children* 10 (2): 76–101. doi:10.2307/1602690

Rosebery, A.S., M. Ogonowski, M. DiSchino, and B. Warren. 2010. "The coat traps all your body heat": Heterogeneity as fundamental to learning. *Journal of the Learning Sciences* 19 (3): 322–357. doi:10.1080/10508406.2010.491752

Stevens, R., S. Wineburg, L.R. Herrenkohl, and P. Bell. 2005. Comparative understanding of school subjects: Past, present, and future. *Review of Educational Research* 75 (2): 125–157.

Taylor, K.H. 2018. The role of public education in place-re making: From a retrospective walk through my hometown to a call to action. *Cognition and Instruction* 36 (3): 188–198.

Taylor, K.H. 2020. Resuscitating (and refusing) Cartesian representations of daily life: When mobile and grid epistemologies of the city meet. *Cognition and Instruction* 38 (3): 407–426. doi: 10.1080/07370008.2020.1766463

Tzou, C., E. Meixi, Suárez, P. Bell, D. LaBonte, E. Starks, and M. Bang. 2019. Storywork in STEM-Art: Making, materiality and robotics within everyday acts of indigenous presence and resurgence. *Cognition and Instruction* 37 (3): 306–326.

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Critical Consciousness in Engineering for Sustainable Communities

A Justice-Oriented Approach Connecting Schools and Communities

BY GELING XU, AERIN BENAVIDES, ANGELA CALABRESE BARTON, EDNA TAN, SELENA BLIESENER, GINA DIFRANCESCO, AND SCOTT CALABRESE BARTON

Critical consciousness is an important dimension of integrated science and engineering, or STEM, learning. Education is never neutral—it either supports students in conforming to the status quo, or it engages youth in a practice of liberation (Friere 1971/2000). Critical consciousness calls attention to how learning involves an awareness of understanding how inequality operates in society, including its structural roots, and the agency to engage in action toward social transformation. It is a powerful way to connect classrooms and communities toward the goals of justice-oriented STEM education (Upadhyay et al. 2021).

This article shows how an Engineering for Sustainable Communities (EfSC) approach to teaching engineering in the middle grades can support strong connections between classrooms and communities by fostering critical consciousness. We show how critical consciousness should not be viewed as separate from learning the content and practices of STEM, but rather as a way to orient how and why learning STEM matters in everyday life and hoped-for futures.

To accomplish this, we

- present the EfSC approach,
- draw on insights from student engineering design work to illustrate what critical consciousness looks like in STEM learning and its role in building connections between classrooms and communities, and
- offer implications for educators.

Our approach to supporting critical consciousness in teaching and learning STEM is grounded in a stance that engineering design requires people to integrate STEM ideas with social awareness. As students learn science and engineering knowledge and practice through class work, they need opportunities to improve their abilities to apply the learned knowledge in new contexts. Such contexts include the many problems that exist in the school community—students bullying each other, feeling school should be more fun, or needing more opportunities to celebrate achievements, which become important fodder for critical consciousness and problem-solving in STEM education.

Why Critical Consciousness in STEM Education?

Minoritized youth can face dehumanization and marginalization in schooling on a daily basis. These oppressions are heightened in STEM education through the underpinning norms, routines, discourses, and practices of whiteness and heteropatriarchy. Not only do these norms define what it means to know, do, and become in STEM, they also shape what and how classrooms and communities interact in STEM education.

Supporting critical consciousness as an explicit goal of STEM education is important because it fosters awareness, critique, and transformation of oppressions as they play out in classrooms and society. Critical consciousness can be thought about in terms of a praxis-informed cycle. It involves moving from *awareness* and *critique* or "critical awareness" to *action-taking* in ways that further inform awareness, allowing the cycle to continue. Critical awareness involves a process of learning to see, question, and analyze current social realities, including both social arrangements and structures, and how they limit opportunities, perpetuate injustices, and otherwise constrain people's lives. One "has to see the world in its true dimensions and possibilities before attempting to generate change" (Cammarota 2016, p. 237). Action-taking involves developing the perceived capacity and commitment to engaging in action to address perceived injustices, as well as the actions themselves (Diemer et al. 2021). Critical action can be individual or collective and reflects how people understand oppressions and their imaginations for social change.

Engineering education—engaging in design, from problem posing to designing and prototyping solutions—is a powerful space to support critical consciousness. This is especially true when the problems taken up are authentic, and students have opportunities to design and build solutions for the real world. Furthermore, moving from critical awareness to action-taking supports students' deepening technical knowledge and practice, and their understandings of current social realities (oppressions) and possibilities for social transformation. Studies show that supporting students in developing a critical consciousness simultaneously supports academic motivation and achievement, while promoting critical awareness (El-Amin et al. 2017).

Bridging Classrooms and Communities

Much of the design work in integrated science and engineering has focused on science and engineering practices, problem-solving, and exploring the value of integrating content areas for learning (Upadhyay et al. 2021). Despite the rich possibilities for connecting engineering design *with* communities, little work has been done supporting teachers in doing so with students. We are particularly concerned with how to design for supporting critical consciousness as a part of engineering design in ways that purposefully connect families and communities with engineering in authentic ways.

We, a team of engineers, teachers, and educational researchers, developed a *framework* to support middle school teachers and students in centering community and environmental considerations as they learn about and engage in the practices of EfSC (Calabrese Barton and Tan 2019; Tan et al. 2019). This approach takes into account social, political, cultural, and environmental concerns from community members toward a sustainable technological solution. The National Academies (2010) suggested that an important part of engineering education is to engage learners in understanding the importance of both the community and the environment in engineering design, and the engineer's responsibility in the process. They refer to this approach as Engineering for Sustainable Community Development. We drew upon this framework to co-design and enact engineering units focused on sustainable communities and energy transformations. These units were implemented, reviewed, and revised with 18 sixthgrade teachers and hundreds of students in Michigan and North Carolina. All unit materials are available online.

Our Engineering for Sustainable Communities (EfSC) Framework has four main principles:

1. *Uses Community Members' Ideas in Engineering.* Working alongside community members to improve the daily lives of people they know, students learn about the importance of community input about the problems affecting them, and community suggestions for possible solutions. Throughout the engineering design process, students elicit multiple community perspectives about the problems they defined,

their proposed solutions, and multiple design interactions/ prototypes.

2. *Helps the Community Solve Problems Through Engineering.* By helping the community solve problems, students learn and experience how all community members have the right and responsibility to contribute to defining problems and designing solutions. Community members are treated more justly, and collectively design solutions that work toward improving the community.

3. *Cares About the Environment.* Caring about the environment involves designing solutions while minimizing impact to the environment. This can mean maximizing materials already available in classrooms and communities, using renewable resources (such as cardboard from delivered boxes), supporting renewable energy sources, and building projects that last.

4. *Designs Solutions for Now and in the Future.* Balancing trade-offs equitably among environmental and social effects of designs is a design process that values increasing community members' wellbeing and the development of involved people and communities. The involvement of relevant perspectives in both engineering and local communities (e.g., parents, teachers, engineering experts) and evaluating the degree of their impact in the design process, helps maintain the balance of perspective in this process.

By integrating technical and social dimensions of problems and solutions to the process of localizing engineering design, teachers support students in seeing themselves as welcome and able to use engineering to support their community. Furthermore, EfSC principles align with the call "to define problems more precisely, to conduct more thorough process

TABLE 1

Engineering design challenges: curricular materials.

Design Challenge	Focus	Overview	Example Projects from Michigan and North Carolina Sites
How can I design electric art for family/friends? (2 weeks)	Identify, investigate, and design for inter-personal sustainability concerns	• Energy transformations and sustainable energy approaches • Engineering practices that draw upon interest, creativity, and care	• Light-up "drool proof" card for baby brother • 3-D light-up mug for mother • Light-up anime poster card for classroom
How can I make my classroom more sustainable? (3–4 weeks)	Identify, investigate, and design for classroom sustainability concerns	• Energy transformations • Regulating power loads • Renewable energy sources • Sustainability framework for happy, healthy, just classrooms/schools • Engineering practices that draw upon interest, creativity, and care	• Light-up limbo stick to support more classroom fun breaks • Bathroom monitoring system to ensure no child gets walked in on • Compliment box that lights up for students to share positive ideas with each other
How can we help stop the spread of invasive plant species? (3–4 weeks)	Identify, investigate, and design for community sustainability concerns	• Ecosystems (Interactions, Energy, and Dynamics) • Sustainability framework for maintaining biodiversity and ecosystem services • Engineering practices that draw upon interest, creativity, and care	• Novel systems for harvesting local invasive species (garlic mustard) • Paper-making from harvested mustard

of choosing the best solution, and to optimize the final design" (NGSS 2013) through recognizing the active role school and community members can play in engineering design.

EfSC supports movement of people, ideas, and resources across these different and connected communities as a part of the engineering design process. Students learn about how their classroom community is situated within a school community, which, in turn, is situated within their local community. Teachers help students navigate from a disciplinary core idea (e.g., energy transformations) to a problem space where they can define a problem worth solving and develop realistic and testable designs based upon current knowledge, empirically investigating technical and social dimensions, and operational constraints and specifications (e.g., What, powered by alternative energy, can I build to prevent bullying?). We want students to be able to say, "I can solve this problem collaboratively here in my community right now using what I know and what I have" rather than waiting to only use their STEM expertise in long-term future career goals.

Bringing EfSC to the Middle Grades Classroom: I-Engineering

We have developed and tested I-Engineering with the following tools and materials in collaboration with partnering teachers and schools (Table 1). Each challenge is guided by a driving question and moves students through three phases.

Phase 1: Defining the Problem. This phase focuses on learning how to define an engineering problem, which requires thoughtful integration of engineering and community expertise. To support youth in more precisely understanding a design task's boundaries—including its criteria and constraints from this integrated vantage point—we designed lessons to support students in seeking out, analyzing, and integrating both scientific and community knowledge to specify, expand, or limit movement toward possible solutions. This phase introduces students to the principles of EfSC.

TABLE 2

How can I make my classroom more sustainable? Unit flow

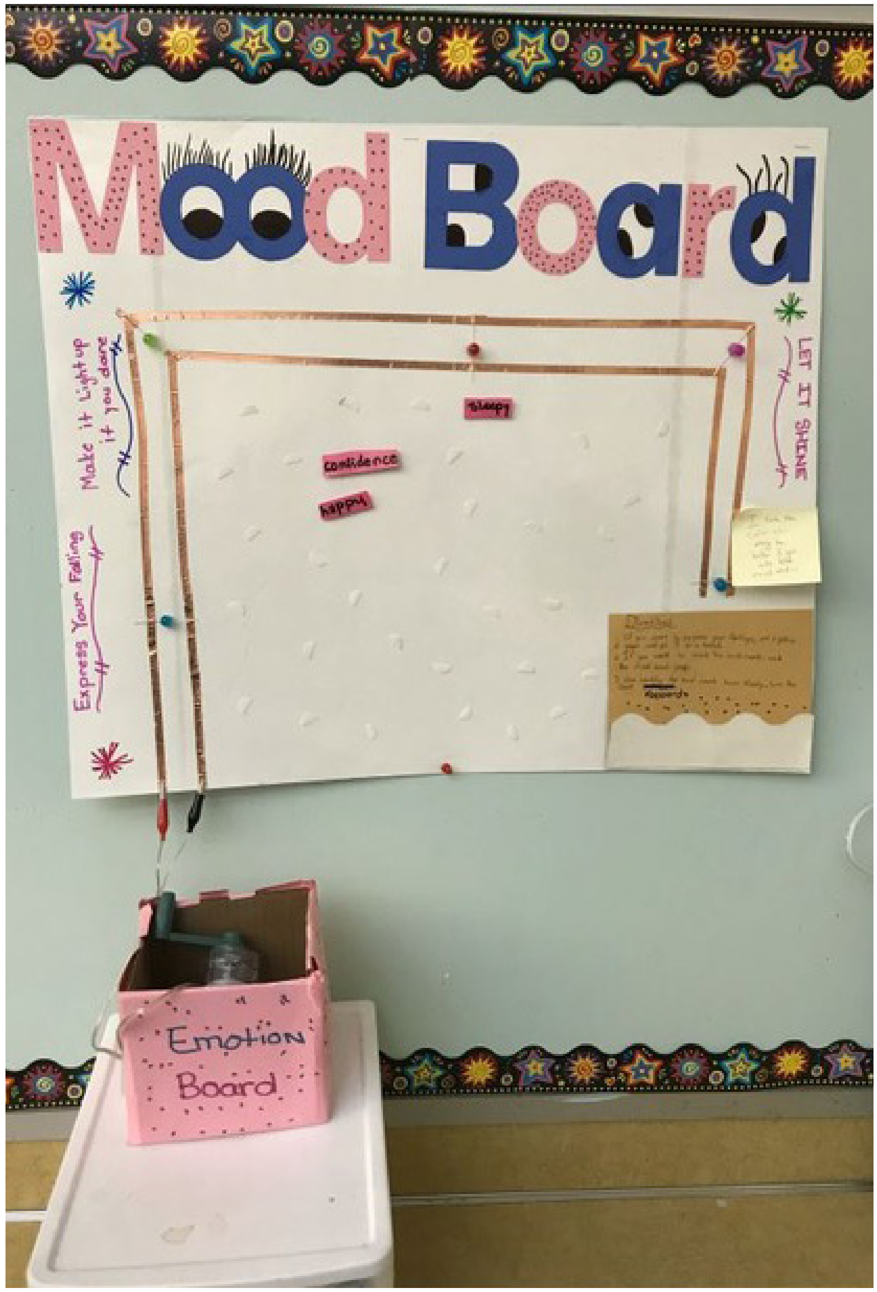
#	Lesson	Key Focus	Community Ethnography Integration
1	Introduction	Big Ideas in Engineering for Sustainable Communities **Lesson 1:** Engineering for Sustainable Communities	• Examining and discussing how youth their age use community ethnography as a part of engineering design
2–3	Exploring big ideas	**Lessons 2 and 3:** Powering Sustainable Communities (unless the previous unit was electric art): Needs, Demands and Challenges	• Generating community narratives
4–9	Iterative Design Cycle 2	Sustainable Classrooms: Defining Problems and Designing Solutions Through Community Ethnography **Lesson 4:** Engineering Design Challenge Intro **Lesson 5:** Defining the Problem: Using Community Ethnography to Define Engineering Challenges **Lesson 6:** Initial Design **Lesson 7:** Optimize Design With Community Feedback **Lesson 8:** Prototyping **Lesson 9:** Refining Designs Through Technical Tests and Community Feedback	• Using community ethnography as a part of engineering design • Surveys and observations of peers and community members • Dialogs with community on project ideas/design • Observation
10	Community Sharing	**Lesson 10:** Sharing Engineering Designs With the Community	• Community narratives

Phase 2: Designing Solutions. Students are supported in systematically fleshing out their design solutions. Teachers engage students in community surveys as part of the design process to support students in generating and analyzing data from multiple perspectives in engineering design. Teachers then help students figure out how the social dimensions of the design interact with the technical elements. The design process focuses on:

- the ongoing refining of design constraints and evaluating possible solutions toward optimization;
- multiple cycles of designing/conducting tests toward optimizing solutions;
- gathering/analyzing data from multiple perspectives including peers, school personnel, and families; and
- engaging in dialog on complicated conflicts in perspective and design trade-offs.

FIGURE 1

Light-up mood board group innovation to encourage peers to express their feelings.



A significant aspect of this design phase includes presenting design solutions—with rationales and data—to outside experts, including engineers, science educators and community members. Students are supported in breaking down the process through a sequential series of physical representations.

Phase 3: Prototyping and Optimizing Solutions From Multiple Perspectives. In this phase, youth build, test, and refine working prototypes as they communicate ongoing findings with school and community stakeholders to critically think through maximizing trade-offs. The lessons support youth in making visible the iterative nature of design work. Students are scaffolded in functionally decomposing, organizing, and trying out different computations informed by different perspectives/feedback obtained.

In this manuscript we report on student work from our unit focused on "How can I make my classroom more sustainable?" (Table 2). As a part of the unit, students are given the design challenge bounded with the following criteria: Innovate something in the classroom in a way that would address a classroom and community sustainability problem. Students were required to use a renewable energy source (such as solar panels or hand crank generators), 10 mm LED lights, copper tape, and any materials available in and around their classroom and school.

What Students Learned in the I-Engineering Unit

We share descriptions of two group projects from partner teachers' classrooms to show how EfSC supported students in developing critical consciousness as a part of engineering learning, and how it powerfully connected schools and communities. We show that students' critical consciousness in EfSC was built on three forms of critical awareness: community, technical-social iterative design, and sustainability. As we present these cases we show how:

- By engaging in community ethnography as a part of engineering design (e.g., surveys, interviews, and observations), students developed a critical awareness of community needs and wisdom.
- By engaging in engineering design of authentic community problems where both technical and social know-how mattered, students developed a critical awareness of how iterative design could be used to better their community in consequential ways.
- By supporting designs incorporating green energy sources and environmentally friendly considerations, students gained critical awareness of environmental sustainability.

Then, as students iteratively engaged in local, real-world engineering design challenges, they moved from critical awareness to taking action in ways that bridged their social and technical knowledge.

Case Study: Ms. L's Class Mood Board

Students in Ms. L's class in the Mood Board group (Figure 1) addressed the problem that students need a way to express their feelings. Ms. L asked the class how they might find out what problems members of their classroom and school community cared about. The class co-generated questions such as, "What challenges related to a happy and healthy community do you think are most important?" Students then surveyed and interviewed peers, school personnel, and families. After analyzing responses, students noted that the majority of respondents indicated a need for a stronger sense of community, along with the importance of helping people and fostering a happier classroom.

The group originally planned to make a light-up basketball hoop recycling bin, which they thought would bring fun into the classroom. However, as group members analyzed survey data and shared those insights with visiting community members and peers, they became aware that many students were struggling to feel welcome because they felt sad, angry, and frustrated due to being bullied, having friend difficulties, and getting in trouble. Sage described:

> *"Originally, we were going to make a recycling bin.... When Ms. S. [a student's mom] came and sat with us and she started asking questions, and we were like, 'Oh, we didn't think about that, we didn't think about that.' So, we went to our second idea."*

Students' emerging critical consciousness on the lack of opportunity to express a range of emotions that contributed to an unhappy/unhealthy classroom community was prompted by community survey findings.

FIGURE 2

Bully free zone group innovation to establish a safe zone in the classroom.

The group parlayed their developing critical awareness of community into action when they decided to design a "mood board." Sage stated this project was important because, "Students normally don't have a way to express their feelings and show how they feel. Normally you can only talk to someone or use your body language. Some people don't feel comfortable doing that. When someone's using the Mood Board, it's easier for them to express their feelings." Layla pointed out that she is sometimes sleepy in class because she stays up late to greet her mom coming home from her night shift. Her sleepiness causes her to feel cranky and get in trouble. The group explained:

> *"We created an invention to help solve this problem. Students can put their hand in the box and pick a mood that fits how they're feeling. Then they put it on the board. If students want to light up the board, all they have to do is turn the hand crank."*

Students noted that people could use the light-up recyclable paper board with LED lights on a copper tape parallel circuit to draw attention to their posted feelings. They also explained that if a student sees someone share that they are feeling angry or sad, then "you can practice empathy and try to make them feel better in some way or show you understand" because their project helps call attention to people's moods. In this way, the students pushed for the importance of recognizing and making visible a range of student feelings as important in school science. Students also handed out "mood board cards" to their peers, school personnel, and family members to encourage use of their design. Sage explained:

> *"I handed out those mood board cards to my parents. I gave one to Kali and Xander. They were like, "Oh, wow." They were excited! They were like, 'We could use something like this. Wow, I'm so impressed with you.' My mom was like, 'Oh, you're so successful in your group. I wanna meet them!'"*

Sage later said her mom wanted to come in to try out the mood board.

The group struggled to get their prototype to work the way they wanted and had to engage in many iterations, thus increasing their critical awareness of the intersections of technical engineering design with social design for community needs. They engaged in many cycles of testing the prototype: "First, we tested our lights to see if it worked. Another test we did is we tested if our moods [the mood options they offered] fit everyone." They modified how their board was designed and used, as Kai explained, "We changed the design. Yeah, we changed the design, and the way we put our copper tape on the circuit, . . . we changed the moods, the feelings." Sage further noted, they "wanted everyone in their class to put how they are feeling up on the board at the beginning of the day, and change it if they want to, as the day goes on."

Case Study: Ms. P's Class Bully Free Zone

Students in Ms. P's class in the Bully Free Zone project (Figure 2) addressed the problem that school needs to be more fun, positive, and safe from bullying. Surveying members of their classroom and school community along with parents, they found that 25% of participants felt that school needed to feel safer. Using interviews with peers and personal experiences, they narrowed down the "need to feel safe" to a particular problem space—bullying. Group members wrote, "We chose to address this problem because students were bullying each other. Bullying created a lot of drama in the school, and this created students to feel really bad about themselves."

Collecting and analyzing survey data helped the group develop critical awareness of classroom community needs. They learned how important safety was to their community. Going to the school's restorative justice room for bullying was an insufficient solution in their minds. Lataya explained that:

> *"The restorative justice room was a waste of time. It didn't work and caused them to have to leave their classrooms Students wanted to be able to stay in their own classrooms and have a space to be protected." (Researcher Field Notes)*

Critical awareness shifted to action taking when students put their understandings of community need into designing a possible solution. Using survey data, the group designed an area they called the Bully Free Zone. If a student felt bullied, they could go into this zone where teachers and peers would know they needed to feel safe, rather than needing to negotiate with the bully immediately in the restorative justice room. The group felt their innovation addressed bullying more directly because the Bully Free Zone would let students know that someone was there for them, without the need of finding and informing a teacher at the point when one is hurting from being bullied. Several parents and grandparents visited on "feedback cycle" day and offered supportive ideas and suggestions, such as having a colorful sign to help students feel cheery and having an agreed-upon way to use the design so that kids wouldn't "get in trouble" if they moved around the classroom to get to the Bully Free Zone.

Students used recyclable paper to make the Bully Free Zone signage prototype sustainable. They added a used paper box glued on the wall to hold the hand crank, incorporating reused materials into their design. They used a renewable energy source to light up the circuitry. The group discussed using a solar panel, then decided on a hand crank so that a student could have control over when the board would light up. Their new awareness of renewable energy helped them consider a design to help protect the environment, evidence of another kind of critical awareness students gained in engineering with care toward environmental sustainability.

The group wrote that, "Our invention makes us feel happy and excited . . . We learned about how to make different types of circuits." Students also learned to make sense of different types of power demands and energy transformations as their design evolved from a simple circuit to a parallel circuit, making their design effectively work with a 5v hand generator. This helped the group better understand trade-offs in engineering design, as they sought to balance technical and social needs. This kind of critical engineering awareness became an important aspect of their critical consciousness as they sought to solve problems faced by their community via engineering.

Implications for Teaching Engineering

With support, students are able to develop meaningful understanding and insights into how community-identified issues—often grounded in issues of injustice—can be integral to engaging in engineering. Engaging in a community survey was generative to students developing critical awareness both regarding community and iterative design, as well as how community and engineering can be deeply connected. As shown in the illustrative cases, students engaged in both rigorous meaning-making of community-identified issues in tandem with engineering practices and disciplinary core ideas.

In addition to aligning with the science standards, the EfSC principles highlighted the importance of engineering for addressing community-identified issues related to social justice. Deep meaning-making in both community issues and engineering practices were key to the emergence of the critical consciousness we see in students and teachers.

An EfSC approach supports students in developing a critical consciousness in technical-social iterations in ways that powerfully bridges schools and communities. As we illustrate with our cases, an EfSC critical consciousness involves both critical awareness (community, iterative design, and sustainability) and action (authentic designs for actual use in classrooms and schools) (see Figure 3). Below,we describe how teachers can foster these forms of awareness and action-taking so central to critical consciousness. Please see Supplemental Resources, "Data Analysis for Evidence of EfSC Principles," for more information on how these themes were determined.

Critical Community Awareness. We supported students in developing critical awareness of communities by integrating community ethnographic survey ideas, interviews, observations and feedback conversations across all stages of the engineering design process. Student groups analyzed these data and built evidence-based claims about issues that mattered to communities. They used these claims as the basis for articulating bounded problems that could be addressed through engineering. For example, students cared about their community members, building projects to solve problems such as "school needs to be more fun and positive." Students also took up projects that promoted social healing. Survey data analysis supported students' deeper meaning-making of social data—what different issues there are, how they might be related, and why they matter.

FIGURE 3

Critical consciousness in engineering for sustainable communities.

Therefore, we recommend that teachers add more community-related topics in their classes and encourage students' thinking more about other community members' ideas.

Critical Technical-Social Iterations Awareness. Students' iterative design awareness was strengthened by having to make sense of data from different epistemological origins and needs, such as how both disciplinary core ideas such as energy transformation and community insights informed their prototyping for particular community concerns. These often went hand in hand, (e.g., a parent suggested the need for a brighter sign, then required the youth to shift from a simple to parallel circuit). Teachers could incorporate multiple perspectives in their teaching of engineering design. This process involves making sense of both the *technical* and *social* elements of design Students experience—through iterative design as informed by particular community ideas/feedback—the interdependent and symbiotic nature of community and engineering.

Critical Sustainability Awareness. We supported students in developing critical awareness of sustainability by asking students to consider their design ideas against broader questions of what supports communities in being healthy, happy, and just. For example, the 19 groups we looked at all chose to use a hand crank to provide energy for prototypes. All groups chose to reuse materials or use recyclable materials, protecting the environment. Teachers introduced students to clean energy and the importance of sustainable development. Students researched different types of energy, and the benefits of clean energy, then applied this knowledge to their projects. This process helped students understand sustainability and helped them develop critical sustainability consciousness, which is an important part of engineering and technology ethics—and important to our future. Hence, teachers are encouraged to add more sustainability-related knowledge into every topic and ask students to use reusable and recyclable materials in their daily projects to develop students' sustainable awareness.

Conclusions

An EfSC approach offers the field of science and engineering education lessons toward promoting justice and community healing. Teachers found benefits for their students when they included critical consciousness in STEM education. Their students developed critical engineering skills in conjunction with caring for their communities. Students also developed sustainable engineering skills that they can use in life. We, as science and engineering educators, need to better prepare all students for an uncertain and challenging future.

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REFERENCES

Calabrese Barton, A., and E. Tan. 2019. Designing for rightful presence in STEM: Community ethnography as pedagogy as an equity-oriented design approach. *Journal of the Learning Sciences*. DOI: 10.1080/10508406.2019.1591411

Cammarota, J. 2016. The praxis of ethnic studies: Transforming second sight into critical consciousness. *Race Ethnicity and Education* 19 (2): 233–251.

Diemer, M.A., A. Pinedo, J. Bañales, C.J. Mathews, M.B. Frisby, E.M. Harris, and S. McAlister. 2021. Recentering Action in Critical Consciousness. *Child Development Perspectives* 15 (1): 12–17.

El-Amin, A., S. Seider, D. Graves, J. Tamerat, S. Clark, M. Soutter, J. Johannsen, and S. Malhotra. 2017. Critical consciousness. *Phi Delta Kappan* 98 (5): 18–23. https://doi.org/10.1177/0031721717690360

Freire, P. 1971/2000. *Pedagogy of the oppressed.* New York: Continuum.

National Research Council. 2010. *Engineering, social justice, and sustainable community development: Summary of a workshop*. Washington DC: National Academies Press.

Tan, E., A. Calabrese Barton, and A. Benavides. 2019. Engineering for Sustainable Communities: Epistemic Tools in Support of Equitable and Consequential Middle School Engineering. *Science Education*. DOI: 10.1002/sce.21515

Upadhyay, B., K. Coffino, J. Alberts, and A. Rummel. 2021. STEAM education for critical consciousness: Discourses of liberation and social change among sixth-grade students. *Asia-Pacific Science Education*, 1–32.

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Sustaining Community-School Relationships Around Shared Visions of Climate Justice and Science Teaching

BY DAVID SEGURA, DANIEL MORALES-DOYLE, SUSAN NELSON, AMY LEVINGSTON, AND KAREN CANALES

For the last 15 years, organizers from the Little Village Environmental Justice Organization (LVEJO) have been collaborating with science teachers from the Greater Lawndale Little Village High School for Social Justice (SOJO). These collaborations have sought ways to bring campaigns for environmental justice into the classroom while finding opportunities to bring science learning into the community. In this article we describe how our relationships have been reciprocal and sustainable over the years. We attribute this to a focus on holding expansive and principled visions of environmental justice through science teaching. We also explain a central assumption of our work: Youth from communities like North Lawndale and Little Village on the West Side of Chicago are important leaders in the intergenerational movement for a "just transition … from an extractive economy to a regenerative economy" (Climate Justice Alliance, n.d.). We use examples from our collaborative work to illustrate key features and lessons from our attempts at community-based science learning for climate justice. For context, we share a brief history of the community-based organization and the school.

History of LVEJO

In 1994 a group of parents and community members from Gary Elementary School in Chicago's Little Village neighborhood banded together to halt school repairs that were exposing summer school students to toxic fumes and particulates. These efforts coalesced into the formation of LVEJO, which is an organization that has been fighting environmental racism in the working class, predominantly Mexican immigrant community ever since. LVEJO's theory of change is rooted in the belief that when people understand the root causes of their experiences of oppression, they have the power and agency to transform their world. Their campaigns have taken a broad view of environmental justice (EJ) and its intersections with other issues for justice ranging from access to public transit, immigration policy, and even police brutality and mass incarceration. The organization's most widely celebrated victory was the 2012 closure of two coal-fired power plants on Chicago's southwest side that had been grandfathered into exemptions from the Clean Air Act four decades prior. LVEJO is now the largest EJ organization in the midwestern United States.

History of SOJO

Prior to 2005 most students from Gary and other Little Village elementary schools attended the lone public high school in the neighborhood, just a few blocks from LVEJO's office in the basement of a residential building. By the late 1990s the high school was in a crisis of overcrowding and underfunding. The state had allocated substantial funds to build a new high school in the neighborhood to alleviate this problem, but the mayor-controlled school district had done nothing with those funds even as two elite selective-enrollment high schools in affluent neighborhoods were built and opened in the same district, using allocations from the same timeframe.

After exhausting all sanctioned pathways to urge the district to build a new school in the neighborhood, 14 community members launched a hunger strike on Mother's Day in 2001 to demand the construction of a new school. The hunger strike lasted for 19 long days before district and city officials finally heard the community's demands for educational equity. An extensive process of negotiation, planning, and design followed, which involved substantial back-and-forth, collaboration, and compromise between district administrators, community members, educators, and even consultants and funders (see Stovall 2016). The outcome of that process was a plan for a high school campus, in the Little Village Industrial Corridor, to house four small high schools. These schools serve Little Village (officially known as South Lawndale) and North Lawndale, an adjacent predominantly African American neighborhood. The school's placement in one of Chicago's 26 industrial corridors highlights the neighborhood's lack of available land and the common challenges related to the selection of school sites in polluted areas (Mohai and Kweon 2020).

This process that founded the Little Village Lawndale High School Campus, which includes SOJO and the three other high schools, established distinct visions for each of the small schools on the campus. SOJO's vision sought to continue the community-based activism embodied in the struggle to build the school. The visions of the other three schools include having access to high-quality STEM education, maintaining and celebrating multicultural arts, and world languages.

Sustainable Relationships Between Teachers and Organizers

LVEJO organizers and board members graciously worked with SOJO teachers as they learned about the current and historical EJ struggles within the community and worked to turn those issues into curriculum. LVEJO was an ideal partner as teachers tried to figure out how to take up this charge in the school science labs.

During the development and initial years of the school, curriculum design and teacher professional development was focused on treating three overlapping types of knowledge as equally important: classical, critical, and community knowledge (Gutstein 2006). Classical knowledge is what is typically valued in school curriculum. Critical knowledge emphasizes questioning the powers that be and critiquing the status quo. Community knowledge refers to the grassroots understandings of community members that exist outside of the purview of formal institutions of schooling. Working with LVEJO helped science teachers connect forms of community and critical knowledge developed by community members and EJ organizers with the classical science content they were charged with teaching.

The initial meetings between SOJO science teachers and LVEJO established a long-term relationship that continues. These relationships have been maintained by continuity and connections among the people who work in both the school and the organization. For example, one of the authors was a founding member of the science department who has continued in that role for the last 15 years. Another author is an alumna of the school who became an organizer with LVEJO, a position she has held for the last seven years. The other three authors have each spent at least seven years as full-time faculty at SOJO. One also served for a year on the LVEJO board. Furthermore, the executive director of LVEJO has been a leader in the organization and a vocal supporter of the school since the founding hunger strike.

The first meetings between teachers and LVEJO centered on the most visible symbol of pollution, a coal-fired power plant approximately a half mile from the school. Teachers developed curricula and projects focused on the coal power plant in all of SOJO's science classes, including biology, chemistry, physics, environmental science, and advanced placement (AP) science classes. But the partnership has evolved and continued even after LVEJO members and their allies forced the power plant to close in 2012. This evolution has mirrored the continued struggles for environmental justice in the neighborhood. Both LVEJO organizers and SOJO teachers have worked together on multiple campaigns and curricula as new issues arose within the community. Mutual engagement and flexibility to take up new issues beyond the coal power plant has been a primary reason for the maintenance of this 15-year relationship.

Expansive and Principled Visions of Climate Justice

The continuing work between LVEJO and SOJO is built on an expansive view of climate justice, rooted in the shared belief that oppression is multi-faceted, interconnected, and deeply interwoven with social, political, and economic systems. With broader views of climate justice, our collaborations have occasionally connected directly to climate change while at other times the connection may only be apparent upon closer examination. Some LVEJO campaigns directly fought to curtail sources of carbon dioxide, like the struggle to close the coal power plant and multiple campaigns to prevent ever-increasing diesel truck traffic through the neighborhood. Others, like the push for more green space, wider access to public transportation, or reduction of volatile organic compounds (VOCs) in manufacturing processes are connected to the issue of climate change indirectly. In these cases classroom instruction facilitated students making connections (through science content learning) between local LVEJO campaigns and global issues of climate change. Our work together has also been predicated on an expansive view of science teaching where addressing social justice science issues supersedes the disciplinary boundaries that typically characterize biology, chemistry, or physics classes.

A particular example is an interdisciplinary sophomore capstone project that examines the role of capitalism in the extractive materials economy that is responsible for climate change and other environmental catastrophes. This capstone project draws on multiple content area classes to have students evaluate a consumer good that is important or relevant to them, examine and analyze its life cycle, and calculate the energy impact of its production and movement globally. This project also works to turn classroom instruction into real-world action. For example, with the assistance of LVEJO, students organized to be part of a climate march in the city center.

Taking a broader approach to both science teaching and understanding climate change also allows for an organized analytical approach for the complex interconnections related to climate justice. From a scientific point of view, students may learn that excess carbon dioxide caused by burning fossil fuels is the primary driver of carbon dioxide in the atmosphere. But an expansive view of student learning crosses disciplinary boundaries to deal with the ways that climate change is caused by extractive social, political, and economic systems predicated on the exploitation of human labor and the Earth. The interdisciplinary connections in this project include students learning about the history of exploitation of the Earth as rooted in colonialism, conquest, and genocide (Hill 2010; Rochlin 2012). At SOJO, science teachers consider these historical understandings as foundational to understanding environmental injustice related to climate change. This teaching is positioned as justice-centered and antiracist in its framing of white supremacy as justifying the exploitation of "undiscovered" lands and erasure of Indigenous people (Jacob et al. 2021).

Reciprocal Relationships Between the School and LVEJO

Mutual engagement was also maintained by reciprocity between LVEJO and SOJO when working on issues. This was strategically done in ways as identified by each other to draw on the strengths of LVEJO and SOJO respectively. LVEJOs established presence within the community, and its campaigns sought community input using door-to-door outreach, a level of community contact around science concerns that would be difficult for teachers to pursue. This is especially true in a small school where there are fewer faculty among whom to divide responsibility for committee work, outreach, and sponsoring of extracurricular activities.

The common goals of LVEJO and SOJO helped align classroom instruction with active opportunities for engagement among students while validating science curriculum as

FIGURE 1A

Part of a student presentation on the door knocking campaign experience.

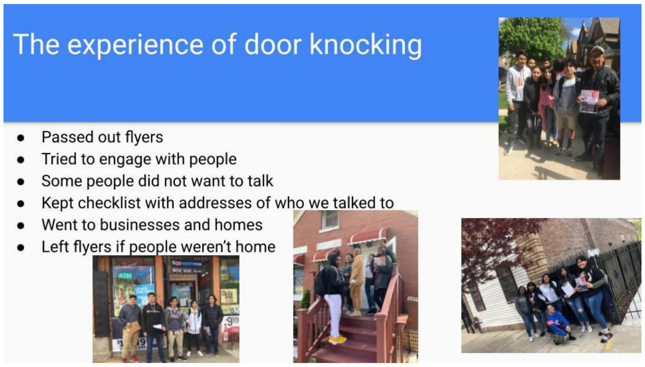
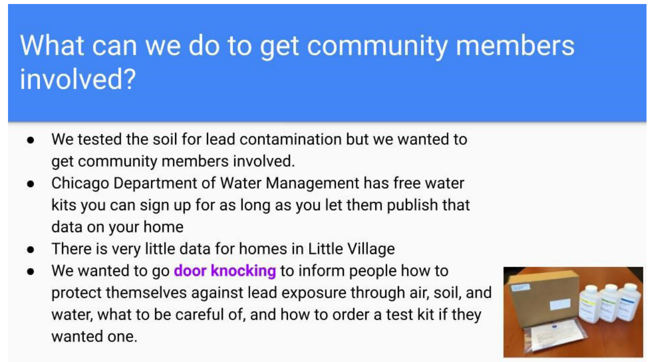


FIGURE 1B

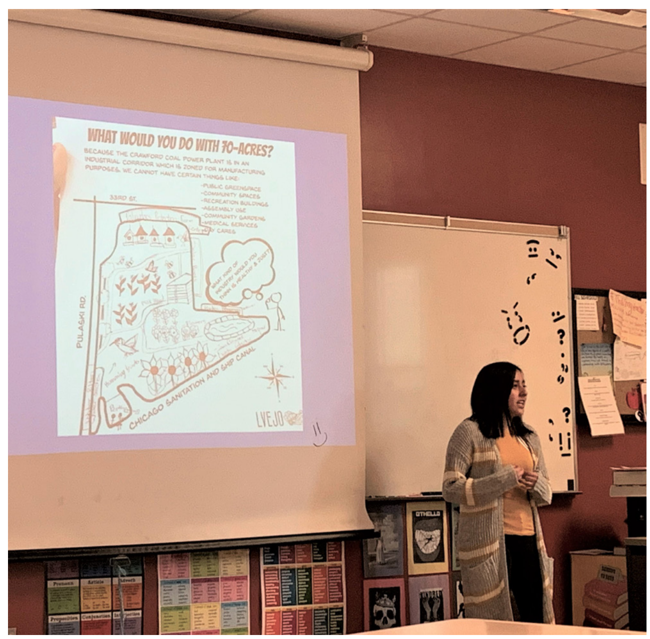
Part of a student presentation on the door knocking campaign experience.



grounded in community-based environmental issues (Figure 1a and 1b). As teachers sought to design community-based, justice-centered science lessons, LVEJO provided access to an organization that was already engaged in direct actions to address the injustices faced by community members, modeling social justice that was the goal of the school. This narrowed the scope of teachers' responsibilities to implementing instruction and supporting (not leading) the organizing, while still providing students with an outlet for acting on what they were learning. This mutual engagement provided opportunities for building capacity within the school that focused on community knowledge and connections. It also formed connections between LVEJO and students who were already engaged, knowledgeable, and motivated for action on community environmental issues while also leading to volunteer and employment opportunities for students (see Figure 2).

FIGURE 2

LVEJO staff (also a SOJO alum) leading workshop planning use of former power plant site.



SOJO Teaching About LVEJO Campaigns

SOJO teachers have sought to support the work of LVEJO by designing curriculum that integrates the current and historic LVEJO campaigns. For example, in environmental science class students learn about a former Superfund site, the Celotex site, that LVEJO successfully helped pressure the EPA and city to convert into a 21.4-acre park. This case study was an example of the tensions between equity and accountability, grounded in science. Students learned about the environmentally persistent contaminants on site, polycyclic aromatic hydrocarbons, while balancing accountability for landowners and manufacturers of tar and roofing products who used the land over its history. Additionally, students applied earlier learning of life-cycle analysis to identify and explain how lax environmental regulations created conditions for the contamination of the land. They considered how this contamination was an artifact of inadequate waste management and was related to larger calls for sustainability often ignored in the manufacturing and waste disposal process. Lastly, students learned that knowing more about types of contamination and their consequences for public health is useful evidence in arguing

FIGURE 3

Canales leading LVEJO'S community asset toxic tour with a group of science teachers.

FIGURE 4

Community member presenting community-based designs for the CELOTEX site. Screenshot from CELOTEX documentary released by LVEJO.

FIGURE 5

Gravel cap on CELOTEX site that was not initially approved by the EPA. Screenshot from CELOTEX documentary released by LVEJO [there is no other 'cap' like this on any U.S. toxic sites].

for social change. This was the case with this former Superfund site as directly connecting health impacts on residents to site contamination and runoff kept continued pressure on elected officials and corporate landowners to act, albeit not with the expedience desired by community members.

While learning about environmental policy, students were tasked with identifying solutions while considering the social and political nature of the remediation process that had extended remediation talks across multiple decades. When this case study was initially included in the SOJO science curriculum, the owners of the site, the EPA, and community members had not yet reached an agreement about the adequacy of the remediation, which included a cap unapproved as appropriate by the EPA. The EPA later said the cap was adequate. Rather than causing students to be confused, these tensions lent urgency and relevance to students learning about the use of scientific evidence and community voice in public policy, environmental remediation, and urban planning. Students considered—in their science classes and in their neighborhood context—how topics like sustainability, persistence of environmental contaminants, erosion, runoff, the precautionary principle, and life-cycle analysis intersect with community power and the political nature of change. Teachers supported students to make connections between this case study and larger issues in land development, including the building of schools on toxic land and in industrial corridors, as had been the case with SOJO and some of its feeder elementary schools.

During this unit, LVEJO organizers supported teachers' and students' environmental concerns by providing resources and making connections. For example, LVEJO provided internship opportunities for students and acted as a resource to learn about the history of the site from the perspective of residents. Since this was one of LVEJO's long-term campaigns, LVEJO not only had a rich knowledge upon which teachers could draw to familiarize themselves with the site (see Figure 3), it maintained a history of its own advocacy. For example, SOJO teachers showed an LVEJO-produced documentary (see Figure 4, 5, and 6) that tracked the trials and tribulations of 20 years of action, which lead to constructing a park on the site.

In chemistry, students have engaged in measuring and analyzing particulate matter and VOCs. This unit originated from

FIGURE 6

Undated newspaper article on the fight by community members to transform the CELOTEX site into a park. Screenshot from CELOTEX documentary released by LVEJO.

Controversia por un nuevo parque en La Villit

Gisela Orozco La Raza

Opiniones encontradas se han generado debido a la posibilidad de que el nuevo centro recreativo se erija en los terrenos de la que fuera la fábrica de asbestos Celotex.

Mientras que la Corporación para el Desarrollo Comunitario de La Villita (LVCDC) ha recaudado más de 11 mil firmas de los vecinos del área, que quieren que el parque se construya en la antigua escuela de oficios Washbourne (calle 31 y Kedzie), hay quienes tienen una opinión distinta.

Tal es el caso del Distrito de Parques de Chicago, el Concejal George Cárdenas (D-12) y el senador estatal Antonio Muñoz, quienes apoyan que el nuevo recinto recreativo se erija en los terrenos de la ex fábrica de asbestos Celotex.

Incluso, Cárdenas y Muñoz introdujeron una propuesta en la municipalidad para que se autorice la adquisición del terreno ubicado en el 2800 S. Sacramento Ave. Según declaró Jesús "Chuy García, director ejecutivo de la organización, ese lugar no es apropiado porque el

"Nosotros estamos fundam dos en lo que la comunidad di estamos imponiendo ningún rio, ahora resulta que el seño denas quiere su parque, si habia dicho nada", comentó.

Y agregó que la corporació ne un comité que está trabajan la construcción del parque Washbourne y que cada mié se reúne en la biblioteca de la 27 y la Pulaski.

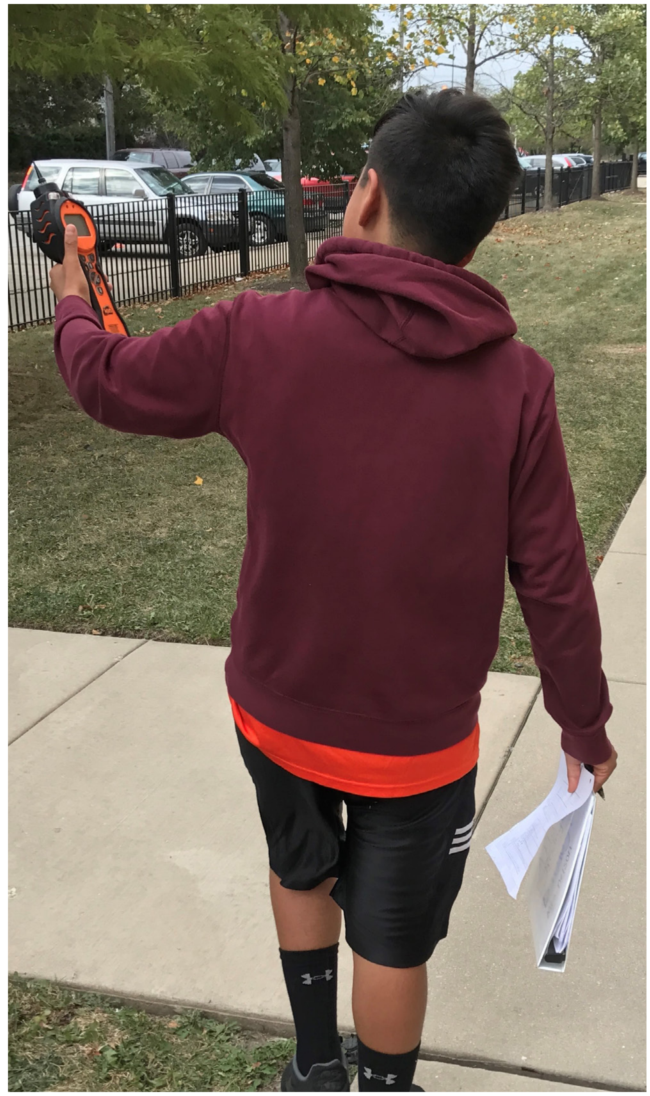
En tanto Howard Ehi miembro de LVEJO, dijo que comunidad quien debe decidi uso darle al terreno de Celote

Expresó que buscan que una división entre zonas re ciales e industriales en el ár que no es sano que se erijan cas en los vecindarios.

"Tenemos la oportunidad cidir qué queremos para est si queremos parques, escuela sas, tenemos que elegir com munidad; será un paso atrás si mos que la ciudad construy

FIGURE 7

Student collecting air-monitoring data.



LVEJO's campaigns around the number of diesel trucks in the neighborhood. With the school and much of the neighborhood located in an industrial corridor, the development and expansion of Unilever's Hellman's Mayonnaise site, the demolition of the smokestack from the closed-down power plant (during the pandemic), and the construction of the distribution warehouse owned by HILCO, the increased truck traffic and overall air quality is a major community concern. These issues also display the ways in which the city exploits specific neighborhoods and places the burden on the people in those neighborhoods to provide proof that the environmental impacts residents experience are detrimental. This issue has served as an entry point to our study of spectroscopy and the instruments we use in chemical analysis—how they work and their limitations (Morales-Doyle, Childress Price, and Chappell 2019). We have also studied the biochemical ways that VOCs can impact long-term health. The unit has also provided an opportunity for students to design and carry out an experiment to measure the air quality within the school building.

Organizers from LVEJO have supported this work in the classroom with students when presenting their campaigns. These presentations have not only defined the problem and explained the health impacts of long-term exposure to particulate matter but have also provided the sociopolitical context that has created the overwhelming burden of pollution placed on Little Village. LVEJO's engagement and lessons with youth also serve as a starting point for students to imagine what they want their neighborhood to look like. Students can use their scientific understandings to influence the decisions impacting their neighborhood. For example, after studying the health and biochemical impacts of particulate matter and VOCs, students wanted to advocate for rezoning the area around the school and other residential areas near industrial pollutants and diesel truck routes while continuing a more rigorous study of the air quality in the neighborhood.

LVEJO Supporting SOJO Youth Participatory Science Projects

One of the primary forms of engagement between SOJO and LVEJO through the years has been through youth participatory science (YPS; Morales-Doyle and Frausto 2021). YPS projects position students as experts by engaging them in data collection and analysis of the air they are breathing or the soil in the neighborhood. In a unit designed around analyzing the contaminants in the microclimate around the school, LVEJO loaned air monitors to students (see Figure 7) so they could experience real-time collection of particulate matter data. LVEJO youth interns spent a week showing students how to use the instruments to collect data throughout the day. This first collaboration was spurred by an LVEJO project involving community science and air quality data collection.

While students may not have contributed a substantial amount of data collection in the larger scheme of the project, LVEJO organizers viewed students experiencing this sort of community-engaged science as part of their work. Teachers and organizers believed that allowing students to see what they already instinctively knew about the air around them, but in a scientific context, was a powerful learning experience. This provided an entry point for students to become passionate about using their knowledge to change the situation. A few years later, a SOJO teacher reached out to LVEJO for technical support regarding data collection about VOCs. For years, students and staff at SOJO had complained about a chemical smell around the school. While LVEJO was not leading a VOCs campaign at the time, they nonetheless offered time and resources to support students in examining the smell.

LVEJO has continued to respond to the needs and desires of the students and school community. Over the past several years in chemistry class, students have been studying heavy metal contamination in soil and water, focusing on lead. With a university partner, students have collected soil and water samples from around the community that were analyzed for lead levels. Many of these samples contained lead levels above the EPA action limits of 15 parts per billion (ppb) for water, and 400 parts per million (ppm) for soil in play areas. Students wanted to respond to the issue in multiple ways—one of which was to inform community members through a door knocking campaign and give them access to sign up for free water testing through a citywide program. At the time, lead contamination in soil and water was not one of LVEJO's campaigns, but they supported this work in several ways. Their support included designing and implementing a lesson on organizing and door knocking in sophomore civics class and helping students create flyers (see Figure 8). LVEJO organizers co-planned and accompanied students on their door-knocking campaign and facilitated a reflection on the experience afterward. Furthermore, they offered financial support for the printing of flyers, home water filters, while also providing connections to healthcare (if necessary) for any community members who had found high levels of lead in their test results.

FIGURE 8

Flyer made by LVEJO for distribution during a door knocking campaign.

The type of expertise that LVEJO community organizers bring into the classroom is invaluable to a teacher wanting to do this work with students, especially when it may not fit into even an expansively conceived science curriculum. These experiences can often propel teachers and students to become more comfortable and capable in civic participation around science issues (see Figure 9). Heavy metal contamination is tangentially connected to climate change: Heavy metal pollutants are emitted by burning coal and other espe-

FIGURE 9

SOJO students presenting on their community work on lead in water.

FIGURE 10

Two students collecting soil samples on the school grounds.

cially dirty fossil fuels, and mercury is often released when permafrost melts (Schaefer et al. 2020; Schuster et al. 2018). But even more important than the scientific connection, these parts of our collaboration have been important for cultivating youth involvement in the struggle for climate justice and a just transition (see Figure 10).

Navigating Conflicting Perspectives/ Disagreements

While LVEJO and SOJO's views of climate justice were aligned, there are always varied perspectives of justice within any community. In one example, an LVEJO campaign sought to block the expansion of Unilever, a multinational consumer goods company that has been manufacturing Hellmann's Mayonnaise for over 100 years. Unilever's expansion meant many of the diesel-powered vehicles would drive directly behind a local K–8 school, one of SOJO's feeder schools. To alleviate community resistance to this project, Unilever offered the elementary school 2.5 acres of land to both expand their campus and add a community playground and gardening space. The space was much needed as the school was so overcrowded that they were borrowing classroom space from an old Catholic school a block away. Plans for the playground and gardening space were quickly revoked after community members voiced their concerns of the proximity to heavy-duty diesel vehicles. However, plans for the expansion of the campus continued in order to address the overcrowding issue this school faced. This highlighted the tensions that exist, where campaign "losses" or "wins" do not exist, but instead differing groups are impacted to a greater or lesser extent by controversial compromises. Similar outcomes have come from other campaigns. For example, when the coal power plant was closed, there was no promised remediation of the site, which has since become a giant warehouse in spite of LVEJOs organized objections. In the case of La Villita Park built on the Celotex site, we discussed the controversy about whether the EPA would approve the two-foot gravel and clay cap under the park that contained the contamination in the soil below ground level (EPA 2016).

Occasionally, SOJO and LVEJO have also had diverging ideas about how to best address community issues through the school. This is to be expected as the school and LVEJO share many goals but are not the same entity. In one case, teachers applied for funding from a large nonprofit organization for a community garden at the school. LVEJO organizers had concerns about the large nonprofit's lack of community knowledge and potential ties to corporate partnerships. LVEJO has a vibrant community garden of its own, but it is too far from the school for students to readily access during class time. Teachers agreed with LVEJO's critique of the funder but saw a strategic opportunity to meet a long-existing goal with minimal risk of co-optation or interference by the funder. In the end, SOJO and LVEJO worked together through opposition to analyze the best location for the garden. The garden has created an opportunity for students to take action regarding healthy food access, nurturing their ability to grow food, while drawing upon community and ancestral agricultural knowledge. Teachers also make connections with other YPS projects through conversations about raised beds and soil contamination in the community. The complexities of politics within the city and community—and even between LVEJO and SOJO—sometimes lead to competing views of what should be done to address inequity and where environmental issues fit within community priorities and politics. We view students, teachers, and organizers grappling with these complexities together as an invaluable source of learning about the potential role of scientific evidence in movements for climate and environmental justice.

Youth in EJ Communities as Leaders of an Intergenerational Just Transition

The campaigns waged by LVEJO have been focused on the self-determination of the Little Village community that has suffered the ill-effects of living in the midst of an industrial corridor where the expediency of business interests has been prioritized above the well-being of people and ecosystems. We believe that it is precisely this type of grassroots organizing by marginalized communities that has the power to spearhead a just transition that allows life to thrive through and beyond the climate crisis. While focusing in their backyard, LVEJO has taken an abolitionist approach, rather than a not-in-my-backyard (NIMBY) approach to their advocacy. For example, community members supported the capping of the Celotex Superfund site below La Villita Park because they did not want to ship the toxic soil into another marginalized community for disposal.

Within the context of partnership with LVEJO, science courses at SOJO have eschewed traditional notions of scientific literacy and STEM pipeline pedagogies in favor of prioritizing the development of active community members and students. This has helped encourage students develop perspectives of justice and sustainability as purposes to pursue STEM pathways rather than prioritizing personal or national economic gain or national defense (Valladares 2021).

REFERENCES

Climate Justice Alliance. [n.d.]. Just transition: A Framework for change. https://climatejusticealliance.org/just-transition/

EPA. 2016. *Success story: Celotex corporation*. United States Environmental Protection Agency. https://semspub.epa.gov/work/05/933569.pdf.

Gutstein, E. 2006. *Reading and writing the world with mathematics: Toward a pedagogy for social justice*. London: Taylor and Francis.

Hill, G. 2010. *500 years of Indigenous resistance*. Oakland, CA: PM Press.

Jacob, M.M., K.L. Gonzales, D. Chappell Belcher, J.L. Ruef, and S. RunningHawk Johnson. 2021. Indigenous cultural values counter the damages of white settler colonialism. *Environmental Sociology* 7 (2): 134–146. DOI: 10.1080/23251042.2020.1841370

Mohai, P., and B.S. Kweon. 2020. Michigan School Siting Guidelines: Taking the Environment into Account.

Morales-Doyle, D., T. Childress-Price, and M. Chappell. 2019. Chemicals are contaminants too: Teaching appreciation and critique of science in the era of NGSS. *Science Education* 103 (6): 1347–1366. https://doi.org/10.1002/sce.21546

Morales-Doyle, D., A. and Frausto. 2021. Youth participatory science: a grassroots science curriculum framework. *Educational Action Research* 29 (1): 60–78.

Rochlin, J. 2012. Mercury, mining and empire: The Human and ecological cost of colonial silver mining in the Andes. Bloomington, Indiana: Indiana University Press.

Schaefer, K., Y. Elshorbany, E. Jafarov, et al. 2020. Potential impacts of mercury released from thawing permafrost. *Nature Communications* 11 (4650). DOI: 10.1038/s41467-020-18398-5.

Schuster, P.F., K.M. Schaefer, G.R. Aiken, R.C. Antweiler, J.F. Dewild, J.D. Gryziec, ... T. Zhang. 2018. Permafrost stores a globally significant amount of mercury. *Geophysical Research Letters* 45, 1463–1471. DOI: 10.1002/2017GL075571.

Stovall, D.O. 2016. *Born out of struggle: Critical race theory, school creation, and the politics of interruption*. New York: SUNY Press.

Valladares, L. 2021. Scientific literacy and social transformation. *Science and Education* 30 (3): 557–587. DOI: 10.1007/s11191-021-00205-2.

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3

(RE)CONNECTING THE STEM LEARNING ECOSYSTEM

LESSONS FROM THE PANDEMIC

INTRODUCTION

Distance Learning

More Than a Stopgap

BY BETH MURPHY, Field Editor, *Connected Science Learning*

The pandemic has required us to connect in new ways—including how we engage in learning—and many of the resulting innovations will continue to have an impact for the foreseeable future, certainly in more significant ways than eliminating snow days.

It may feel like we've been frozen in time for a few years; however, the reality is that the world is different now than it would have been if the pandemic had never occurred. We've adapted to previously unimaginable circumstances, leading to changes and advances that otherwise might never have happened—at least not this quickly—in all aspects of our lives, including teaching and learning. While I hope students never have to return to endless hours on Zoom or Google Meet, the use of online technology will undoubtedly continue to be a regular fixture in the learning landscape.

Experts report that the pandemic has accelerated the pace of innovation in virtual learning, propelling us years ahead of where we otherwise might have been. In many instances, distance learning has been more than a stopgap or a poor substitute for the classroom; rather, it has also been a catalyst for designing new ways to teach and learn. These new online resources, tools, and learning environments have the potential to democratize access and effectively eliminate the need for proximity between the learner and the learning resource, whether that resource is a person, place, or thing. For example, initiatives to broaden access to museum collections through digitization have been underway for years. However, the pandemic elevated the priority of such efforts nearly overnight. These and other innovations have the potential to provide learners with all sorts of connected learning experiences that blur lines between school and the world beyond.

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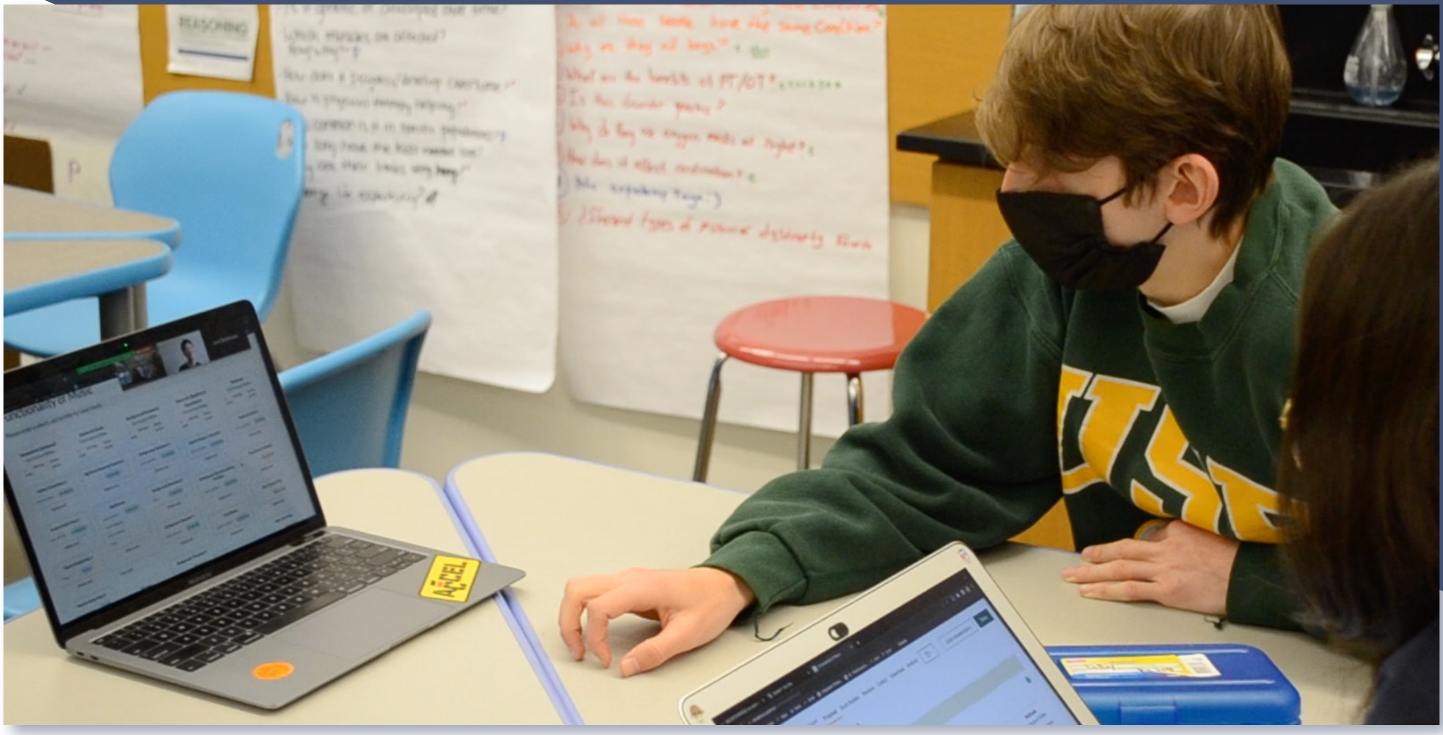


MindHive

An Online Citizen Science Tool and Curriculum for Human Brain and Behavior Research

BY SUZANNE DIKKER, YURY SHEVCHENKO, KIM BURGAS, KIM CHALONER, MARC SOLE, LUCY YETMAN-MICHAELSON, IDO DAVIDESCO, REBECCA MARTIN, AND CAMILLIA MATUK

MindHive is an online, open science, citizen science platform co-designed by a team of educational researchers, teachers, cognitive and social scientists, UX researchers, community organizers, and software developers to support real-world brain and behavior research for (a) high school students and teachers who seek authentic STEM research experiences, (b) neuroscientists and cognitive/social psychologists who seek to address their research questions outside of the lab, and (c) community-based organizations who seek to conduct grassroots, science-based research for policy change. In the high school classroom, students engage with lessons and studies created by cognitive and social neuroscientists, provide peer feedback on studies designed by students within a network of schools across the country, and develop and carry out their own online citizen science studies. By guiding them through both discovery (student-as-participant) and creation (student-as-scientist) stages of citizen science inquiry, MindHive aims to help learners and communities both inside and beyond the classroom to contextualize their own cognition and social behavior within population-wide patterns; to formulate generalizable and testable research questions; and to derive implications from findings and translate these into personal and social action.

Leveraging open science to increase science literacy

The COVID-19 pandemic has brought science to the front page of our lives and with it, science literacy challenges. The rapid spread of the virus has been accompanied by a spread of misinformation that has made it difficult for many people to discern scientific evidence from less reliable sources of information (Van Bavel et al. 2020). This aligns with a recent communication by the National Institutes of Health about science literacy, which cites surveys conducted in the United States and Europe that found that many members of the general public do not have a firm grasp of basic science concepts or the scientific process and tend to value anecdotes over evidence. Vulnerable communities in particular often feel disconnected and wary of science, making them not only less likely to participate in research studies but also less likely to adhere to public health recommendations (e.g., see a recent article in *The Atlantic* about vaccine hesitancy). Suspicion of science and scientists is accompanied by the fact that scientists' relationship with the public has historically been unidirectional, non-transparent, and noninclusive. For example, human neuroscientists and psychologists conduct research *on* the public but do not necessarily communicate *with* them about the research.

To address issues related to replicability, transparency, and inclusion in science, scientists increasingly embrace a so-called "open science" approach. MindHive strives to align itself and familiarize learners with six main open science tenets (Fecher and Friesike 2014):

- make knowledge freely available to all platform users (Democratic),
- make the science process more efficient and goal-oriented (Pragmatic),
- make science accessible to everyone (Public),
- create and maintain tools and services (Infrastructure),
- measure the scientific impact of research (Measurement), and
- support community inclusion and commitment (Community).

MindHive supports this open science approach in various ways. For example, we "practice what we preach" by making the MindHive platform project completely open source: The code of the source code that is used to build the platform can be examined on the code platform GitHub, which should promote transparency and ensure the longevity of the project. Another requirement for open science is the ability to share resources—in our case anonymized data—which can be used for re-analysis and further research. Anonymized data from MindHive studies can be accessed on the platform by authorized users, and all the educational research data is made available via open access data repositories such as The Open Science Framework and the Qualitative Data Repository.

Peer feedback on study designs not study outcomes

In recent years, a number of findings in psychology research have turned out to not be replicable, and this "Replication Crisis" can be quite damaging to the public's trust in science (Earp and Trafimow 2015). Therefore, many human brain and behavior scientists are now advocating for a fully transparent research model for psychology research that resembles what is already common practice in clinical science: a public pre-registration of how you plan to collect and analyze data. This is also slowly changing how scientific peer review is operationalized: Increasingly, scientific journals invite scientists to submit (and review) research projects for publication *before* data collection occurs, moving away from a model where scientists give and receive peer reviews after the entire study is completed. This forces scientists to be open and transparent about which steps were part of the research plan from the beginning, and which decisions were made *after* data collection took place. But it also has another benefit: Scientists are able to improve their research plans based on peer reviews before investing time, energy, and money into possibly flawed studies.

In MindHive, students are also encouraged to give and receive peer feedback on study proposals and not completed studies. Peer review takes place with classmates and, crucially, with students in other classrooms across the country. This process allows students to maximally benefit from the review process: They are not only able to tweak their study design based on feedback from their peers, but the act of giving feedback to peers also likely helps students improve their own study (Li et al. 2010). Second, and relatedly, this process refocuses the emphasis from study outcome to study design. We have found in previous classroom human brain and behavior experiments that students (and professional scientists, for that matter) are very focused on whether their hypotheses were borne out, and the perceived failure or success of a study is often linked to the results alone. This pressure to confirm hypotheses and emphasis on study outcomes over study design can lead to questionable research practices, "over-interpreting" data, and, in extreme cases, fraud. In MindHive, we therefore flip this process around: Students learn that results are meaningless if the research question is not wellformed, or if the study design is not well-aligned with the research question. In the peer review process, students are rewarded for their ideas rather than their study outcomes. As such, we hope to increase fascination with science inquiry and not "just" with science discovery. We would like students to walk away from MindHive with a "Check out my idea! How cool is that?" rather than "Check out my results!"

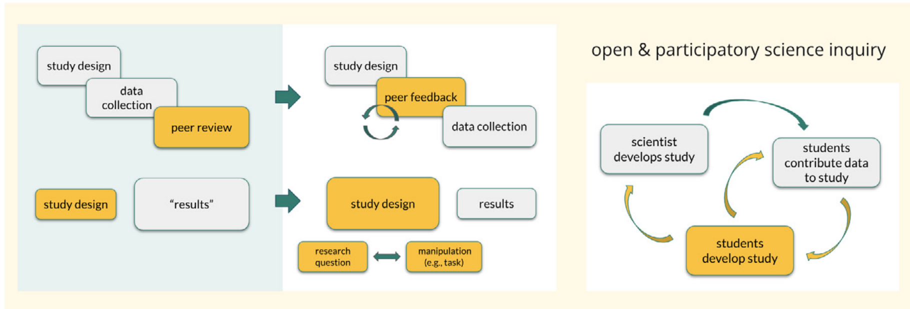
Citizen science

In addition to promoting data and content to "be freely used, modified, and shared by anyone for any purpose." Open science advocates have stressed the importance of citizen science (Eitzel et al. 2017; Fecher and Friesike 2014) defined broadly as public engagement in scientific research. Citizen science has been shown to boost science literacy in both formal and informal learning settings (Bonney et al. 2016; Harris et al. 2020), enabling participants of all ages to appreciate science inquiry as an iterative and collective endeavor to which they can provide valuable contributions.

In most citizen science initiatives, the public helps collect data for research designed and analyzed by professional scientists (Bonney et al. 2009). MindHive instead advocates a partnership model wherein experts and non-expert participants are included as stakeholders in all stages of scientific inquiry, including conception and design (see Figure 1; Dikker et al. 2021). MindHive follows *a participatory science learning approach* (Koomen et al. 2018; NGSS Lead States 2013) by emphasizing authentic problems and the social negotiation of knowledge in the context of open science and citizen science. Additionally, educators are participating in the process and increasing their understanding of how to teach the nature of scientific inquiry as well. In the next section, we discuss how this model can be put into practice.

FIGURE 1

A citizen science partnership model.



LEFT PANEL: MindHive encourages educators to adopt an "open science" approach in their science inquiry teaching: Peer review can be performed in multiple rounds, ideally takes place before students engage in data collection, and emphasizes evaluating the research question and how it is translated into a concrete study design. **RIGHT PANEL:** MindHive advocates a participatory citizen science model: Students are involved in all stages of scientific inquiry.

The MindHive curriculum

All activities on the MindHive platform are supported by curricular materials. The lessons are co-designed with scientists and teachers, ensuring that the vision for application of the curriculum and its integration into a larger school program is relevant to current practice. For example, the content is aligned with the *Next Generation Science Standards* (NGSS Lead States 2013) and is structured to follow the "5 Es" (Engage, Explore, Explain, Elaborate, and Evaluate; Bybee et al. 2006). The unit is "alive" in that it is iterated on and improved with every implementation, and lessons are stand-alone where possible to serve educators' varying teaching needs. Due to the wide applicability of research methods and to the relevance of cognitive and social neuroscience perspectives across fields, the program can be integrated into a range of high school science contexts, from Environmental Science to Molecular Biology. In approximately 12–24 lessons, the program guides students in: (1) scientific knowledge generation, (2) citizen science and ethics in human cognitive and social neuroscience research, (3) human brain and behavior case studies, (4) study design, (5) peer review, and (6) data analysis and synthesis.

The MindHive platform

The MindHive platform features tools for developing study proposals and for giving and receiving peer reviews, and a public database of commonly used online cognitive tasks and surveys from which users can drag-and-drop to build research studies aligned with their research questions. To promote iterative research design and to scaffold their own study design, students are encouraged to "clone" and build upon scientist-initiated studies from the platform.

Discover

The Discover area allows students to explore and participate in studies created by cognitive and social neuroscientists. The Discover area also features a section where they can explore and partake in studies created by other students, and try out tasks and surveys that are featured on the platform.

Develop

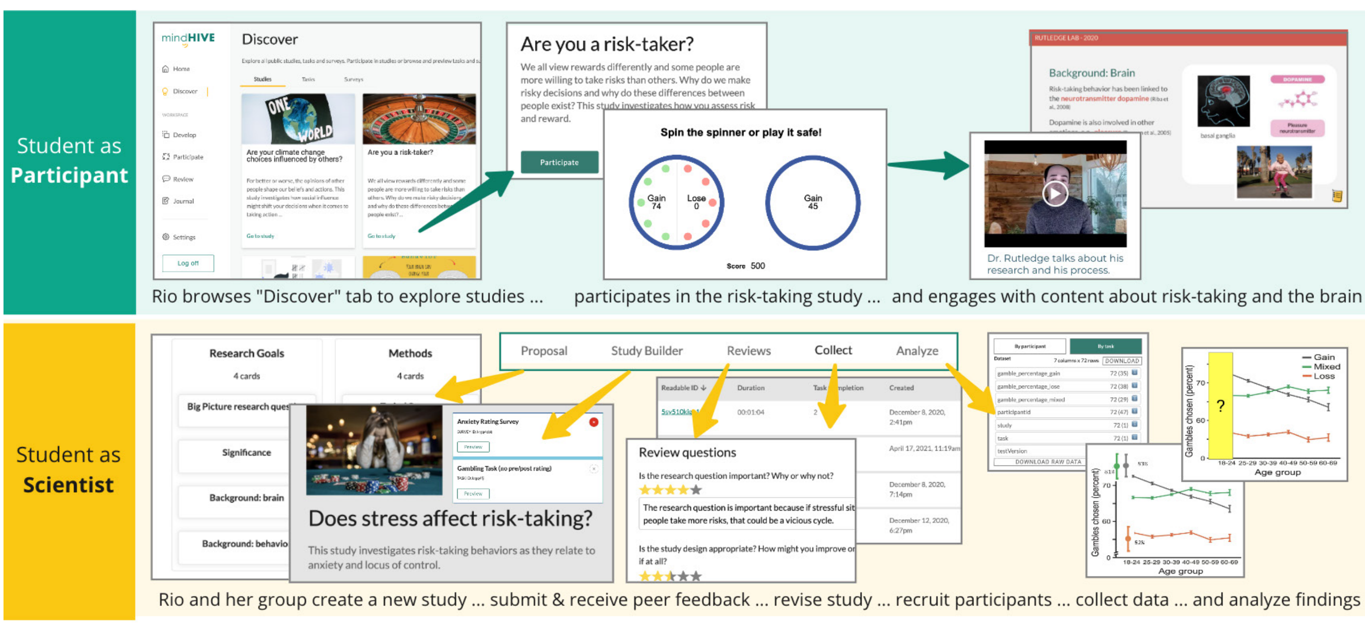
The Develop area allows students to develop and carry out their own online citizen science studies. The Proposal tab consists of text-based "cards" designed to help students learn to create realistic collaboration plans. Students can assign different sections to themselves and each other (e.g., Anna and Rick flesh out the Background section, Luna writes the Importance section, Hiram and Ember are in charge of describing the Methods, etc.); provide and receive comments from their teachers, peers, and scientists; and toggle between draft and print views of their proposal. This format allows for a variety of learners to engage successfully through complex material thanks to the pre-organized tasks that build toward a successful proposal. The Study Builder consists of an intuitive interface that allows students to create a study page and build an experiment using a block-based design approach: Students can mix, match, and tweak tasks from a database of validated tasks and surveys (described below). Students can read what other students thought of their study in the Review tab. Finally, the Collect and Analyze tabs allow them to manage and analyze the data collected in their study.

Public Task and Survey Bank

The public task and survey bank includes well-established and well-validated psychological tasks and surveys. For example, the Stroop Task is a widely used task to probe a persons cognitive control, in this case their ability to ignore contradictory information. Participants are asked to identify the color of words, the meanings of which sometimes match their color (e.g., the word *red* printed in red), and sometimes do not (e.g., the word *green* printed in red). The survey bank features questionnaires that are widely used to probe people's emotional states, personality traits, demographic info, etc. For example, the Big Five Personality Inventory is a personality trait questionnaire that is commonly used by scientists and that students can implement in lieu of popular but not scientifically validated "personality tests" they might otherwise choose for their studies. Other questionnaires ask about participants' mood and anxiety, coping strategies, perceived status in society, etc.

FIGURE 2

Mindhive functionality for students.



TOP: As part of her MindHive learning activities, Rio participates in a gambling task designed by neuroscientist Robb Rutledge, who studies the brain basis of risk-taking behavior. On completing the study, Rio and her classmates learn about risk taking and the brain and watch a video recorded by Dr. Rutledge in which he talks about how he became a scientist and why he studies risk taking and happiness. **BOTTOM:** Rio and her peers decide to pursue a study asking whether stress affects risk-taking behavior. They clone Dr. Rutledge's risk-taking study, add a stress survey from the public survey bank to the gambling task, and edit the image and description of the study page. After revising their study based on feedback from peers and their teacher, they distribute a link to their study for data collection. After data collection is completed, Rio and her group mates analyze their study data by choosing and graphing variables [e.g., the relationship between participants' self-perceived stress level and how often they choose to take a risk in the gambling task].

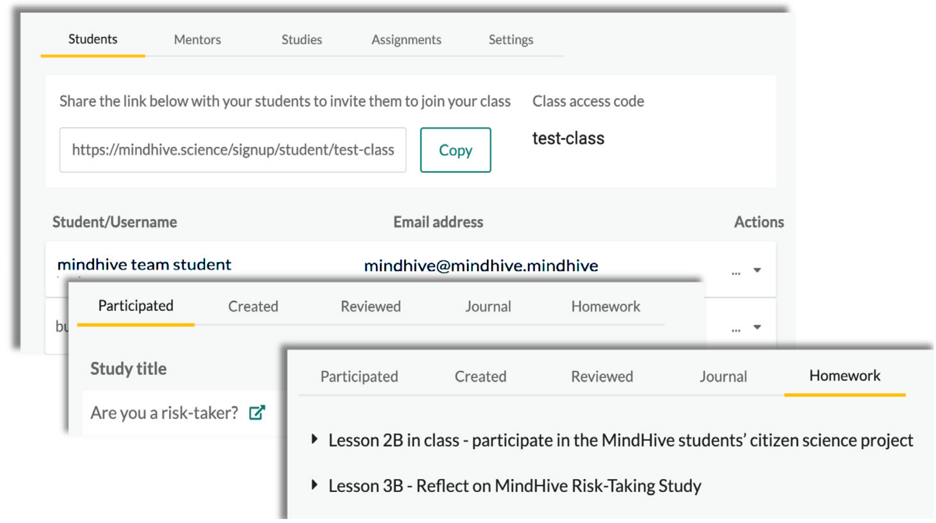
Figure 2 exemplifies how an 11th grader, "Rio," engages with the MindHive platform to learn about human brain and behavior science, and combines existing tasks and surveys to create a study about risktaking and coping.

The teacher experience

To assist teachers in supporting their students, MindHive provides the basic infrastructure of a Learning Management System. Teachers can create classes and add students; create class networks with other teachers; keep track of the studies that their students have participated in, reviewed, or developed; create study proposal templates and comment on them; and create and manage assignments and group chats (see Figure 3). Teachers are supported in facilitating the program through multiple resources including access to research, researcher support, and guidance from the mentor on the MindHive team. Detailed activities, rich discussion prompts, and thoughtful student explorations are included so that teachers can choose how to optimize their classroom practices with the material. Teachers can further guide and support students through the inquiry process by incorporating external resources. For example, Frontiers for Young Minds and Columbia University's brainSTEM program both host scientific articles targeted at teen and adolescent readers, and can be used as inspiration for students' research questions and as support for their background research.

FIGURE 3

Mindhive functionality for teachers



LEFT PANEL: Teachers can create classes and invite students to join a class. **RIGHT PANEL:** Teachers can view which studies students have participated in, created, and reviewed. They can create assignments, and view student assignments and journal entries.

Protecting student data

Since the MindHive program is centered around human behavior, data protection is integral to the platform and to the students' learning experience. Students learn about the importance of ethics in human brain and behavior research, engage in class discussions around data protection and privacy, and experience firsthand what these data protection practices mean for them and for their study participants.

The platform has an authentication system with multiple levels of authorization that depend both on the user role (teacher, student, scientist, or participant) and on individual preferences. For example, only teachers and classmates will see student names; only researchers with official approval from their institutions Internal Review Board (IRB) can see contact details for their study participants; students have different "avatar" usernames depending on whether they are study participants or students so that their teachers and peers cannot readily access their study data; and if a student indicates that their data should only be used for educational purposes, that data will not be displayed to researchers but will only be available within the scope of their class. Importantly, contrary to many data platforms in the United States, MindHive users own their own data. In compliance with General Data Protection Regulation (GDPR) standards, European Union GDPR users can request that any of their data be deleted at any time.

Flexible implementation

Both the structure and curriculum content can be flexibly implemented in both formal and informal learning environments. For example, Human Brain and Behavior lessons (see Table 1 in Supplemental Resources) are constructed as case studies that can be "mixed and matched," and teachers can choose to put emphasis on what they deem most important: study design, peer review, data collection and analysis, or all of the above. This flexibility allows teachers to use functionalities of the platform to frame and support, as opposed to detract from, required (standards-based) course content, as much of the MindHive curriculum focuses on crosscutting concepts (e.g., cause and effect) and widely applicable science practices (e.g., planning an investigation). Having said that, as a full-fledged curriculum, MindHive is a better fit for an elective or a class based on the *NGSS*, as opposed to preparation for standardized examinations, such as the Regents examinations of New York State.

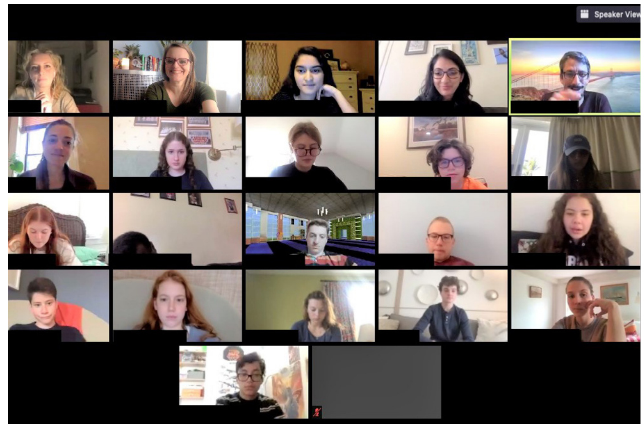
The Study Builder is designed to enable for both group-based and individual student projects, and peer feedback can be arranged both between classmates and between students from other classes (across or within schools). As a result, the program is suitable for full remote, hybrid, or in-person contexts both within formal and informal learning contexts. For example, in addition to guiding in-class projects, the program can support the development of extracurricular projects, such as science fair submissions, by enabling students to design, receive feedback on, and run their own studies outside of the classroom. As discussed in the next few sections, the MindHive platform and program are designed to increase students' research skills while teaching them about the scientific process and human brain and behavior content. As described below, this makes MindHive accessible to different age ranges (9th to 12th grade so far) and classes (Environmental Science, Biology, Neuroscience, after school research clubs, etc.).

Benefits of an online platform

MindHive's flexibility in implementation is in part made possible by the fact that the platform is browser-based. Students do not have to download anything, and they can access the platform through any device that is connected to the internet, although it's important to note that not all the functionality is suitable for mobile devices. Beyond easy access, MindHive is designed as an online platform to allow students, teachers, and scientists to work on science inquiry in an iterative and collaborative manner. Studies and data sets continue to live on the platform beyond individual implementations, allowing students to "clone" scientist-initiated studies and ask follow-up questions, contribute data, or even adopt student-initiated studies and continue data collection and analysis. Second, MindHive emphasizes collaboration *between* schools. Since the launch of MindHive in 2020, students have engaged in study participation and peer review between geographically and demographically diverse schools across the United States, including both private and public schools ranging from New York City to Tennessee. Third, the online setup facilitates remote student-teacher-scientist partnerships. This is especially attractive for students who may not live near research universities, and who may not have easy access to in-person science mentorship programs. Finally, as described more in detail below, the remote nature of MindHive has made it possible to continue to support students in their science inquiry throughout the COVID-19 pandemic, and also in other online learning environments, which are part of an increasing market.

FIGURE 4

Screenshot Of "Zoom School" in April 2020. Courtesy Kim Chaloner. For Student Reflections, see Matuk et al. 2021.



Implementing MindHive during a global pandemic

Since its inception in the Spring of 2020 through Spring 2022, MindHive has been implemented in 15 classrooms, serving around 350 students. Students and scientists have together designed or drafted about 250 studies for which 1600 data sets have been collected.

Beyond classroom implementations, the MindHive platform has been used to promote STEM engagement and identify community needs by supporting local citizen science projects. In the Brownsville Sentiment Equity Project, the MindHive team worked with six local community organizers and residents, researchers from UC Berkeley, and not-for-profit organizations. Public sentiment to co-design a cognitive and social neuroscience citizen science project centered on cognitive and social-emotional outcomes linked to pandemic-related changes in the community of Brownsville, Brooklyn, one of the hardest-hit areas in New York City (the Brownsville Sentiment Equity Project).

Scientists, students, and communities entering a lockdown together

MindHive was first launched in March of 2020 as part of a pilot implementation with 17 Environmental Science students in Manhattan. New York City was the epicenter of the COVID-19 pandemic and the MindHive team and students entered the

FIGURE 5

Mindhive example studies.

U.S. lockdown together. The curriculum was (re)framed to use COVID-19 to illustrate scientific discovery in an ongoing crisis (e.g., *Should the vaccine be rolled out fast or should we await clinical trial outcomes? Which research questions are important now and which will be important beyond the pandemic?*), science communication (e.g., *What is the value of releasing study outcomes before they have been scrutinized by other scientists?*), and human behavior (e.g., *Why do college students decide to go party in Miami in the middle of a pandemic? Are you more likely to adopt socially desirable behaviors from your peers or from your parents?*). Alongside these lessons, students participated in scientist-initiated studies on the platform that illustrated risk taking across the age span and social influence from peers vs. parents.

Using the global relevance of the pandemic, students then created their own studies, in groups of four, focusing on human brain and behavior in relation to COVID-19. Students asked research questions about mental health and social isolation, remote vs. in-person learning, and how social behavior can make or break public health directives. For example, students asked whether personality traits might predict how well a student thrives in "Zoom school" (see Figure 4). Read an account of this implementation from the teacher perspective here.

After implementation, NYU scientists incorporated the students' research questions into a study entitled "How do you cope during the pandemic?" (henceforth referred to as the Pandemic Citizen Science Study), for which data was subsequently collected from high school and university students through Fall 2020 and Spring 2021. Findings from 206 students suggest that personality traits indeed affect how connected students felt to their peers and teachers in in-person vs. remote learning environments. Furthermore, there was a mismatch between students' remote learning preferences and what they were offered: While students overwhelmingly preferred asynchronous learning (e.g., being as signed materials they could complete at their own pace), none were offered asynchronous learning models at their schools or colleges.

Collaborative inquiry: study design and peer review

In the 2020–2021 school year, MindHive was implemented by six teachers at five different schools across the United States, reaching approximately 240 students. Students participated in the Pandemic Citizen Science Study (see previous section) in addition to scientist-initiated studies on the topics of risk taking, social influence, and mindfulness. As in the Spring of 2020, students then designed their own studies, either in groups or individually (this varied by implementation). Unlike the Spring 2020 implementation, not all student studies were focused on the pandemic, but students still gravitated toward personally and socially relevant topics such as learning, mental health, climate change, and political polarization (see examples below). Students and teachers were supported in their study design by a team of neuroscientists and psychologists from different research institutes and at different career levels (ranging from recent BA graduates to tenured faculty). Additionally, each teacher was matched with another teacher to create a "class network" to allow students to review and participate in studies developed by other students from other classrooms.

What students are learning

Across implementations, students report an increased appreciation of and fascination with science after participating in MindHive. For example, one student remarked that the experience was valuable for helping them "to think critically, which is really important throughout science and life as a whole… just being able to again delve beneath the surface of a certain question…. and then also just seeing how asking a question can develop into this huge research study." Importantly, students indicate that they learned to better appreciate the collaborative nature of science and the value of different perspectives in generating both ideas and conclusions. Students further demonstrated that they acquired skills related to the process and challenges of creating a scientific study and developed concrete strategies to improve their own studies and research proposals. When asked in a survey what they learned from developing a proposal on the MindHive platform, one student responded: "I learned that you need to be very thorough, in your instructions as well as your explanations of the experiment and the science behind the experiment. I also learned that it is very valuable to have your peers review your work because looking at the proposal from a fresh pair of eyes will show you which parts you need to work on." These and other findings are reported in more detail in (Matuk et al. 2021).

Examples of studies designed by students

In Supplementary Resources, we have included four examples of studies created by MindHive students in the 2020–2021 school year. MindHive Example Studies 1, 2, 3, and 4. Click on the links in each PDF to explore each study.

You can find more studies at the MindHive Discover Page.

Challenges

Many students reported gaining a deeper understanding of the thought and time it takes to design and implement a research study. While this learning outcome is beneficial as it indicates a comprehension of research processes in the real world, it also emphasizes a larger challenge present in designing curriculum and tools to support authentic scientific inquiry for students. Each aspect of the research process—from writing a proposal to engaging in peer review—requires both time and support that can be difficult to accommodate in a classroom setting. As MindHive continues to develop, it is increasingly important to focus on the ways that different parts of the research process (proposal development, data analysis, peer review, etc.) can be modularized, combined, and meaningfully integrated into different aspects of a curriculum so that the curriculum and design process is manageable within the constraints of a classroom for both students and teachers. Additionally, the time constraints of a classroom setting means that sometimes students do not get the chance to analyze and report on data collected through the project they designed. While our goal is for students to value the process of study design over the end results, we have learned that it is important for students' self-efficacy to give them a sense of closure, which comes from following through every stage of the research process.

Another challenge for MindHive relates to community building, scaling, and sustainability. Overall, the flexibility and accessibility of MindHive's online platform and resources offer the potential for students, scientists, and communities to work together and engage in scientific inquiry across a variety of contexts. However, more work needs to be done to discover how we can best foster a community of scientists and participants beyond individual classroom implementations, and continue to support meaningful partnerships between students and scientists beyond the project's funding.

Conclusion

MindHive is an online citizen science initiative that can be used both inside and beyond the STEM classroom to help learners and community members engage in authentic human brain and behavior science inquiry. It offers flexible tools that help bridge the gap between in and out-of-school STEM learning (e.g., by facilitating scientist-student-community partnerships). All studies and platform activities are paired with content where personally and socially relevant issues—such as the COVID-19 pandemic and climate change—are used as anchor phenomena. These serve not only to support human brain and behavior science learning (e.g., risk taking, memory, social behavior) but also to illustrate issues related to the "making of science," such as research ethics, the difficult balance between rapid and rigorous scientific discovery, and the cultural shift in the scientific community toward open science practices.

Open science, among other goals, includes improving the public-scientist relationship by improving transparency and science communication. In line with these goals, MindHive adheres to a participatory science learning approach and emphasizes student-scientist-community partnerships in human brain and behavior science inquiry: The platform and program is a co-design effort by and for teachers and students, and by and for community representatives. As such, MindHive sets itself apart from other neuroscience and psychology STEM learning experiences by supporting learners and community members to make sense of and be active stakeholders in human brain and behavior science as it relates to their everyday lives.

More information can be found at the MindHive information page for educators.

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REFERENCES

Bonney, R., H. Ballard, R. Jordan, E. McCallie, T. Phillips, J. Shirk, and C.C. Wilderman. 2009. Public Participation in Scientific Research: Defining the field and assessing its potential for Informal Science Education. A CAISE inquiry group report. *Online Submission*. http://files.eric.ed.gov/fulltext/ED519688.pdf

Bonney, R., T.B. Phillips, H.L. Ballard, and J.W. Enck. 2016. Can citizen science enhance public understanding of science? *Public Understanding of Science* 25 (1): 2–16.

Bybee, R.W., J.A. Taylor, A. Gardner, P. Van Scotter, J.C. Powell, A. Westbrook, and N. Landes. 2006. The BSCS 5E instructional model: Origins and effectiveness. Colorado Springs, CO: BSCS, 5, 88–98.

Dikker, S., Y. Shevchenko, K. Burgas, and C. Matuk. 2021. MindHive: A Community Science Platform for Human Brain and Behavior Research. In *TMS Proceedings 2021*. PubPub.

Earp, B.D., and D. Trafimow. 2015. Replication, falsification, and the crisis of confidence in social psychology. *Frontiers in Psychology* 6: 621.

Eitzel, M.V., J.L. Cappadonna, C. Santos-Lang, R.E. Duerr, A. Virapongse, S.E. West, C.C.M. Kyba, A. Bowser, C.B. Cooper, A. Sforzi, A.N. Metcalfe, E.S. Harris, M. Thiel, M. Haklay, L. Ponciano, J. Roche, L. Ceccaroni, F.M. Shilling, D. Dörler, … Q, Jiang,. 2017. Citizen science terminology matters: Exploring key terms. *Citizen Science Theory and Practice* 2 (1): 1.

Fecher, B., and S. Friesike. 2014. Open science: one term, five schools of thought. *Opening Science*, 17–47.

Harris, E.M., C.G. Dixon, E.B. Bird, and H.L. Ballard. 2020. For science and self: Youth interactions with data in community and citizen science. *Journal of the Learning Sciences* 29 (2): 224-263. https://www.tandfonline.com/doi/abs/10.1080/10508406.2019.1693379

Koomen, M.H., E. Rodriguez, A. Hoffman, C. Petersen, and K. Oberhauser. 2018. Authentic science with citizen science and student-driven science fair projects. *Science Education* 102 (3): 593–644.

Li, L., X. Liu, and A.L. Steckelberg. 2010. Assessor or assessee: How student learning improves by giving and receiving peer feedback. *British Journal of Educational Technology: Journal of the Council for Educational Technology* 41 (3): 525–536.

Matuk, C., R. Martin, V. Vasudevan, K. Burgas, K. Chaloner, I. Davidesco, S. Sadhukha, Y. Shevchenko, E. Bumbacher, and S. Dikker. 2021. Students learning about science by investigating an unfolding pandemic. *AERA Open*.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

Van Bavel, J.J., K. Baicker, P.S. Boggio, V. Capraro, A. Cichocka, M. Cikara, M.J. Crockett, A.J. Crum, K.M. Douglas, J.N. Druckman, J. Drury, O. Dube, N. Ellemers, E.J. Finkel, J.H. Fowler, M. Gelfand, S. Han, S.A. Haslam, J. Jetten, … R. Willer. 2020. Using social and behavioural science to support COVID-19 pandemic response. *Nature Human Behaviour* 4 (5): 460–471.Tan, E., A. Calabrese Barton, and A. Benavides. 2019. Engineering for Sustainable Communities: Epistemic Tools in Support of Equitable and Consequential Middle School Engineering. *Science Education*. DOI: 10.1002/sce.21515

Upadhyay, B., K. Coffino, J. Alberts, and A. Rummel. 2021. STEAM education for critical consciousness: Discourses of liberation and social change among sixth-grade students. *Asia-Pacific Science Education*, 1-32.

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Rethinking Online Science Learning

Creating Virtual Research Experiences Using Digitized Museum Specimens

BY KIRSTEN R. BUTCHER, MADLYN LARSON, MCKENNA LANE, AND MITCHELL J. POWER

A lasting impact of the COVID-19 global pandemic likely is the permanent inclusion of online learning in K–12. The rapid move to online learning left many teachers, parents, and students pining for in-person learning and highlighted major gaps in the online resources necessary for fully remote K–12 learning. But it also underscored considerable strengths of online formats for flexible learning and instruction—particularly as district capacities expanded and familiarity with online instruction increased. Many administrators now envision a permanent end to unplanned school closures (goodbye, snow days!) and long-term support for (at least intermittent) online learning. But what does continued online instruction mean for science learning, where hands-on learning is central to students' developing skills and knowledge?

Science educators implementing online instruction have faced myriad challenges, including providing effective feedback and guidance while students engaged in more independent work. We greatly respect and admire the passion and dedication that science teachers have invested in finding creative ways to implement science inquiry during online pandemic instruction. As we move beyond "emergency" remote instruction and build on shared experiences with online science teaching, it is an ideal time to rethink science inquiry online and to collectively pursue new approaches to authentic science instruction with online resources.

Museums have been digitizing scientific collections for many years (e.g., the Field Museum, the Smithsonian), and multiple collecting institutions contribute digitized specimens to centralized databases (e.g., iDigBio, SCAN Bugs, Arctos, Intermountain Regional Herbarium Network). Although these databases are freely available and represent a significant resource for scientists, they lack user-friendly support for public exploration and provide insufficient scaffolding for classroom integration (Butcher et al. 2021). Our work seeks to bridge the existing chasm between digitized scientific collections and classroom learning. Digitized artifacts and specimens in museum collections are public resources with largely untapped potential to transform online science education.

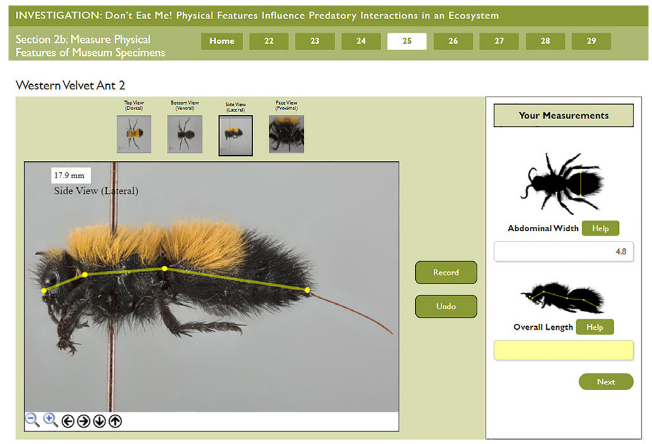
Using digitized natural history collections from museums offers transformative opportunities to engage students in scientific exploration and analysis of real artifacts and specimens. For example, in one of our online investigations, students measure velvet ant specimens (see Figure 1)—very small female wasps with one of the most painful stings in the world! Digitized specimens offer a compelling—and sting-free—data collection experience. This example highlights the potential for natural history collections to reduce (or remove) multiple barriers that limit educational use of museum specimens, including

- museum loans to schools often are restricted to a small number of specimens that are damaged or otherwise unsuitable for inclusion in the museum's permanent science collections;
- real specimens may be too valuable, fragile, or dangerous to allow hands-on manipulation by any public learners; and
- even when specimens can be handled by public learners, specimen characteristics may make it difficult for learners to collect accurate physical data (e.g., specimens may be very small).

Beyond removing barriers, online science investigations of digitized museum specimens offer numerous opportunities to *enhance* authentic science learning in classrooms.

FIGURE 1

Interactive tools allow a student to measure the abdomen width and overall length of this western velvet ant. (Note the substantial stinger visible on this specimen.)



Why Use Digitized Museum Collections for Online Science Investigations?

- Natural history museum collections contain relevant data about pressing global issues (e.g., climate change), allowing students to learn science content, concepts, and practices by investigating contemporary science topics.
- Digitized museum collections reduce socioeconomic and geographic barriers to museum access, creating more equitable opportunities for students to engage in specimen research.
- Museum collections are engaging and interesting—students describe museum specimens in our investigations with vivid, emotional terms (e.g., cool, weird, freaky). Real-world materials help students connect scientific research to their own interests and experiences.
- Data collection from real, compelling museum artifacts and specimens—rather than artificial simulations or abstract data sets that are more commonly used—creates routine opportunities for engagement in interest-driven, sustained investigations.
- Working with data from digitized museum collections offers contextualized opportunities for students to practice arguing from evidence for effective sensemaking.
- Our museum-based investigations support students in understanding the enterprise of science as a whole—engaging with a question, gathering and analyzing relevant data, reasoning about findings, and communicating explanations.

Developing Collections-Based Science Investigations for Authentic, Online Learning

Over the last seven years, our interdisciplinary team of museum educators, domain experts/research scientists, and learning scientists from the Natural History Museum of Utah (NHMU) and the University of Utah has sought to transform science learning opportunities via the development of online investigations for middle school learners that leverage museum collections and align to the science practices of museum researchers. Resulting investigations are provided free online (ResearchQuest.org) to support three-dimensional science learning in keeping with the *Next Generation Science Standards (NGSS)* (Butcher, Larson, and Lane 2019; Butcher et al. 2021; Butcher, Runburg, and

Hudson 2017). Two fundamental beliefs are at the heart of our approach:

1. K–12 students need supported experiences in authentic research to develop knowledge, skills, and identities in science.
2. All learners are entitled to access, explore, and conduct research on contemporary questions using the scientific collections available in national and global repositories.

Our design process is that the Natural History Museum of Utah (the collecting institution)—with its unique access to real specimens, science experts, and cutting-edge research—leads the development and publication of online investigation materials. But before designing investigation materials, we meet with teachers and scientists to determine existing synergies between *NGSS* standards and available scientific collections. We then move to collaborative design sessions with focus groups of teachers (typically 5–10 drawn from a pool of educator advisors) to review mockups and target activities. Based on teacher feedback, the design team next develops an online prototype that is evaluated independently by teachers (usually around 10) for approach, length, difficulty, and instructional supports. Following revisions, we engage current and future educators (around 20–25 individuals) to test a beta version of the investigation for refinement prior to full classroom testing. At each of these stages, teachers provide qualitative (e.g., free-form evaluative comments and reflection) and quantitative (e.g., ratings) feedback that helps our museum-based design team optimize investigations to be age-appropriate, aligned to standards, and flexible for customization based on teachers' classroom needs and schedules.

Digitized Collections Transform Research Opportunities for Learners

Before the COVID-19 pandemic, the Natural History Museum of Utah was focused on creating digital investigations for collaborative pairs of students learning in-person (see Figure 2). However, the time is right to build on this work to create fully online, asynchronous research experiences using scientific collections; this shift is warranted by more than just the realities of the global pandemic. Today's scientists routinely use online research with digitized collection specimens to conduct research and develop new insights about our world. For example, scientists have used museum collections to identify measurable changes over time as the Earth warms—including earlier plant flowering times (Davis et al. 2015) and changing appendage size in animals (Ryding et al. 2021). A decade ago, the world's natural history collections contained an estimated 2–4 billion specimens (Ariño 2010)—digitized educational access to even a fraction of those specimens represents an astonishing public resource for science learning.

When embedded in well-supported, online experiences, digitized collections provide an engaging foundation for students to investigate contemporary science questions. With support from the National Science Foundation, our design team is developing a new set of online investigations—called EPIC Bioscience—that will be accessible on the Research Quest website. In EPIC investigations, learners collect and analyze data from digitized specimens in entomology, vertebrate zoology, and botany to address pressing global issues: climate change, biodiversity loss, resource scarcity, and human impacts on ecosystems. Learners collect data directly from digitized specimens using a variety of methods (e.g., observations, ratings, measurements, classification), then analyze their findings to construct evidence-based arguments about the complex, cascading effects of rapid changes in modern ecosystems. Current EPIC Bioscience investigations are being developed at the middle school level, aligned to four *Next Generation Science Standards* (*NGSS* MS-LS2-1 through MS-LS2-4).

FIGURE 2

Research Quest investigations support authentic investigations with digitized artifacts, specimens, and scientist documentation, such as the fossil map being analyzed by these students.

Online Science Investigations Go Beyond Digitized Classroom Resources

Transitioning to all online delivery during the COVID-19 global pandemic provided illuminating insights on how to design asynchronous investigations in ways that enhance learner motivation, attention, and engagement. Prior to the pandemic, our team had years of experience in designing, testing, and refining Research Quest investigations as digitized resources for collaborative student use in face-to-face classrooms (using laptops, Chromebooks, or iPads). Our initial design and development of EPIC Bioscience investigations were based on these successful, previous digital resources—materials were online and ready for guided classroom instruction. But as classrooms transitioned to remote learning and needed increased opportunities for independent, virtual learning experiences, we set out to explore the potential for EPIC investigations to facilitate meaningful *asynchronous* online science investigations.

We conducted a series of evaluations with practicing and preservice teachers to examine the content, flow, and instructional supports offered by EPIC investigations. Ten practicing science teachers individually stepped through the online investigations and provided quantitative ratings and detailed qualitative feedback. In addition, 21 preservice teachers completed the investigations from a learner perspective, then provided (qualitative and quantitative) survey feedback on investigation quality and support. We intentionally evaluated materials with multiple teaching populations to ensure their value and ease of implementation for broad populations of educators.

Analyses drew upon several data sources. First, we examined quantitative, Likert-style ratings data (e.g., Strongly Agree – Strongly Disagree) for statements related to design features (e.g., Guidance: Students will know what to do at each step). Second, qualitative feedback (e.g., What did you like *best* about this activity? What did you like *least* about this activity? What advice do you have for successful implementation of the investigation in classrooms?) was analyzed via thematic coding (see Table 1). Fi-

TABLE 1

Percent of data in which each (positive or negative) theme was identified explicitly.

	Data Source		
	Practicing Teacher Feedback	**Pre-Service Teacher Feedback**	**Pre-Service Learning Videos**
Positive Supports *(Aligned to Design Priorities)*			
Learn-By-Doing Engagement *(Priority 1)*	44%	62%	n/a
Supported by Data Scaffolds *(Priority 2)*	78%	62%	n/a
Helpful Instruction and Step-by-Step Guidance *(Priority 3)*	13%	43%	n/a
Strong Engagement with Specimens *(Priority 4)*	35%	48%	96%
Heightened Engagement with Modern Formats *(Priority 5)*	44%	39%	81%
Issues / Challenges *(Aligned to Design Priorities)*			
Repetitive Activities Lower Motivation/Engagement *(Priority 1)*	68%	53%	77%
Challenged by Data Collection *(Priority 2)*	22%	10%	15%
Ignore or Reject Peer Data *(Priority 3)*	24%	24%	53%
Need Expert Guidance/Fail to Engage with Feedback *(Priority 4)*	18%	10%	86%
Superficial Processing of Traditional Content *(Priority 5)*	22%	0%	86%

nally, videos of preservice teacher learning sessions (where they completed investigation activities while thinking aloud) were analyzed to determine the presence or absence of major themes. Themes were identified in think-aloud statements as well as in observed, on-screen actions. Resulting themes (both positive and negative) were compared to previous observations and findings collected during in-person, classroom use of Research Quest investigations. This provided us with key insights about when asynchronous, online learning may require different features than those that were effective for synchronous, online learning.

Results from EPIC evaluations indicated the need to consider unique design features for online, asynchronous investigations. Even experienced educators (who are used to providing high-quality guidance and support in classroom environments) did not anticipate the extent to which asynchronous investigations would require additional considerations beyond synchronously supported digital materials. As seen in Table 1, only around 20% of practicing teachers (and even fewer preservice teachers) anticipated that learners would reject peer data, fail to engage with feedback, or process instructional content superficially; in contrast, these issues were observed frequently in the videos of asynchronous learning sessions (53–86% of learner experiences demonstrated these issues).

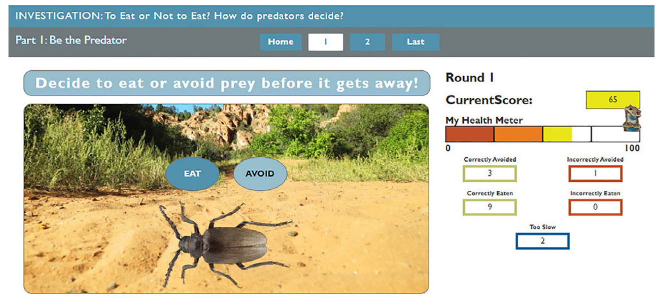
Drawing from these findings, we extracted five design priorities to guide revisions as well as to inform the design, evaluation, and selection of other online science investigations. During our revision process, we discovered that implementing these design priorities for asynchronous learning resulted in creative and efficient materials that translate to synchronous, face-to-face contexts with fidelity and offer future instructional flexibility.

Priority 1: Dive Into Student-Driven Exploration for Motivation and Hands-On Learning

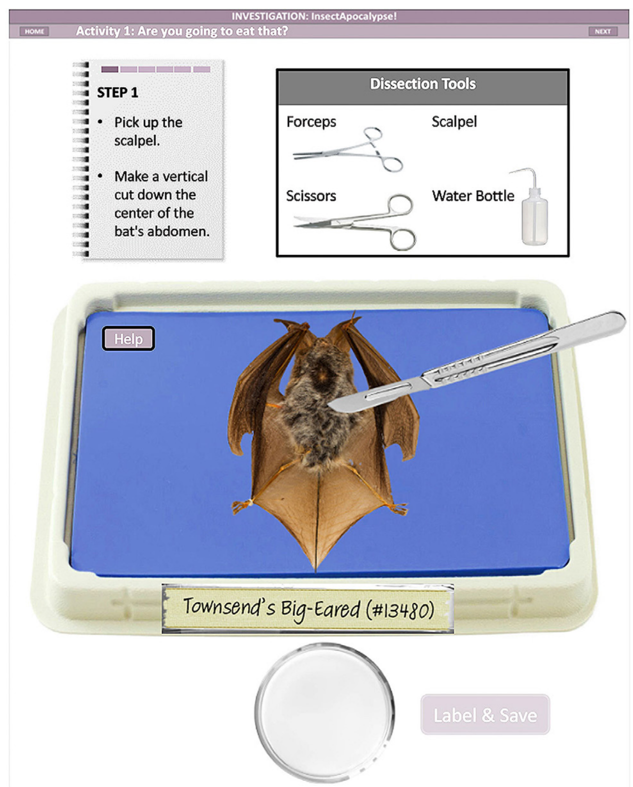
Prior to engaging students in hands-on lessons, classroom teachers often seek to activate students' prior knowledge and motivation—for example, by identifying observed phenomena, discussing compelling questions, or demonstrating connections to real-world contexts. Comparing in-person learning sessions with Research Quest investigations (see Figure 2) with the asynchronous learning sessions with EPIC Bioscience investigations, we have observed that social dynamics in the classroom—including interpersonal relationships among teachers and students—draw the learner into classroom preparation activities in ways that are difficult (if not impossible) to replicate in asynchronous, online investigations. In asynchronous learning sessions, we have observed that—even if they read or watch online introductory materials—learners often fail to encode the information in such a way

FIGURE 3

These introductory, learn-by-doing activities are designed to activate student questions and ideas, motivating subsequent data collection and analysis.



The image above shows an educational game. Students decide to eat or avoid prey. Students form predictions about how physical features of prey can influence predator behaviors.



This image shows students dissecting stomach contents of bat specimens to identify typical diets. Given declining insect resources, will these bats be able to adjust their diets and survive?

that they apply it to subsequent activities. We infer that, lacking the social context of the classroom, prior knowledge activation and motivation in online, asynchronous investigations must be targeted by immediate, highly experiential opportunities; that is, creating questions, motivation, and awareness via learning-by-doing. Essentially, this flips the order of more traditional classroom instruction—through guided, student-driven exploration, students *prepare themselves* to engage with key concepts by generating questions, activating ideas, or wondering about outcomes.

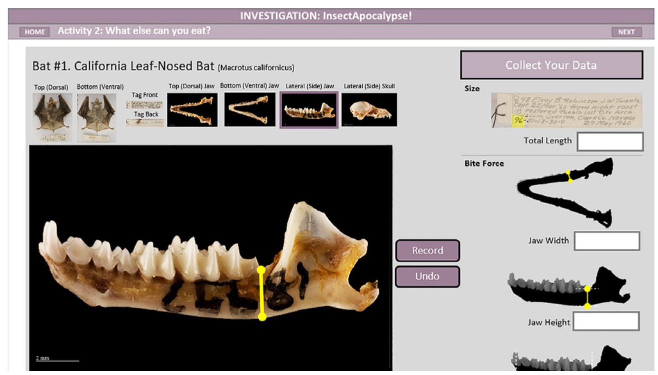
We have implemented this design priority in our EPIC Bioscience investigations by creating customized introductory activities that require little prior knowledge or facilitated instruction and get students immediately engaged with digitized specimens (see Figure 3). Students dive right in—interactions are experiential but supported via immediate feedback that is automatically provided by the online system (not by teacher intervention). Students become motivated to complete investigations through questions and ideas that arise *during* these introductory, exploratory experiences. In the case of EPIC Bioscience investigations, these learn-by-doing experiences are carefully designed to align to investigation questions and target standards. When using learn-by-doing materials that are not strategically aligned to standards or investigations, teachers need to create clear goals and prompts that help focus learners on key concepts, principles, questions, hard-to-see phenomena, or counterintuitive outcomes without delaying their entry into the exploratory experience.

Interactivity is essential during introductory activities and critical to redefining "hands-on" learning in modern educational contexts. Educators may not find the hands-on opportunities provided by digitized specimens (particularly static images) to be immediately obvious. However, we have found that a series of high-quality images can be decidedly interactive as students zoom in and out, switch views, and measure or organize these images in a variety of ways. In fact, embedding images into online science investigations can enable a more in-depth exploration than is possible with the physical specimens themselves. Particularly for small/fragile physical specimens, online images and interactive tools allow learners to observe specimens in greater detail and to virtually manipulate them in more dynamic ways (see Figure 4). Teachers can leverage new forms of hands-on science by seeking online investigations that allow student-directed exploration with real (but virtual) specimens.

FIGURE 4

Redefining "hands-on" learning in modern educational contexts.

In the image above, a museum scientist holds a bat skull and jaw. Museum specimens like these are small and delicate, limiting opportunities for hands-on investigation.



This image shows digitized specimens, which allow observation of small details, dynamic exploration, and hands-on measurements using online tools and support.

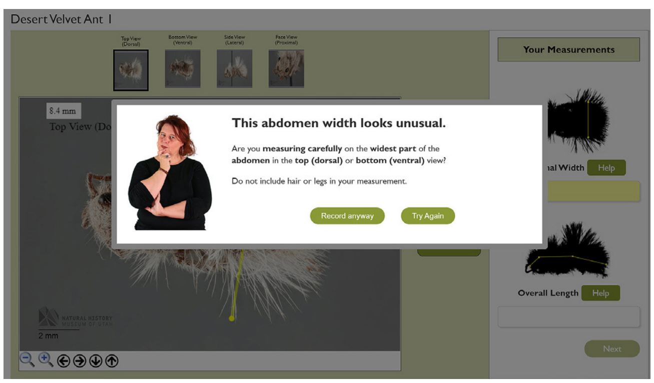
Priority 2: Use Online Scaffolds to Offload Complex Demands

Fully supported, online science investigations not only provide students with frequent access to high-value scientific specimens (i.e., specimens of sufficient quality and importance to be included in a museum collection) but also provide opportunities to offload some methodological and organizational aspects of science investigations in ways that allow students to focus more strongly on data analysis and interpretation. When collecting data in traditional science investigations, significant amounts of student (and teacher) time can be spent recording and organizing data to facilitate analysis. Data documentation and organization are, without a doubt, essential skills for students to learn. But students who struggle with basic documentation may not complete an investigation or may wind up with unusable data at the end of their efforts. In the case of digitized specimens, online scaffolds help ensure sufficient progress and successful documentation, so that all students have the opportunity to reason with data that they collected. EPIC Bioscience investigations model data documentation and organization (see Figure 5) and provide students and teachers with multiple options for access (e.g., downloading data tables and summaries).

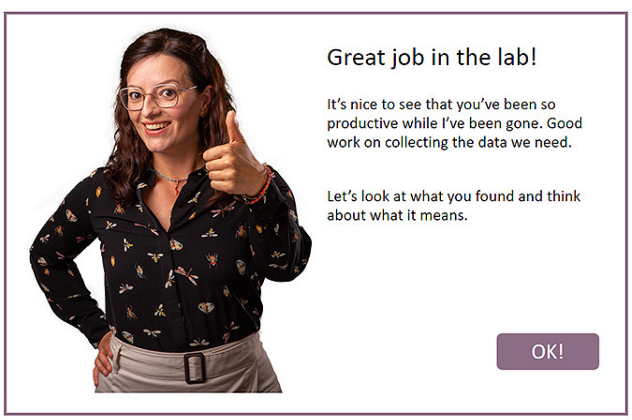
To facilitate development of data understanding, we recommend that teachers seek online investigations in which data documentation and organization is supported and modeled, but not hidden. Students should *not* move from data collection to a "magic" presentation of results—they need to see how data is recorded and formatted for analysis! We also recommend teachers prioritize resources that allow students to view, access, and (ideally) download their own data. Data downloads can serve as the basis of extension activities, where students further explore

FIGURE 6

Practicing scientists in the domain serve as virtual mentors, providing guidance and feedback on data collection, investigation progress, data analysis, and reasoning.



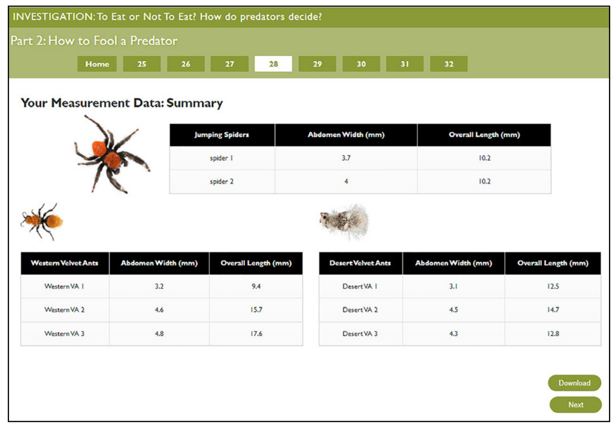
Feedback can take the form of constructive criticism to encourage accuracy and monitoring.



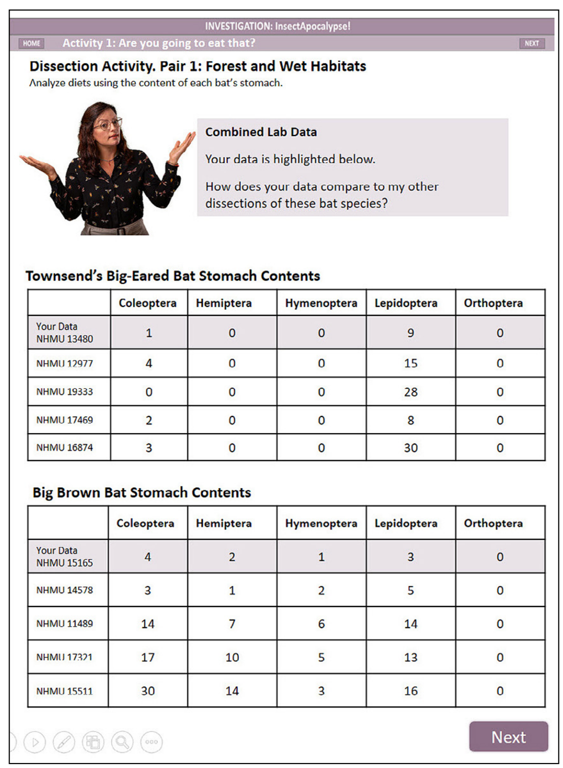
Feedback can also include positive feedback and encouragement.

FIGURE 5

EPIC Bioscience investigations automatically record data as students collect it. Scaffolded supports in the investigation model effective documentation and organization of data for analysis.



The image above shows that instructional supports include visual cues to connect data to speciments and the option to download student data.



Modeling data documentation and organization also facilitates comparison of one's own data to data from other researchers, as seen above.

a data set for which they understand its context and meaning—because they collected it!

Priority 3: Digital Mentors Are Critical Sources of Feedback and Guidance

One of our more surprising design findings was that peer-comparison and feedback—methods that worked well in classrooms to support error revision and reflection—were not effective approaches to enhancing reflective thinking during remote science investigations. Students completing asynchronous, online investigations routinely assumed that peer data was incorrect or their own data was "close enough." As a result, asynchronous learners were unlikely to reflect on discrepant data or conclusions—even if they previously had expressed confusion or uncertainty about their own processes or ideas.

This finding provides a daunting challenge when developing online science investigations, as real-time advice and feedback by live mentors (e.g., scientists or teachers) is not a scalable option. Thus, we must be creative in finding ways to help students attend to feedback and guidance during self-directed, remote work. Our approach with EPIC Bioscience has been to create customized, virtual support that is aligned to students' actions and progress in the investigation but does not require live human monitoring. We recruit practicing scientists in the domain of an investigation (e.g., entomology) to serve as virtual mentors. Scientists pose for a series of photographs that vary their facial expressions and gestures, allowing us to create customized virtual screens that reflect positive and negative feed-back, questions, and other conversational turns (see Figure 6). Guidance and feedback is not live, but it is immediate and customized to a student's individual actions in the system. Digital mentors facilitate social connection as well as providing ever-present support.

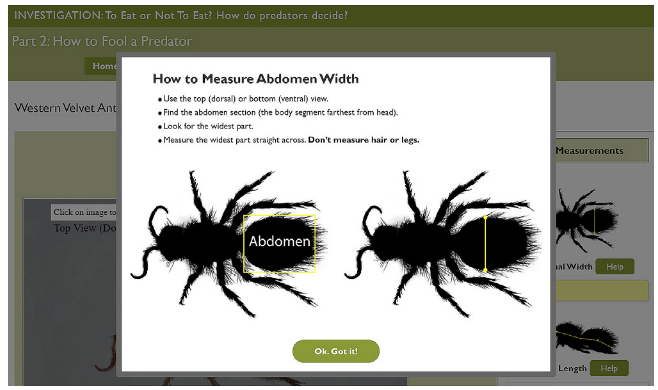
Beyond our Research Quest and EPIC Bioscience investigations, not all systems offer digital mentorship. In these cases, teachers are advised to look for online materials that provide immediate feedback on student actions and incorporate some form of social characters (e.g., avatars) to connect with learners. We recommend that teachers avoid "all positive" systems where praise is provided for any response—students should receive positive feedback for correct/accurate responses and constructive feedback to improve incorrect/inaccurate responses.

Priority 4: Use Visual Feedback and Cues for High-Impact Instruction

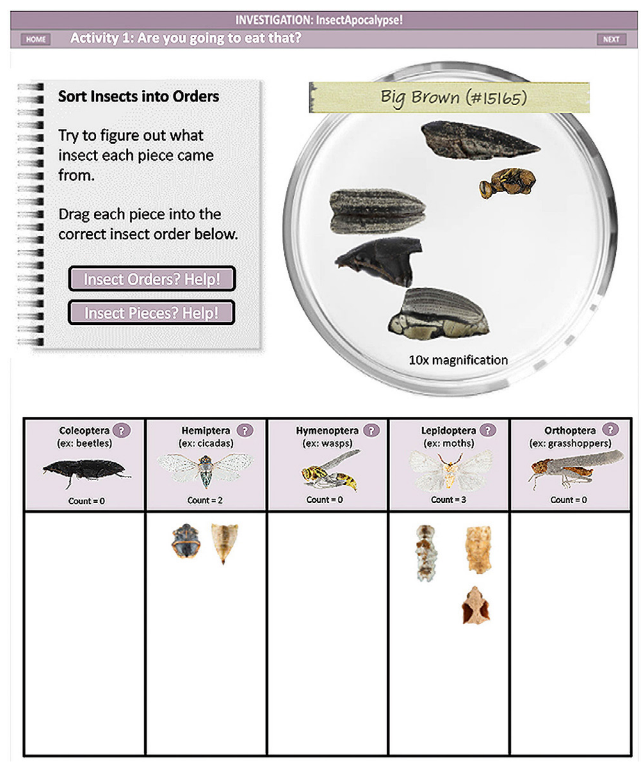
In instructional contexts, we want students to understand what they are doing, why they are doing it, and why it matters. In

FIGURE 7

Visual instruction and feedback is particularly important in online contexts.



Visual instructions or help can enhance attention to key information or methods. Visual cues are easy to remember, allow students to get started quickly on activities, and support at-a-glance troubleshooting.



Visual cues and examples can replace extensive text instructions, and interactive features can provide visual feedback. If a student drags an insect from the petri dish into the incorrect order, it will snap back until correctly sorted.

classrooms, these goals often form the basis of instructional explanations that support meaningful classroom discourse. However, in online contexts, even brief instructional explanations can result in text-heavy experiences that disengage students. Students frequently skip even small amounts of text online, making alternative presentations of instructional content critical for effective learning. To solve this problem, we have challenged ourselves to develop visual approaches to instruction, hints, and help (see Figure 7). As we prioritized visual design, we found that we often were able to replace paragraphs of text explanation with clear, focused visuals accompanied by very brief supporting text.

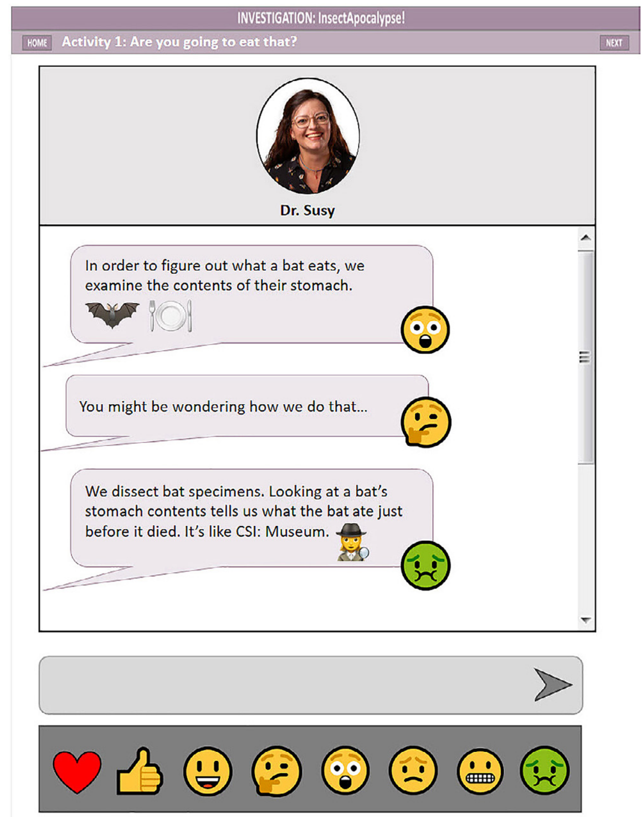
In selecting online investigations, we recommend that teachers prioritize visual instruction, as well as visual cues in help or scaffolding. Teachers also can look for resources that use visual cues to help students get started quickly on activities. We recognize that learners with visual impairments may not benefit equally from these materials, and an emphasis on visual feedback and cues is not an excuse to ignore best practices for accessibility (e.g., high-quality alt text). However, carefully designed visual content has been a woefully underused technique to support, engage, and guide learners online.

Priority 5: Enhance Interest via Modern Instructional Formats

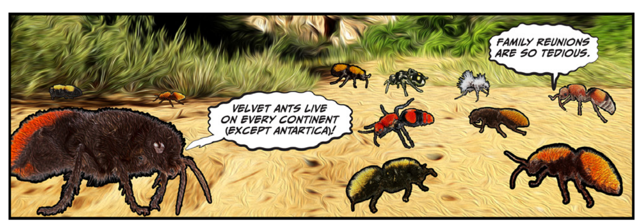
Today's students are 21st-century learners who have been immersed in technology and media exposure since birth. Online formats afford us the opportunity to be creative and playful with our instructional materials in ways that draw upon and connect to what students see and experience in their everyday lives. We have been challenging ourselves to think about the materials that students see outside of school and to creatively repurpose those materials for instruction (see Figure 8). For example, in one investigation, we use educational comics to introduce key concepts (e.g., What is mimicry?) and background information (e.g., What is a velvet ant?). In another activity, students select an emoji to react to—and thereby self-pace—text message guidance from their (digital) scientist mentor. We continue to challenge ourselves to present instructional content in innovative and unexpected formats to engage learners and encourage teachers to look for instructional materials that mimic the rich media and technology-based communication in which 21st-century learners are immersed.

FIGURE 8

Adapting technology from students' real world experience can lead to creative and relatable instructional formats.



Students select an emoji to self-pace scientist guidance delivered by text messages.



Instructional comics are used to introduce students to key concepts and to develop background knowledge relevant to the investigation.

Limitations and Remaining Challenges

Our work has uncovered several existing limitations and remaining challenges in using student-centered, authentic science investigations for asynchronous online formats. One current limitation is the relatively small number of collections-based research investigations that are available to teachers. Sustained integration of online, collections-based research into classroom learning will require that we continue to expand the number and range of available investigations. Another limitation is that—despite many improvements in online access made during the global pandemic—inequities in connectivity remain. Access to high-speed internet and high-quality devices must continue to be improved to achieve fully equitable online science learning.

Another limitation and challenge is that authentic science research in classrooms requires time and patience for sufficient data collection. Realistic research necessitates collecting data from multiple samples to ensure representative data for analysis. Although our current investigations streamline data collection by allowing students to combine their own data with larger samples, teachers will need to cultivate student stamina for sustained data collection.

A related limitation and key challenge—one with which we continue to grapple—is the increased demands that authentic science investigations place on students' data literacy skills. Students can become distracted by unimportant patterns in graphs or small differences in measured data that are not relevant to larger questions Students likely will need early (and repeated) exposure to concepts of variability, error, and outliers.

Finally, a critical challenge in online science investigations with real specimens is helping students become comfortable with uncertainty and disagreement. This can be especially difficult in asynchronous environments. Classrooms are social, interactive settings where peers play a valuable role in proposing alternative ideas, hypotheses, or interpretations. Strategic documentation can help students develop multiple ideas and examine evidentiary support more carefully (Butcher et al. 2019), but it is particularly useful when combined with classroom discourse. Teachers likely will need to implement online tools for discussion (and to seed student communication using targeted questions and prompts) to expose students to a range of thinking, findings, and outcomes—particularly to explore how and why findings may differ.

Join the Research Quest Community

We hope that you are enthusiastic about the incredible potential of museum specimens to engage your students in compelling, authentic online science investigations. Create a free account at ResearchQuest.org to access all investigation materials and teacher resources—you also can contact our team via your account. We welcome your ideas, feedback, and suggestions as we move forward, together, toward a new era in online science learning.

We also are seeking partners from museums or collecting institutions interested in developing their own collections-based investigations. We would be delighted to share our experiences and helpful materials (i.e., guidance for collections selection), as well as to strategically combine collections to address temporal or spatial gaps. We invite you to get in touch and join us in our mission to transform science learning by making classrooms a place where students can engage in authentic research with digitized collections.

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REFERENCES

Ariño, A.H. 2010. Approaches to estimating the universe of natural history collections data. *Biodiversity Informatics* 7 (2). doi:10.17161/bi.v7i2.3991

Butcher, K.R., M. Larson, and M. Lane. 2019. Making critical thinking visible for student analysis and reflection: Using structured documentation to enhance effective reasoning and communication. *Science Scope* 42 (8): 44–53.

Butcher, K.R., M.J. Power, M. Larson, M.P. Orr, S. Velásquez-Franco, M.A. Hudson, and V.J. Bailey. 2021. Museum leadership for engaging, equitable education: The transformative potential of digitized collections for authentic learning experiences. *Curator: The Museum Journal* 64 (2): 383–402. doi:https://doi.org/10.1111/cura.12423

Butcher, K.R., M. Runburg, and M. Hudson. 2017. Using digitized objects to promote critical thinking and engagement in classrooms. *Library HiTech News* 34 (7): 12–15.

Davis, C.C., C.G. Willis, B. Connolly, C. Kelly, and A.M. Ellison. 2015. Herbarium records are reliable sources of phenological change driven by climate and provide novel insights into species' phenological cueing mechanisms. *American Journal of Botany* 102 (10): 1599–1609. doi:10.3732/ajb.1500237

Ryding, S., M. Klaassen, G.J. Tattersall, J.L. Gardner, and M.R.E. Symonds. 2021. Shape-shifting: changing animal morphologies as a response to climatic warming. *Trends in Ecology & Evolution*. doi: https://doi.org/10.1016/j.tree.2021.07.006

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4

PREPARING AND SUPPORTING STEM EDUCATORS IN INFORMAL AND FORMAL SETTINGS

INTRODUCTION

With, Not *For*

The Distinction Matters

BY BETH MURPHY, Field Editor, *Connected Science Learning*

For most of my career, I've worked at the interface between in- and out-of-school STEM learning—finding common ground and shared values between program providers like museums or other nonprofits and schools—for the purpose of improving science teaching and learning in both formal and informal settings. Time and time again, my engagement in these cross-sector collaborations has reinforced that working together allows for combining strengths, sharing resources, overcoming obstacles, filling gaps, and achieving results in ways that none of the individual partners would likely be able to do on their own. In my experience Aristotle was right: The whole is truly greater than the sum of its parts.

I've spent most of my career working with schools from the outside—and I admit that in the early days I failed to appreciate the distinction between developing programing *for* as opposed to *with* schools. Oftentimes, we educators from informal settings focus on how the practices in our repertoire can be applied in the formal science classroom—essentially, how classroom teachers should do what we do. What we talk about less often is how practices commonly used in the science classroom can be of significant value to educators in informal settings. Fortunately, I learned fast.

I was lucky that the science museum where I worked had an exceptional relationship with a nearby large, urban school district; this allowed me to easily reach out to and work closely with district-level science specialists. This relationship helped me gain an appreciation for what museums could learn from schools—not just what schools could learn from museums—when it came to teaching science. Through collaboration, we could capitalize on each other's strengths and learn from each other. It became clear that if we worked together, we could design programs that would meet both organizations' needs and help both achieve their goals and engage more students, thus accomplishing things that were unlikely to happen without partnership.

Having had this opportunity to see what can happen through authentic collaboration has shaped my professional values perhaps more than any other experience. It is the type of informal-formal relationship I continue to strive for in my work and encourage other organizations to develop, and what excites me about being a part of *Connected Science Learning*. While in- and out-of-school learning environments have different features and constraints, maybe to a large degree good science teaching is good science teaching—regardless of setting. All the more reason to bridge the informal-formal divide and work together.

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Growing Understanding From a SPARK

BY DEBORAH HANUSCIN, ABBY WHATLEY, BRIDGET DAHLMAN-OETH, PAOLA SANCHEZ, BENJAMIN DIXON, AND DANIEL SAVAGE

Since their release in 2013, many states have adopted the *Next Generation Science Standards* (NGSS Lead States) or have revised their own standards in ways that reflect the *NGSS*. These standards require a significant shift in the way science is currently taught in most classrooms, as well as how we prepare new teachers (Bybee 2014). Notable among these shifts are the integration of science and engineering; the focus on deeper understanding as well as application of science content; the emphasis on coherence in developing concepts; and the intent for classroom activities to reflect the interconnected nature of science and how science is practiced in the real world (NGSS Appendix A). Research shows that by collaborating in the planning, enactment, and reflection on *NGSS*-aligned lessons, preservice teachers can build their practical knowledge of the *NGSS* (Hanuscin et al. 2016). However, there are limits to what can be accomplished within the fairly brief experience of the science methods courses preservice teachers take. At the same time, school districts must balance the tensions between the reality of limited resources (e.g., time and money) and the ideal conditions necessary to shift classroom practices to align with the vision of the *NGSS* (Shelton 2021). Therefore, teacher education programs may also find it challenging to provide high-quality practicum experiences in science that model *NGSS*-aligned instruction (Hanuscin et al. 2016).

Science museums provide rich opportunities for learners of all ages to engage with science. And, while there is overwhelming evidence that informal institutions can positively impact *children's* science learning (NRC 2009), there is also evidence of the role and potential for museums to support the learning of both preservice and inservice *teachers* (Smetana et al. 2017). We recognize that informal science institutions like museums can play an important role in supporting schools and teachers in addressing the *NGSS* (Short 2014; Schmidt et al. 2014) but may need to develop their capacity to do so (Jablonski 2017; Anderson et al. 2006). Museums may also encounter difficulties in shifting the focus from field trips being viewed as stand-alone events to learning experiences that are part of a broader learning ecosystem for science (Anderson et al. 2006).

Our goal in this project was to develop a partnership that connected science learning in museums, elementary classrooms, and teacher preparation programs that would enhance the capacity of all partners to teach in ways that align with the *NGSS*. Specifically, we created a practicum partnership through which we developed and piloted complementary classroom curriculum modules and museum-based learning experiences. Our efforts are a response to calls to support teachers in bridging the various domains in which students experience science and to model how preservice teachers could create and sustain connected learning opportunities for future students (Smetana et al. 2017).

TABLE 1

Resources and needs of project partners.

Partner	Resources	Needs/Challenges
Bellingham Public Schools	• Students & Teachers • Pedagogical expertise & mentoring • Experience working with children	• High quality *NGSS*-aligned curriculum materials • Opportunities for professional learning
SPARK Museum of Electrical Invention	• Exhibits, materials, and resources related to the history of science and engineering • Expertise in science & engineering content • Field trip program	• Alignment between field trip program and classroom learning aligned to the *NGSS* • Promote understanding of museum as part of a larger learning ecosystem
SMATE Program at Western Washington University	• Expertise in teacher education • Expertise in instructional design • Expertise in *NGSS* • Prospective teachers	• Practicum opportunities for prospective teacher to enact *NGSS*-aligned instruction • Support for continued learning of prospective teachers

Partners and Motivation

The primary partners in the program include the SPARK Museum of Electrical Invention, Bellingham Public Schools (BPS), and Western Washington University's Science, Math, and Technology Education (SMATE) program—all of which are located in Bellingham, Washington. We describe each partner and their motivations for forming the partnership below.

The SPARK museum houses a world-class collection of artifacts representing the historic development of electricity, radio, and early technology from the 1600s through the present day. Visitors can observe and interact with artifacts from the laboratories of the early pioneers of electricity, from magnets and Leyden jars to Edison lightbulbs, vacuum tubes, telegraph and telephones—as well as witness a ninefoot-tall Tesla coil in the museum's MegaZapper show. SPARK has a longstanding relationship with area schools, including BPS, through their field trip programs, and the museum regularly receives teacher requests for additional curriculum resources to support their instruction. With a full-time staff of only two, however, the museum has limited capacity to meet these needs. To provide high-quality curriculum resources, SPARK staff identified their own need to better understand the *NGSS* and to align their field trip program to the needs and interests of teachers.

BPS serves approximately 12,000 students (66% White). While the district recently adopted a new science curriculum at the middle school level, the current elementary curriculum materials predate the state's adoption of the *NGSS*. Only 50.1% of students in BPS met the science standards for the 2018–2019 school year. The district has a longstanding relationship with WWU through the placement of prospective teachers in BPS classrooms for their practicum and student teaching experiences and the district previously partnered with WWU's Spanel Planetarium in 2016 to customize their programs for fourth- and fifth-grade students to strengthen the alignment with the

NGSS. However, the director of teaching, learning, and technology integration for the district recognized the need to do more to support teachers and students in meeting the *NGSS* at the elementary level.

The SMATE program at Western Washington University offers science content, science methods, and practicum courses for future K12 teachers. SMATE recognizes the particular challenges to meeting the needs of prospective elementary teachers, the majority of whom do not major in science (Banilower 2019), and who will need to develop the capacity for continued science learning as teachers. SMATE faculty (who have tenure in the sciences or education) have engaged in professional learning related to the *NGSS* and worked to revise its courses and programs to better reflect these new standards; one part of this process related to the practicum experience and the desire to avoid preservice teachers using outdated curriculum materials that did not align with the *NGSS*.

Program Development

The partnership was initiated when the education director of the SPARK museum (Abby) reached out to a WWU faculty member (Debi) to gain expertise related to the *NGSS*, and invited her to give a talk to local informal educators on the topic. At the same time, BPS had reached out to WWU faculty regarding their desire to focus on providing support for integrating STEM in the elementary grades. Because of the existing field trip partnership between SPARK and BPS, it made sense for all three partners to come together. Program development began with conversations among partners about their needs and potential approaches. By coming together, we were able to leverage resources and expertise of all partners to address our individual challenges and meet our collective needs (See Table 1).

The program we developed was a practicum-based partnership through which preservice teachers—working collaboratively with the support of their professor, SPARK museum staff, and BPS personnel—would develop a set of curriculum modules aligned with the *NGSS* and complementary to the SPARK field trip program. BPS teachers participating in the SPARK field trip program would host WWU students for their practicum, during which they would collaborate to implement and evaluate the curriculum modules. Finally, with input from all parties, the preservice teachers would revise the curriculum modules and make them available at no cost to teachers through the SPARK museum's educational resources.

The Curriculum Modules

Development of the curriculum modules (Figure 1) took place over one academic quarter (the elementary science methods

FIGURE 1

Timeline for development of the curriculum modules.

Fall 2019

- Preservice teachers attended a panel discussion with SPARK and BPS staff at the start of their methods course as an orientation to the project.
- Preservice teachers visited the SPARK museum and participated in a mock "field trip" experience and gain familiarity with real-world examples of science and engineering through artifacts in the collection.
- In their methods course, preservice teachers were introduced to the *NGSS* and worked to identify and unpack relevant performance expectations.
- Preservice teachers co-developed curriculum modules aligned to the *NGSS* using existing high-quality resources, with support from faculty and SPARK/BPS staff.

Winter 2020

- Preservice teachers co-taught the curriculum modules in pairs, collaborating with grade-level teams (grade 4) at four BPS elementary schools.
- Using feedback from implementation, preservice teachers collaborated with classroom teachers to revise and improve the modules.

Spring 2020

- SPARK museum staff, WWU faculty, and preservice teacher volunteers collaborated to transform the curriculum modules into an accessible eBook format (with virtual options for activities).
- Curriculum modules were made freely available and shared within BPS and more broadly at NSTA conferences in joint presentations by SPARK staff and WWU students.

course) with implementation and revision occurring in the subsequent quarter (the elementary science practicum). We leveraged existing high-quality curriculum materials, such as those curated resources in the National Science Teaching Association's *NGSS* Hub, and adapted successful *NGSS*-aligned approaches used by others (e.g., the development of "client cards" for introducing engineering tasks described by Capobianco and colleagues, 2013). We also used the BSCS 5E Learning Cycle (Bybee 1997) as a framework for instructional design and conceptual storylines (Hanuscin et al. 2016) as a way to support coherence within and across lessons.

The completed curriculum modules (see Figure 2) address five *NGSS* performance expectations spanning engineering and physical science (Figure 3). All modules include supporting materials about the pedagogical framework (5E), as well as a conceptual storyline for each module (Hanuscin et al. 2016), materials needed, handouts, information about the *NGSS* alignment, and more so that educators can understand how to implement and/or adapt the materials for use with their students in productive ways. Lesson activities use artifacts from the SPARK collection and complement the field trip to the SPARK museum, which can serve as either a provocation or culminating event. When students visit the museum, they are presented with real-world examples of the work of scientists and engineers with a focus on the historical evolution of ideas and electrical devices, showcasing the development and optimization of devices over time. In this way, the field trip provides context for students' work in the classrooms and helps them make connections between what they are doing and what scientists and engineers do.

FIGURE 2

Overview of curriculum modules.

Part 1: Introduction - What Do Engineers Do?

Students are introduced to the unit and examples from SPARK's collection that illustrate how electrical devices have been designed to solve various problems, and how their designs have improved over time. They are then introduced to a series of "client cards" that motivate them to solve a problem using the engineering design process to design an electrical device. They create an Engineering Manual in the modules that can inform their designs.

Module 1: Circuits as Systems	Module 2: Energy Flow in Circuits	Module 2: Makey-Makey A Circuit Work
Students learn how the components of a circuit function together as a system.	Students learn more about how energy is transferred and transformed as it moves through a circuit.	Students use Makey-Makey to enhance the functionality of their circuits.

Part 2: Culminating Event - Design Showcase

Students apply what they have learned in the modules to design and test a device that converts energy from one form to another. They present their final designs to their peers.

Evaluation

The creation and revision of the curriculum modules helped achieve our goal of developing the capacity of all partners to make many of the conceptual shifts identified in Appendix A of the NGSS. As an unfunded initiative, we did not have the resources of an external evaluator; however, we engaged in joint reflection on our partnership to assess its value and consider whether and how we might continue to collaborate in this way. In evaluating the success of our partnership, we sought evidence for this in preservice teachers' reflections, the modules themselves (including both drafts and the revisions made during implementation), and feedback from students and teachers. Below we highlight four key shifts that we believe our partnership supported.

One key shift in the *NGSS* **is the integration of science and engineering**. Few, if any, elementary teachers take coursework in engineering (Banilower 2019). The SPARK museum–with its focus on historical developments in science, technology, and engineering–provided excellent examples of this integration in real life and contributed to conceptualizing how science and engineering might be integrated in the classroom. Developing the curriculum modules provided an opportunity for preservice teachers to expand their knowledge of both science and engineering, and the relationship between them. According to Danny:

> *My subject matter knowledge for teaching science has also expanded to include engineering, which I had little knowledge of prior to this course. Students are doing science when the goal is to answer a question. Students are doing engineering, on the other hand, when the goal is to define and solve a problem.*

The integration of science and engineering also provided opportunities for focusing on deeper understanding of content as well as application of content. This shift was particularly chal-

FIGURE 3

These *NGSS* performance expectations provide the foundation for the curriculum modules.

Performance Expectations	Connections to classroom activities
3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.	Students identify the problems that items in the SPARK collection were designed to solve. Students are introduced to a series of 'client cards' that describe problems that can be solved by designing an electrical device.
4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.	Students observe how different circuit configurations function, and how energy can be transferred as light, heat, and sound via electric current.
3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.	Students compare various iterations of electrical items in the SPARK to understand their optimization in solving a problem. Students develop knowledge about circuits and how they can be designed in different ways to solve the problem they choose.
4-PS3-4. Apply scientific ideas to design and test a device that converts energy from one form to another.	Students design and test a device to solve the problem of their choice, using the understanding they build about how circuit systems work in each module.
3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.	Students test their prototype devices and use peer feedback to optimize their designs before creating a 'product pitch' for their solution.

lenging for preservice teachers, who initially conceptualized science as being more activity-focused. As Ben explained, "My initial lesson plan represented my preconception of science being more driven by hands-on activities where students just magically grasp the big concept I wanted them to learn." In the modules, the client cards presented problems that invited students to use the knowledge they developed about circuits and energy to design a solution. Several preservice teachers commented on the success of this approach and their observations of students' ability to apply their new understandings:

> *The biggest indicator for me was at the very end when the students created their designs. Some even figured out how to use the switch and understood how it worked without ever having seen it. The students' designs all really impressed me because they created creative and unique circuits centered around solving a problem. The proof for me was at the end when I saw their designs and when I talked to the students individually about their designs it was clear that they were understanding and could apply what they were learning.*

Despite this success, preservice and collaborating teachers felt there was a need for greater scaffolding to support all students in drawing on the knowledge they were developing about circuits. In revising the modules, we incorporated a student-generated Engineering Manual to be used at the end of each module as a way for students to keep track of key scientific ideas they had learned that could inform the design of their final solution. Specific prompts for the Engineering Manuals were designed to help make students' thinking visible and allow teachers to evaluate students' progress through the modules, identifying areas for individualized support.

For many preservice teachers, the ideas in the modules were new content that they were learning as they planned; however, the process of creating the modules content knowledge in being able to design lessons in which **the science concepts build coherently** another key shift in the *NGSS*. One of the tools we used to build coherence within and across the modules was a conceptual storyline (Hanuscin et al. 2016, adapted from Bybee 2015). As Paola noted, "Building conceptual and coherent storylines is challenging with new content and teachers must have a strong and deep knowledge base to do this." Building a conceptual storyline for each module helped preservice teachers consider the connections between activities and how those ideas built over time across modules. The notion of a "storyline" also helped them critically evaluate the lessons in terms of whether students were making these intended connections:

> *At times, the lessons did seem a little disconnected, but they did all eventually tie back together. I wasn't entirely sure if the students were understanding the connections while we were teaching the introduction module, module 1, and module 2. But once we got to module 3, the students were using some of the vocabulary we had taught them and making connections between the Makey-Makeys and the circuit systems we had built. It was wonderful to see everything come together!*

Others realized how each piece of the experience—including the field trip—was necessary to create an overall coherent learning experience for students. "Students struggled to make the connections between the concepts we were exploring and how it directly related to the client cards and field trip; however, once we finished at the SPARK museum, they all were excited to "put their engineer caps" on and find solutions to their client cards." This affirmed the importance of the learning that took place in both spaces (school and museum settings).

The activities in the modules—which collaborating teachers noted were "high quality" and more "interactive" than their existing science curriculum materials—were intended to mirror what scientists and engineers do. That is, **to reflect the interconnected nature of science as it is practiced and experienced in the real world.** Conversations between preservice and collaborating teachers during implementation made clear, however, that what was missing were actual examples of real scientists and engineers that might challenge stereotypical views about who can do science. In the revision process, SPARK museum staff were again an important resource. With their help, we revised the modules to highlight the work of scientists such as Lewis Latimer, a black inventor and patent draftsman whose Maxim Lamp, developed in 1881, is in SPARK's collection. This also prompted us to strengthen the connection between real-world examples of science and engineering innovations to specific items in the collection that students would observe on the field trip. In turn, this helped museum staff understand an area in which they could fulfill an important need for teachers in terms of showcasing the diversity of those involved in the history of scientific and engineering developments related to electricity. As SPARK staff explained:

Students working together to successfully complete a circuit to power a fan.

> *Being able to work in partnership helped us fill gaps in what we are able to do, and to carry out our mission and serve students better than we could do on our own. It not only gave us a better understanding of the NGSS, but helped us gain insight into the realities of the classroom and challenges teachers encounter implementing science. This helped us realize what kind of supporting role we can play in meeting the vision of the NGSS.*

Lessons Learned and Challenges

In many ways, our partnership was a success—but not one easy to replicate without careful planning and consideration, as well as investment from all partners. In this section, we describe both lessons learned and challenges we encountered.

Lesson #1: The Benefits of Common/Shared Teaching Experiences

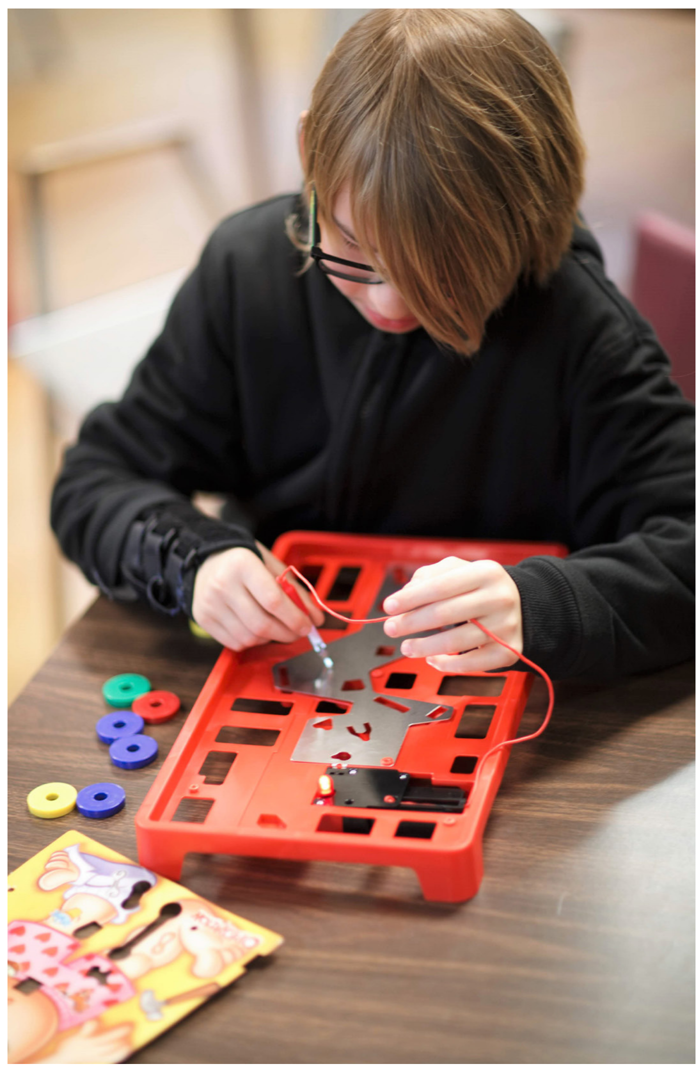
One notable difference between this practicum arrangement and the traditional arrangement is that rather than being spread across grade levels and topics, all preservice teachers were working on and implementing the same lessons. This benefited the instructor while providing targeted support but also created different affordances for preservice teachers to support one another. All preservice teachers were paired for the practicum experience, so they had peer support as well as support from the collaborating teachers. As one explained, "Having a partner teacher to bounce ideas off of and to offer support when things did not go so well was extremely helpful." Working on implementing the same lessons also afforded opportunities for collaboration beyond their teaching partners. Bridget noted, "We met outside of class as colleagues to prepare and support one another." In this manner, preservice teachers could draw on their experiences across classrooms and schools to engage in solving shared problems and challenges in implementing the modules. This also allowed the group to compare and contrast how different approaches worked, or how the same approaches might work differently with different students.

Lesson #2: The Importance of Collaborating as Colleagues

While the structure of the practicum provided a common experience, we recognize that developing trust in each other and the ability to collaborate as colleagues was necessary for realizing the affordances of that shared experience. A sense of collegiality formed in the methods course as preservice teachers worked together but also extended into the practicum as preservice teachers collaborated with classroom teachers. As Paola noted, "This was totally different from any other course or practicum experience; we built relationships as colleagues (with teachers and our peers)." Importantly, the scope and nature of this project was such that collaboration was necessary—no one teacher (preservice or inservice) could accomplish individually what the group could accomplish through collaboration. As Ben explained, "Collaborating with others in this way prepared us for collaborating in the future. It helped me realize how much each person has to offer, and how important collaboration and partnership can be as an educator. I feel more prepared now to collaborate in my future career." Similarly, other preservice teachers noted the value of collaboration with community partners like the SPARK museum, "I feel like I have a blueprint now for how to connect with the community beyond my classroom—I feel empowered as a teacher knowing I can do that!"

Lesson #3: The Value of Authentic Engagement

Our partnership provided a meaningful context for preservice teachers to enact what they were learning in their teacher education program, engaging in an approximation of practice (Grossman et al. 2009) that was authentic to the work of teaching science, not just in terms of collaboration, as mentioned above, but also in terms of teaching practice and motivation. Preservice teachers recognized that their instructional design went "beyond the hypothetical lesson plans" they often wrote in other courses. Rather than viewing the project as an *assignment,* they viewed it as an authentic form of engagement. As



Workshop participant dismantling an operation game to understand how circuits work.

Bridget reflected, "In terms of our motivation, we were not just doing it for the A. When we were connected to all these stakeholders, we were accountable and wanted to make it meaningful and quality." The cycle of planning, enacting, and reflection in which they collaborated with classroom teachers provided them with new insights about teaching. Rather than think at the lesson level, preservice teachers could view the curriculum more holistically, "I was able to see how all the pieces connect (standards, activities, questioning)—and better understand underlying pieces of the curriculum and rationale." Teaching is complex work that can often appear deceptively simple; this complexity became visible to preservice teachers through their engagement in the entire process from unpacking the *NGSS* to refining the curriculum modules. Though daunting, preservice teachers saw the value of this challenging work:

When it was first discussed that we would be creating [the modules] as a class, I immediately felt overwhelmed. But I decided to challenge myself and elected to [work on module 3] even though I felt I had no idea what I was doing. This is something I never would have done at the beginning of [my program] because I wanted to stay within what I was comfortable with. Which makes no sense to me because that's not what I want my future students to do when I teach them science! I want them to branch out and feel confident enough in themselves to try something they are unsure about.

Challenge #1: Time

While we were able to make changes to the nature of the practicum experience, one thing not within our power to change was the schedule. As a "course," the practicum experience is scheduled for Tuesdays, Thursdays, and Fridays from 12:30 p.m. to 2:30 p.m. Preservice teachers are enrolled in other courses as well, so we are limited to this schedule for their teaching in classrooms. This meant that preservice teachers could not teach lessons on consecutive days and that classroom teachers had to be flexible in adjusting their schedules for science to be taught during the afternoon time block. Additionally, because the BPS district implements an "early release schedule" on Thursdays, our window for enacting the lessons was even more limited. Within the 10-week quarter, preservice teachers were able to teach a total of 8 sessions, with the time for collaborating with teachers outside of this varying greatly from site to site. Some grade-level teams had planning time that closely aligned with our schedule, offering greater opportunities for conversation about implementation than others. Additionally, not all preservice teachers got to accompany their classrooms on the field trip, due to their other coursework. An important consideration in undertaking partnerships of this nature is the potential for (mis)alignment of schedules.

Challenge #2: Materials

Access to materials can be a barrier to implementing the kind of instruction envisioned by the *NGSS*. The world-class collection of artifacts at the SPARK museum enables teachers to showcase real-world examples of engineering design that they could not have provided on their own. The SMATE program's equipment center had all necessary materials available for the modules to be implemented in classrooms and was able to supplement the materials available to BPS teachers. However, given the lessons were being simultaneously taught in 12 different classrooms, this necessitated sharing of materials and equipment within and across schools. BPS district staff and SPARK museum were helpful in ensuring that materials were available, but the process was not perfect. In cases where batteries or bulbs were not working, or few Makey-Makey kits were available, classes had to make less-than-ideal adjustments to their plans. Subsequently, Western Washington University and SPARK have worked with BPS on grant funding to provide additional materials and equipment to teachers and have instituted a check-out program for teachers through the materials and equipment resource center housed within SMATE.

Challenge #3: Flexibility

Because we implemented the modules in 12 different classrooms at 4 different schools, there was understandably a high level of variation in the needs, interests, and abilities of students, and the way in which teachers and preservice teachers decided to implement specific activities. For example, some classes voted on a single client card to address, others assigned different client cards to each group, and others allowed individual students to choose. One class even created a new client card based on students' interests. Additionally, some classes focused more on oral and pictorial forms of communication, whereas others relied more heavily on written forms of discourse. As one preservice teacher commented, "I really liked the flexibility we had–it didn't feel like a script to follow–but we were able to see how all the pieces connect and keep to the storyline of the unit as we made changes." Capturing these variations and rationales was an important part of our revision process, to support teachers in making productive adaptations that were consistent with the overall storyline and intention of the modules. We recognize this is likely to be more challenging to teachers who are new to using the materials or who are less familiar with the content.

Next Steps

The modules we created were developed into an eBook format and are freely available to teachers through the SPARK website. We note that both development and implementation of the modules occurred in-person, as this program preceded the shift to online learning necessitated by the COVID-19 pandemic. In response to the pandemic, SPARK museum staff–with the support of WWU faculty and a cohort of volunteer preservice teachers from the program–were able to incorporate virtual options into the eBook for teachers to use during online instruction.

We are excited to observe the continued use of these modules by participants and are working to support others in using the materials as well. Several of the preservice teachers involved in this program were subsequently assigned to student teach in fourth-grade classrooms at other schools in BPS and have been able to collaborate with a new group of teachers in implementing the modules. Several preservice teachers who have since graduated are also using the modules in their classrooms across the state. SPARK, BPS, and WWU are currently engaged in developing professional development opportunities for teachers interested in learning more about the curriculum. SPARK staff and preservice teachers have also presented the modules at NSTA conferences, expanding the pool of users beyond our state and region. Our efforts have also drawn the attention of other informal science education institutions in our region, who will now be engaging in similar collaborations with BPS and a new cohort of preservice teachers from WWU!

Concluding Thoughts

The program we created illustrates the benefit of collaboration between formal and informal education to support teacher learning. By working together, we were able to build knowledge and capacity among all partners to make the conceptual shifts required by the *NGSS*, but also create something that would be useful to others in making these shifts as well. We hope that these efforts will SPARK continued learning among all partners and from CSL readers!

REFERENCES

Anderson, D., J. Kisiel, and M. Storksdieck. 2006. Understanding teachers' perspectives on field trips: Discovering common ground in three countries. *Curator: The Museum Journal* 49 (3): 365–386.

Banilower, E.R. 2019. Understanding the Big Picture for Science Teacher Education: The 2018 NSSME+. *Journal of Science Teacher Education* 30 (3): 201–208.

Bybee, R. 1997. *Achieving scientific literacy: From purposes to practices.* Portsmouth, NH: Heinemann Publications.

Bybee, R.W. 2014. NGSS and the next generation of science teachers. *Journal of Science Teacher Education* 25 (2): 211–221.

Bybee, R.W. 2015. *The BSCS 5E instructional model: Creating teachable moments.* Arlington, VA: NSTA Press.

Capobianco, B.M., C. Nyquist, and N. Tyrie. 2013. Shedding light on engineering design. *Science and Children* 50 (5): 58.

Grossman, P., C. Compton, D. Igra, M. Ronfeldt, E. Shahan, and P. Williamson. 2009. Teaching practice: A cross-professional perspective. *Teachers College Record* 111 (9): 2055–2100.

Hanuscin, D., K. Lipsitz, D. Cisterna-Alburquerque, K.A. Arnone., D. van Garderen, Z. de Araujo, and E.J. Lee. 2016. Developing coherent conceptual storylines: Two elementary challenges. *Journal of Science Teacher Education* 27 (4): 393–414.

Jablonski, D. 2017. *NGSS and science museums: How learning progressions can inform field trip lesson planning for informal science centers.* University of Wyoming. Thesis. https://doi.org/10.15786/13687069.v3

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

National Research Council 2009. *Learning science in informal environments: People, places, and pursuits.* Washington, DC: The National Academies Press. https://doi.org/10.17226/12190.

Schmidt, W.H., and L.S. Cogan. 2014. An Investigation of the Museum of Science and Industry, Chicago's 2012–2013 Get Re-Energized Module. Working Paper# 40. Education Policy Center at Michigan State University.

Shelton, T. 2021. Commentary: Developing NGSS-Designed Instructional Materials with Teachers "At the Table." *Journal of Science Teacher Education* 32 (7): 852–857.

Short, J. 2014, November/December. How can museums help teachers with the Next Generation Science Standards?*Dimensions* 16: 27–31.

Smetana, L., D. Birmingham, H. Rouleau, J. Carlson, and S. Phillips. 2017. Cultural institutions as partners in initial elementary science teacher preparation. *Innovations in Science Teacher Education* 2 (2). https://innovations.theast-e.org/cultural-institutions-as-partners-in-initial-elementary-science-teacher-preparation/

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Teacher-Learning, Meaning-Making, and Integrating ISE Practices in Diverse Urban Classrooms

BY JENNIFER D. ADAMS, AMY DEFELICE, AND SUSAN MCCULLOUGH

The informal science education (ISE) field has long advocated for science-rich cultural institutions and schools to work together to create ecosystems of enriching science teaching and learning experiences for teachers and students (Bevan et al. 2010). Science teacher learning at the nexus of formal and informal education allows teachers to leverage the affordances of each in their teaching practice (Gupta, Trowbridge, and MacDonald 2016). Affordances of ISE teacher learning includes motivating structures for learning to teach, opportunities to learn inquiry-based teaching approaches, unique opportunities for the development of content and pedagogical knowledge, and deeper understandings about the nature of science and work of scientists (Avraamidou 2014). Accessing these affordances in teacher learning contributes to the development of teacher agency and identities that are responsive to the shifting social contexts of the classroom (Adams and Gupta 2017) and supports the development of "more equitable learning ecologies that are inclusive of all students and supportive of student interest driven learning, empowerment and agency" (Rahm 2016, p. 195).

Our research suggests that science teachers aim to inspire lifelong science learning in their students through meaningful science teaching, especially for diverse learners who are often excluded from enriching science learning opportunities (Adams and Gupta 2013). In defining diversity, we avoid the conceptual narrowing that limits the definition to only include racial, linguistic, and ethnic differences (Liu and Ball 2019). Instead, we use an intersectional definition that describes diverse learners as all who are historically underserved in education, including "typically marginalized student groups enrolled in urban school districts, such as culturally and linguistically diverse Latinx or Black students who generally qualify for the federal free/reduced lunch program" (Avalos, Perez, and Thorrington 2020, p. 225) as well as those with physical and cognitive disabilities. Increasing the engagement of diverse learners require educators to be able to create learning experiences that make science relevant in students' lives and their communities (Marco-Bujosa, Friedman, and Kramer 2021). Partnerships and collaborations between informal and formal institutions for teacher education are positioned to meet this aim.

Collaborative Space for Teacher Learning

This article emerges from a larger NSF-funded research-to-practice project entitled Informal Learning Environments in Teacher Education for STEM (ILETES). The core group of the research project was the ILETES Collaborative (hereafter the Collaborative), a group of nine teachers who taught middle or high school science in New York City public schools who had also engaged in ISE either as a part of their preservice or inservice teacher training or both. The preservice training entailed credit-bearing courses taught in partnership with Brooklyn College, City University of New York, and the American Museum of Natural History. Inservice professional development included teacher learning as a part of a citywide initiative that connects science-rich cultural institutions across the city—including zoos, botanic gardens, a science center, and an aquarium—with schools.

The Collaborative was facilitated by a City University of New York (CUNY)-based Principal Investigator (PI) and supported by a faculty member and two doctoral research collaborators, all affiliated with the Urban Education PhD program The CUNY-based PI had prior experiences as a high school science teacher in the same system and as a museum educator at the natural history museum. The research collaborators also had a range of experiences in formal and informal science and museum-based teaching and were therefore able to contribute from both practical and theoretical perspectives.

The Collaborative teachers taught in schools that ranged from being situated in districts with large populations of Black, Latinx, and lower-income immigrant students to an affluent district with predominantly white, middle-class students. With shared interests and goals of improving science teaching and learning in public schools, the ILETES Collaborative met twice a month for over the course of three years.

The Collaborative was designed to be a dialogic space of open-ended discussion with a goal of generating shared understandings about incorporating ISE in their classrooms. The teachers shared videos and photographs of their classes, lesson plans, and other artifacts of teaching while reflecting on the implementations and collectively discussing ways to adapt lessons and improve learning experiences for their students. These meetings became resources for teachers to co-generate meanings of ISE while developing repertoires of activities that were doable within the constraints of their schools and while also meeting the needs of their diverse students. The

meetings were audio recorded, transcribed, and analyzed by the CUNY research team and shared with the Collaborative for member-checking and discussion (Adams, forthcoming).

The Value of ISE for Teachers

In the initial dialogues of the Collaborative, participating teachers leaned toward reflecting on their ISE teacher learning and discussing the ways that they were able to implement what they learned in their classrooms. These early implementations were limited to field trips and narrowly discussed as "hands-on" or "inquiry-based" activities. To deepen this initial understanding of how teachers defined ISE, as researchers we posed the direct question of "How do you define informal science education?" We found that teachers viewed formal and informal learning in contrast and used terms like *rigid* for formal and *flexible* and *dynamic* for informal. They also used terms like *open-ended* and *unexpected* to describe ISE learning outcomes. As Jackie, a middle school teacher noted, "[with formal] you have a plan in mind with inquiry and have some type of idea of what you want kids to learn. In informal you leave it more up to students deciding what their end goals are going to be." Regina, a high school teacher chimed in, "when I think of formal it is more procedural based, here is a lab, here's your procedure, you follow it step by step, but don't skip a step. But things where there is more freedom to either design something on your own or more of an inquiry-based approach [with teacher guidance] is informal." For the Collaborative teachers, initial conceptions of ISE were further associated with bringing authentic science and inquiry-based approaches into the classroom (Adams and McCullough 2021).

With these meanings in mind, the teachers were introduced to the National Academies Press publications, "Surrounded by Science" and "Learning Science in Informal Environments" to see how the field defined ISE and how these definitions resonated with their own notions of teaching and learning in the "formal" classroom. During a discussion of "strands of informal science learning" (National Research Council 2009, p. 43), Wei, a high school teacher in his first year of teaching remarked, "This is just good teaching!"

These initial discussions about ISE provided hints to aspects that teachers valued. Wei noted, "[ISE] could be just thinking, could be discussing, should be sharing out…I think that's almost informal." Luis, a high school teacher responded, "I think kids learn just as much from each other," recognizing the salience of collaboration in learning but also identifying it as ISE. Wei also described ISE as "visual learning and hands-on activities" to "motivate them to [learn] whatever concept I want them to know" and mentioned "collaborative learning" as a part of this motivation process.

Over time, the group cogenerated new meanings of ISE that resonated with their experiences, observations, and values as science teachers. For a National Science Teaching Association presentation, the Collaborative articulated:

> *[ISE is] a way of approaching science teaching and learning that is personally meaningful, has real-world relevance and allows students to engage in science and engineering practices in multifaceted ways in and outside the classroom. ISE approaches encourage creativity and push students to become innovative, critical thinkers, in ways that exceed learning expectations. (Smith, T., et al. 2018)*

For the Collaborative, the meaning of ISE further shifted over time from solely focusing on practices to including the affordances that ISE approaches provided diverse learners. In the following sections we highlight some of the teacher discussions that contributed to the evolution of ISE for the classroom.

Finding Opportunities in Constraints

ISE is often associated with field trips and out-of-classroom learning as well as having a range of tools of science (i.e., microscopes, rock samples, and triple beam balances) in the classroom available to teach science. Further, teachers often felt constrained in their science teaching in their schools. For example, Evelyn often discussed how she had to advocate for science in her school, "I think sometimes the culture of my school is that science is not important." In a school that emphasized math and English language because they were the assessed subjects, science had limited time and resources.

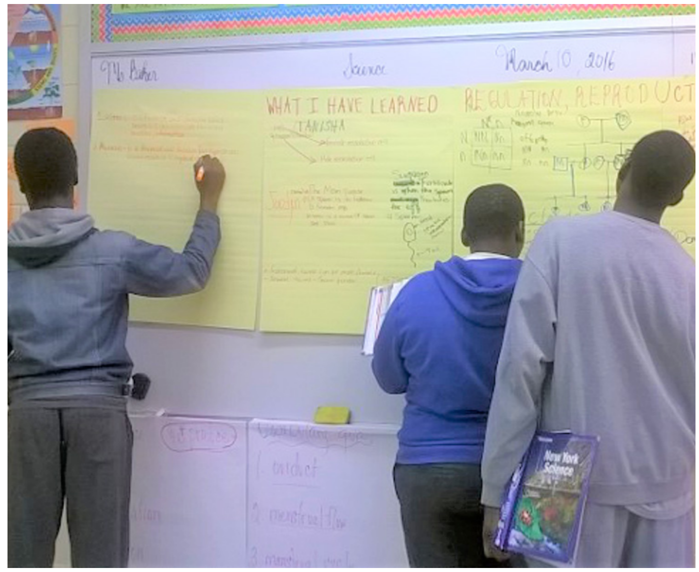
Jackie, a high school teacher concurred, "We're under [a] structure. We can't do what we really want to do, and I think that's why we get frustrated." However, as teachers continued to engage in the Collaborative, these conversations shifted to using ISE approaches in ways that overcame the challenges that come with the realities of schooling.

During the discussion on the six strands of ISE as outlined in "Learning Science in Informal Environments" mentioned above, Jackie noted, "The one I struggle with most is using tools, just because sometimes we don't have them available to us, so it's hard to incorporate that into our lessons … but that's a really important part of science." Matt prompted his colleagues to think beyond ISE as field trips, "why can't we just put the informal inside the classroom, why does it have to be outside the classroom? When you think of what it is—we are learning, we're relaxed, we're critically thinking, why can't we just do that in the classroom?" Matt taught high school Earth science in the Bronx where many of his students lived, "not in public housing, not in regular apartments, but in shelters." His school was concerned about passing rates on the standardized exam, "I've got to worry about [passing rates] or I lose my job." For learning new material and reviewing previously taught content, Matt's participation in the Collaborative supported him to design activities that creatively used his classroom space to foster student-centered, collaborative learning, "I designed a model where I construct alternative, four different paths for the students to go through stations." He initially learned station teaching in an ISE professional development and adapted it for his students with different abilities. As he showed the video of his students engaged in the activity, he described the different pathways where students with differing levels of understanding progressed at their own challenge and also allowed students with higher levels of understanding to help others. His aim was to ensure that the lowest performing students understand, "because if my lowest performing students display an understanding or mastery of the concept … then I know that I am going to have a successful lesson…because I can assume most of my students understand it." Matt's notion of ISE included using the space in his classroom to structure learning that fosters student agency and embedding reflection, peer-to-peer learning and self-assessment to make their learning visible.

Matt's comment prompted the Collaborative to think differently about ISE in ways that disrupted the dichotomy of formal versus informal, moving them toward conceptualizing a continuum of practices along a formal to informal spectrum that meet students' needs and learning goals. The Collaborative became the space where the conceptual resource of ISE was actively reimagined and adapted to meet the needs of their students and resonate with who they were becoming as teachers.

Thinking Expansively About Field Experiences

Evelyn, an African American teacher, valued exposing her mostly Black, Caribbean-immigrant students to a variety of science experiences within and outside of the school. Recognizing the brilliance in her students, she knew that they needed inspiration beyond textbooks and exams, "you put a book in front of them, they read and it's just like, that's it. But then they go out there and they feel like scientists, and they really connect what they are learning; it's like this discovery, wow." For Evelyn, it was important to "connect science and the real world" and therefore she used her weekends to take students on field trips,



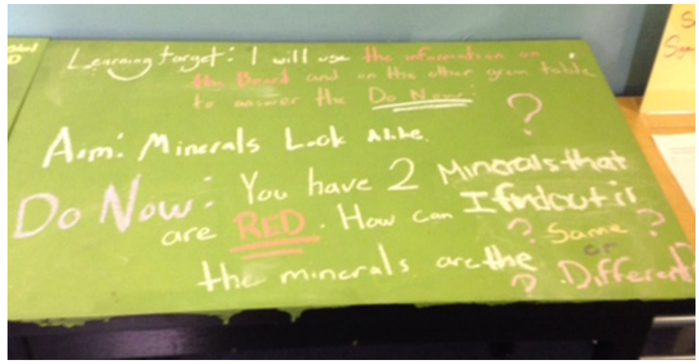
> *I took a group of students out last week Saturday for free – I don't get paid for that – I took them to Rockefeller University, every year they have a science center… and we had an amazing time and just to see my students when they are in those informal learning environments, how they learn, and the opportunity that they have because a lot of them don't get that opportunity on an everyday basis. When I do take them out, I see how things they have learned in the classroom comes back to them. I'm just so passionate about that and seeing them in different environments and they're so excited! That's the thing—they are so beyond excited to just go somewhere different and see different things. And these kids love science!*

Beyond a traditional field trip to an informal science institution, Evelyn sought events where students could experience the relevance of the science they were learning in the classroom, "Our community and especially African American and Latino students, you don't really see them becoming scientists [as often] because they are not [as likely to be] exposed to it and the parents at home [may] not really see the importance of science." More than observing objects and exhibits, Evelyn planned her field trips to allow her students to *interact* with scientists, especially scientists and college science students of color—ask questions and expand on topics that they cover in the classroom. The field trips were also a source of professional growth for Evelyn; experiencing her students' excitement and engagement helped further fuel her passion for expanding science learning opportunities for her students. She noted that the parents began to take notice that "what I am doing is benefitting the kids, but I think it benefits the school as a whole. The parents come, they are involved, they ask about me. They are excited, the kids are excited." Sharing a racialized identity with her students, Evelyn noted, "in our communities…parents really need to understand that science is a very important subject, and that curiosity is the foundation for so many different things—asking questions, getting kids to think logically, just to expand on reasoning and explaining…" ISE experiences allowed Evelyn to share her passion for science with her students and advocate for the importance of science education with school administrators and parents.

Transforming Learning Spaces

When teaching science with an ISE lens, teachers emphasize learner-centered approaches. Matt described: "I become a facilitator without giving too much intervention." Matt described how he first observed this approach in one of his ISE preservice courses, "Informal is exploring with no guidance, professors are stepping back and saying go out there and observe and come back and tell me what you found … students doing the building, professors nudging." He wanted to incorporate this approach as much as he could as it allowed him to step back and watch his students learn and observe what topics and activities resonated with them and the ways they brought their cultures, as youth, into the classroom. For example, Matt shared pictures of tables that he painted with chalkboard paint and windows with students' diagrams drawn with dry erase markers. He used the term "tagging" to describe this practice, transferring a word associated with graffiti or street art into the classroom. This was especially important for his students with Individualized Education Plans (IEPs) as it allowed them to generate their own visual cues for learning. If students were having trouble understanding a concept, he encouraged them to "work it out" on the chalk-desk, this also allowed him to see how they were thinking about a particular concept.

Matt also created a WhatsApp group, a social media communication tool already used by his students, to help reinforce concepts that they learned in the classroom (Adams 2019). In this WhatsApp group students posed questions, viewed Matt explaining concepts on his whiteboard in his garage, and participated in short quizzes while also having dialogues with each other about the concepts they were reviewing. They also offered each other encouraging words and expressed frustration when someone posted an answer before they had worked it out for themselves. In many ways, Matt brought the visual and tactile culture of museums into his classroom.



Engaging in Real-World Science

The Collaborative teachers saw connecting real-world, everyday science with the classroom as a salient aspect of ISE. While real-world science could refer to engaging in practices of scientific research, it could also entail allowing students to learn about the science behind phenomena that is of interest to them. Getting students to ask questions about the natural and built worlds is essential because it affords multi-modal opportunities for science learning (DeFelice 2021).

Evelyn described how she encouraged students to draw on pop culture for a project that would later be shared with families on her school's science night. Her students were able to choose any phenomena of interest to them. "This is the premise: come up with the concept, 'tell me the science behind it, that's it.'" Some chose the "Cinnamon Challenge," a TikTok phenomenon. These students sought to understand what happens when a person ingests cinnamon. While the students did not use human subjects in their investigations, their inquiries still allowed them to examine questions of the type "what happens when..." Students made inferences between the properties of cinnamon and side-effects in humans. Other groups of students examined the science behind beauty trends such as lip enhancement while others stuck to more usual classroom science topics like plant growth. Evelyn reflected on the activity noting the level of student engagement, "I have IEP students who have instructional support, my [special education] students… everyone is working, everyone is engaged, you know during that project everyone was doing something. You had the kids who are the slower kids or 'the bottom third,' they're working, they're engaged like I've never seen." Sofia, a Latina high school science teacher, agreed and responded, "You know it's effective when the student who is usually in the bottom third comes and tells the upper third 'Oh no, you're wrong…'" Sofia and Evelyn both observed how the ISE practices of exploring personally relevant science topics engaged a range of learners.

Similarly, Tara explained a lesson she did on bodies in motion. For the lesson students went outside and participated in activities such as tug of war, relay race, arm wrestling, soccer penalty kicks, and skateboarding to investigate how their bodies move. Tara described the level of engagement in this way: "So the kids who were like quiet, yeah, they were involved. Like everyone was doing it." ISE was a way of bringing everyday science into the classroom. It allowed students to have multiple entry points to and agency for their own learning while allowing teachers to observe their learners, both as unique individuals and as a classroom collective.

Evolving and Adapting as Teacher Learners

Learning to teach is an ongoing process. Teachers regularly seek new approaches or strategies to incorporate into their lessons for their diverse learners. Teachers learn different strategies for teaching through professional development programs, independent research, personal experiences, reflection, and importantly, from other teachers. Through "ongoing augmenting and adapting of resources at hand [to create] new science teaching engagements" (Adams 2020, p. 470), teachers expanded approaches to foster meaningful science learning. As Evelyn reflected, "As a teacher you are always evolving." However, it can be challenging to continually revise one's teaching practice. Evelyn continued, "I just feel like I'm constantly revamping, constantly thinking, but that's my struggle. It's not like, am I struggling as a teacher, but am I underestimating my kids? That's what I'm always thinking. So that's where the informal really gives me a chance to really see what my kids can do on their own without so much instruction." For Evelyn and other teachers in the Collaborative, the ongoing questioning of their practice as teachers, how they were meeting the needs of their students, and the ways they were giving their students agency in their own learning were central to how they articulated and adapted ISE practices for their classrooms. ISE approaches allowed them to observe student learning and engagement, which, in turn, helped them further evolve their practices. Further, the teachers who taught in schools with large populations of racialized students viewed informal science learning as a way for students to build positive associations with science learning (DeFelice 2021; Adams 2020) as well as make science relevant to their home, family, and community, and a space for imagining possible careers.

Challenges and Successes to Dialogic Teacher Learning

The dialogic nature of the Collaborative resulted in a number of successes not typically present in more structured professional development formats. For example, when teachers participate in ISE learning, they often become excited about sharing the same experiences with their students and these experiences are often centered around the resources at the ISE site. However, when teachers return to the classroom and are confronted by existing logistical and administrative constraints, the excitement wanes. This often leads to teachers not implementing ISE experiences or practices in their classrooms. The examples shared in this article suggest that participation in an ongoing dialogic space, like the Collaborative, that allows teachers to share their ideas about science teaching and learning may be an effective strategy for translating professional learning to classroom implementation. The Collaborative meetings were structured in ways that allowed these and other dialogues to emerge. For instance, a "loose agenda" structured the meetings that first involved a check-in and opportunities for teachers to share reflections, ideas, artifacts, and challenges that came about since the last meeting. Usually, these check-ins provided context for fruitful discussions not only around issues of designing activities to teach science content, but also confronting how social issues such as racial inequity exist in science and education. For the teachers in the study, ISE approaches were also equity approaches as they allowed teachers to engage a range of learners and provide opportunities for their students to build positive experiences and identities around science.

Challenges to the ILETES project included being situated in a geographically large school district. Identifying a centrally located meeting spot was constraining for many teachers since it was, at minimum, a 45-minute commute from their schools. This contributed to inconsistent attendance; nonetheless, there were 3–5 teachers at each meeting and a core group of 5 teachers (out of 9) that participated for the entire three years. The teachers in the Collaborative were not active on social media, which resulted in limited interactions between meetings and infrequent dissemination of discussions and practices with a larger audience.

Despite these challenges, teachers shared with us that they found value in the Collaborative. As opposed to mandated professional development, the Collaborative was self-selected, thus participating teachers had an existing commitment to their own professional growth and learning. Further, the longitudinal nature of the group fostered a building of trust which also allowed for deeper conversations. Teachers received a stipend for their participation; however, two of the teachers who did not initially know they would receive a stipend were some of the most consistent participants.

(Re)defining ISE

For the Collaborative, the idea of ISE as a physical resource you can visit persisted, but participants extended their definition of ISE to also include the enactment of student-centered science teaching and learning. From analyzing audio recordings from the Collaborative meetings, dialogues with teachers about the Collaborative, and reflecting on facilitating-observing the group, the following central themes were found to have contributed to the evolution of teacher understandings and implementations of ISE:

- *Engaging in Unstructured Dialogues*—The overarching goal of the Collaborative meetings was to share and discuss ISE practices. Teachers were encouraged to discuss their successes and frustrations around designing and enacting ISE-related practices in their classrooms. This allowed teachers to empathize with each other about their enactment challenges while at the same time collectively view constraints as opportunities for expanding their ISE practices. These unstructured dialogues also mirrored the open-ended, question-oriented, self-directed approaches that the teachers valued in their ISE learning experiences. The overarching question of "how do you incorporate what you learned in ISE in your classroom" allowed a range of discussions to emerge and provided expanded space for the sharing and co-generation of teacher knowledge.
- *Active and Shared Learning*—The learning during the Collaborative meetings mirrored how learning happens in ISE contexts. The teachers learned through dialogues with each other and interactions with shared artifacts and resources. They also used ISE to informally structure their own in-situ professional learning because it created opportunities for them to observe their students engaging in science experiences. Teachers identified specific practices they viewed as consistent with ISE— questioning, observing, discussing, collaborating, critically thinking, imagining—and used these approaches to structure science teaching and learning in their classrooms, thus allowing students to make connections between science and their everyday lives in a meaningful way.
- *Centering Identities*—Teachers collectively recognized that effective science teaching required them to humanize their learners and leverage the strengths that they bring to the classroom. They also discussed how racialization and other oppressions were constraints to effective science learning and ways that they worked in response to resist and transform these constraints. For example, they noted how the Black and Latinx schools typically do not have the science equipment and labs that were found in White, affluent schools. They described how this contributed to students' lack of basic science skills, such as using a microscope or weighing objects using a balance. As many of the teachers in the Collaborative were also racialized and experienced deficit-oriented narratives themselves, the Collaborative provided a safe space for open discussions about these issues. This also offered visceral examples for participating White teachers who had not experienced similar oppressions that positioned all participating teachers to be better advocates for their students. Articulating ISE practices in relation to these discussions allowed teachers to forefront the social identities and learning needs of their students.
- *Leveraging Learners' Strengths*—The framing of ISE as being self-directed, emergent, and creative gave teachers the conceptual space to discuss and design strength-based approaches in their classroom. They viewed ISE as an opportunity to stand back and observe their learners and identify their areas of struggles and strength. ISE gave

teachers the space to ask learners what interests them and design activities around those interests. ISE also allowed teachers to integrate popular cultural references and youth communication styles in the science learning space. The Collaborative teachers shifted focus from required curricular content to also include fostering student interest, engagement, and providing diverse learners with tools for success in the science classroom.

While individual reflection is important for teacher learning, our work shows that reflecting with others is also salient because it is in collaborative interactions that teachers are able to share, discuss, work together, and cogenerate meanings that have the potential to transform science teaching and learning to include more equitable, engaging, and creative practices.

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REFERENCES

Adams, J.D. Forthcoming. Challenging "scientific" paradigms through sociocultural lens and dialogic methodologies in teacher identity research. In C. Siry, C. Schreiber, R. Gomez Fernandez, and B. Reuter (Eds.) *Critical Methodologies for Researching Science Teaching and Learning*. Rotterdam, The Netherlands: Sense.

Adams, J.D., and S. McCullough. 2021. Inquiry and learning in informal settings. In *International Handbook of Inquiry and Learning,* eds. C.A. Chinn and R.G. Duncan, 358–370. Routledge: New York.

Adams, J.D. 2020. Designing frameworks for authentic equity in science teaching and learning: Informal learning environments and teacher education for STEM. *Asia-Pacific Science Education 1*(aop), 1–24.

Adams, J.D. 2019. WhatsApp with science? Emergent CrossActionSpaces for communication and collaboration practices in an urban science classroom. In *Emergent Practices and Material Conditions in Learning and Teaching with Technologies,* eds. T.C. Pargman and I. Jahnke, 107–125. Springer, Cham.

Adams, J., and P. Gupta. 2013. "I learn more here than I do in school. Honestly, I wouldn't lie about that": Creating a space for agency and identity around science. *International Journal of Critical Pedagogy 4,* 87–104.

Avalos, M.A., X. Perez, and V. Thorrington. 2020. Comparing secondary english teachers' ideal and actual writing practices for diverse learners: Constrained professionalism in figured worlds of high-stakes testing. *Reading andWriting Quarterly* 36 (3): 225–242.

Avraamidou, L. 2014. Developing a reform-minded science teaching identity: The role of informal science environments. *Journal of Science Teacher Education* 25 (7): 823–843. DOI: 10.1007/s10972–014–9395-y

Bevan, B., with J. Dillon, G.E. Hein, M. Macdonald, V. Michalchik, D. Miller, D. Root, L. Rudder, M. Xanthoudaki, and S. Yoon. 2010. Making science matter: Collaborations between informal science education organizations and schools. A CAISE inquiry group report. Washington, DC: Center for Advancement of Informal Science Education (CAISE).

DeFelice, A. 2021. Improving place-based environmental education using cogenerative dialogue and photovoice. In *Doing Authentic Inquiry to Improve Learning and Teaching*, eds. K. Tobin and K. Alexakos, 229–248. Brill Publishers.

Gupta, P., C. Trowbridge, and M. Macdonald. 2016. Breaking dichotomies: Learning to be a teacher of science in formal and informal settings. In *Intersections of Formal and Informal Science,* eds. L. Avraamidou, W.-M. Roth, 204–214. Routledge.

Liu, K., and A.F. Ball. 2019. Critical reflection and generativity: Toward a framework of transformative teacher education for diverse learners. *Review of Research in Education* 43 (1): 68–105.

Marco-Bujosa, L.M., A.A. Friedman, and A. Kramer. 2021. Learning to teach science in urban schools: Context as content. *School Science and Mathematics* 121: 46–57.

National Research Council. 2010. *Surrounded by Science: Learning Science in Informal Environments*. Washington, DC: National Academies Press.

National Research Council. 2009. *Learning Science in Informal Environments: People, Places and Pursuits.* Washington, DC: National Academies Press.

Rahm, J. 2016. Project-based museum-school partnerships in support of meaningful student interestand equity-driven learning across settings. *The Canadian Review of Art Education* 43 (1): 184–198.

Smith, T., C. Vasquez, Y. Adam, S. Maydun, E. Baker, T. Gaynor, P. Garcia, and J. Adams. 2018. Bridging the gap: Connecting students' lived experiences to STEM through creativity and informal science learning. Presented at the National Science Teachers Association, St. Louis, MO, United States of America.

Wenger, E. 1998. *Communities of practice: learning, meaning, and identity*. Cambridge University Press.

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Virtual Coaching PLCs In and Out of School

BY KATE COOK, HANNAH LAKIN, SUE ALLEN, SCOTT BYRD, BRITTNEY NICKERSON, AND KATE KASTELEIN

Instructional coaching and professional learning communities (PLCs) are both productive activities for advancing the practice of STEM educators. Both forms of professional learning are best done in collegial peer groups or with independent, non-evaluative coaches. In small educational settings—such as out-of-school time (OST) programs with limited front-line staff or rural schools with limited numbers of teachers in each grade level or subject area—innovative strategies for engaging in professional learning are needed. One approach is to engage educators virtually with peers across multiple organizations or schools.

In Part 1 of this article, we describe a Virtual Coaching PLC approach designed with and for out-of-school educators that blends instructional coaching with PLCs in a virtual environment. Our approach is the cornerstone of the Afterschool Coaching for Reflective Educators in STEM (ACRES) project. Informed by the success of mostly in-school PLCs and instructional coaching, we designed our approach for afterschool providers and library staff—educators who are often isolated in their work and have limited time to engage in professional learning. Lessons learned from our Virtual Coaching PLC work with out-of-school educators are having important, productive impacts on our work with in-school educators. In Part 2, we illustrate the types of adaptations we make when using the approach with in-school educators. Finally, in Part 3, we explore implications for continuing to build upon the mutually strengthening nature of this out-of-school and in-school use of Virtual Coaching PLCs.

Part 1: The ACRES Approach to Virtual Coaching PLCs

Context

PLCs are an increasingly popular approach to professional learning for in-school teachers and administrators. Typically, PLC groups consist of 10–15 professionals engaged in collaborative learning to improve practice, problem solve, learn a new skill, and contribute new knowledge or original products (McKenzie 2014; Vance et al. 2016). Despite the many advantages of PLCs, it can be difficult to engage educators in continued involvement in PLCs due to time and financial barriers (McConnell et al. 2013). Educators working in OST settings often have more restrictive budgets and schedules compared with formal educators, and many OST organizations may not be large enough or centralized enough to easily host and facilitate PLCs. As such, PLCs for out-of-school educators have been slow to take hold, and with a few notable exceptions (e.g., Martin et al. 2019), out-of-school educators have limited opportunities to participate in PLCs to improve practice (Vance et al. 2016).

A second extremely effective approach to improving STEM educator practice for in-school settings is instructional coaching. Instructional coaching often occurs in a coach/educator pairing. Together, the educator and the coach work toward collaboratively identified goals, which may include improving a particular instructional practice, learning a new instructional skill, or improving certain student outcomes (Desimone and Pak 2017; Gibbons and Cobb 2017). While instructional coaching is a promising approach to professional learning, the process is time intensive and requires a designated coach with deep contextual knowledge. Once again, it can be extremely difficult to engage out-of-school educators in instructional coaching cycles due to limited funding, limited time, and fast-paced, ever-changing educational contexts. Just as PLCs have been slow to take hold in OST contexts due to organizational limitations, instructional coaching has been largely limited to formal educational contexts.

Physical distance from professional learning events further exacerbates financial and time constraints, particularly for geographically isolated educators and programs, often resulting in unequal access to professional learning opportunities. Since its inception, the ACRES program has sought to address these challenges by making our professional learning completely virtual for all educators. We have developed and continue to refine many effective strategies and approaches to engaging educators in interactive and collaborative professional learning (see "Beyond the Webinar: Dynamic Online STEM Professional Development"; Brasili and Allen 2019). As a result of our focused efforts to develop fully virtual, interactive, and collaborative PLCs focused on instructional coaching, we were exceptionally well positioned to quickly respond to virtual professional learning needs and strategies resulting from the COVID-19 shutdowns and continued restrictions.

Our Approach

The ACRES project was originally designed to capitalize on the successes of PLCs and instructional coaching in formal educational settings and adapt both strategies in ways that make them accessible and productive for OST educators, particularly afterschool program staff and librarians. The ACRES approach for professional learning draws key components from PLCs and instructional coaching, effectively blending the two such that participants engage in coaching cycles as part of a collegial group.

FIGURE 1

The ACRES approach to virtual coaching PLCS is situated at the intersection of PLCS, instructional coaching, and virtual professional learning and adds our unique approach to culture building, sense-making, and targeted STEM facilitation skills.

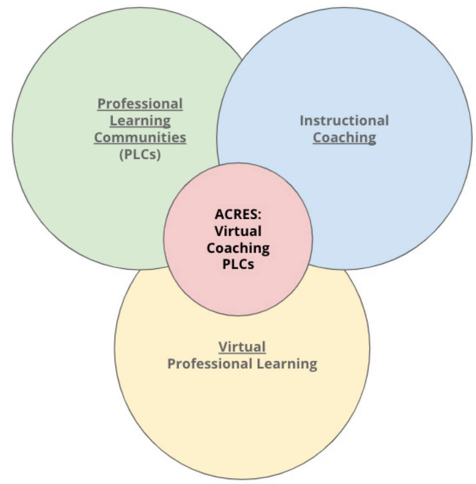


TABLE 1

Core structure of the professional learning, repeated for each STEM skill.

For Each STEM Facilitation Skill:

1. *Introduction*
   a. Skill definition + discussion of video exemplar
   b. Coach models skill during hands-on activity
   c. Sharing of concrete strategies
2. *Practicing the Skill*
   a. Try skill with youth
   b. Video record self
   c. Edit and upload
3. *Getting Coached*
   a. Framing own video for peers to understand
   b. Hearing feedback
   c. Doing the same for others

We refer to this type of professional learning as Virtual Coaching PLCs (see Figure 1). In these PLCs, educators convene in small peer-based cohorts with the goal of improving practice through new skill acquisition and peer-based coaching. Virtual Coaching PLCs are facilitated by non-evaluative facilitators with expertise in developing meaningful, productive communities of practice in the targeted instructional skills of the cohort.

The essential structure of the ACRES approach consists of cycles in which an experienced coach introduces a new skill and participants have time to practice it. They then share a video of themselves using it in their interactions with youth, with accompanying discussion and suggestions from the coach and their peers (see Table 1).

A more detailed description of the structure of the PD follows:

1. **Setup:** Our virtual coaching PLCs are made up of approximately 4–10 educators working in various locations (most often rural) across the United States. We have engaged groups as large as 25 but have found these groups often become unwieldy, which minimizes productive discourse. Groups smaller than 4 are too small to generate substantive dialogue. While some virtual coaching PLCs will take part as a team from one OST program or network, we also have groups composed of educators who were previously strangers. The educators in each PLC provide programming from preK through 12th grade with a majority working with youth in grades 3–5. Materials needed to fully participate include a computer with a webcam, an internet connection, a camera (usually a smartphone) to record their practice, and common household materials for hands-on STEM activities (e.g., cotton balls, tape, scissors).
2. **Introduction:** The skill introduction happens during a group workshop, typically about two hours long. (a) The coach begins by introducing the skill (e.g., "asking purposeful questions" or "giving youth voice and choice"). The group then watches a video of an afterschool educator using the skill effectively (see first photo below), and the coach facilitates a microanalysis of how the skill was used and what response it elicited from the youth. The video analysis helps educators both recognize the skill in action and look for evidence of its impact on the youth. (b) Participants virtually engage in a hands-on activity (e.g., designing a water filter) while the coach demonstrates the skill in context, followed by group discussion (see second photo below). (c) The coach distributes a reference document with concrete strategies for implementing the skill (e.g., a page of specific question-starters). Participants then try out the skill while doing a short hands-on activity.
3. **Practicing the skill:** (a) The educators have two to three weeks to practice the new skill in their programs and with their youth. They can choose to practice the skill in either the context of the same STEM activity demonstrated by the coach or any other hands-on activity of their choosing. (b) Using a smartphone, tablet, or other recording device available to them, educators video record themselves practicing the skill with youth. (Prior to filming, youth and their parents are provided with a courtesy letter informing them that youth may be videotaped while engaging in STEM activities for the purposes of educator professional learning. The letter states that a small number of other educators may view the recording during a coaching session and that following the coaching session, the videotape will be destroyed.) (c) If the video is longer than a few minutes, they edit it down to two or three minutes and upload to a private shared space, such as FlipGrid or Vimeo, where others in the group can view it, but it is not publicly available (since it includes identifiable recordings of minors).
4. **Getting coached:** (a) During one to two group sessions with the coach (each typically 60–90 minutes), the educator frames the video so that others can understand what they are seeing (describing the youth, the activity, the reasons for selecting this part, and any specific thoughts they have about their experience of trying the skill). (b) After watching the video, the peers and the coach take turns offering feedback to the video presenter in the structured form of "one strength" and "one opportunity to consider going forward." (c) Educators take turns presenting their videos and offering feedback, so that each person gets multiple opportunities to think about how the skill can be used and adapted to different settings and activities (see third photo on the next page).

Our professional learning was designed to focus on a subset of skills that (1) have been shown to be fundamental to strong STEM pedagogy in general, (2) align with the tenets of OST programs in particular and their focus on youth development, and (3) can be applied across a very broad set of activities and youth characteristics. The set of six skills includes: asking purposeful questions, modeling the engineering process, modeling science processes, giving youth voice and choice, developing STEM identity and making career connections, and exploring youth understanding (See "Formative Assessment of STEM Activities in Afterschool and Summer Programs"; Sneider and Allen 2019).

Promising Evidence Supporting Our Approach

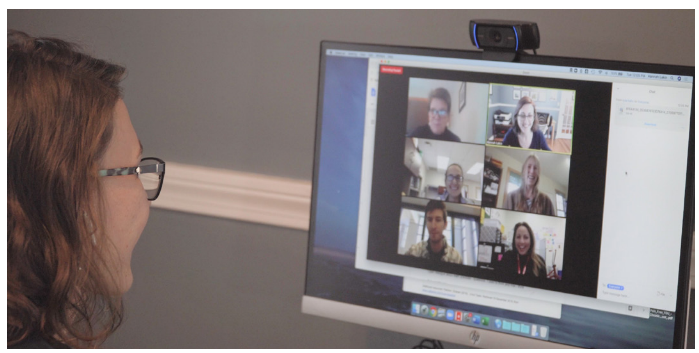
Our initial three-year investigation into using Virtual Coaching PLCs with OST educators has yielded very promising findings. To gain better insight into the ACRES Virtual Coaching PLC model, we gathered data from pre- and post-surveys and interviews with over 40 cohorts. Immediately following participation in an ACRES Virtual Coaching PLC, frontline educators' self-reported confidence increased significantly in relation to the target facilitation skill as well as other ACRES-related capabilities. For example, educators' confidence in their "ability to ask youth good questions as they work on STEM activities" increased from 3.03 to 3.59 on a 5-point scale (with 0 = not confident at all, 4 = extremely confident, $n = 187$, $p < .001$, paired sample t-test).

Further, before and after the course, educators viewed an animated video of a hypothetical afterschool STEM program and provided constructive feedback to the facilitator. Pretest versus posttest comparisons showed a significant increase in educators' identifications of effective use of the target skill—in this case, how to ask youth purposeful questions (pre 4.32 to post 5.44, $p < .01$), especially the more nuanced subskill of following up with youth to clarify their thinking (pre 1.00 to post 1.46, $p < .001$).

Another encouraging finding has been that the positive outcomes of participation in an ACRES virtual coaching PLC stay with educators long after participation in an ACRES cohort. In follow-up interviews six months to two years after participating in the Purposeful Questions module, 95% of educators who had taken the first module (only six hours long) could describe, in detail and with examples, how the ACRES experience had changed the way they work with youth and the way youth had responded to this change. For example, "I think they were resistant at first, but as I gave them more time, or probed with more questions, they definitely responded positively … I've learned to avoid one-word response questions, like yes or no … So those kids did definitely respond to that. It took some time on my part, to create that culture of like, explaining your thinking and probing deeper."

A library educator models a STEM facilitation skill.

An ACRES cohort engages in a hands-on water filter activity while the coach demonstrates the STEM facilitation skill.



An ACRES coach works with a cohort during a coaching session.

Part 2: Using Virtual Coaching PLCs in In-School Settings

While the ACRES model was originally designed to adapt professional learning strategies used in formal education to OST settings, we are finding that our work is coming full circle. The Virtual Coaching PLC model that we developed is now positively influencing our work with in-school educators. Because many of our ACRES team members support educators in both the in-school and OST worlds, the approach used with OST educators began organically influencing our work with in-school educators. Over time, we slowly began incorporating pieces of the ACRES Virtual Coaching PLC model into our regular consulting work with in-school educators.

Our approach—designed to build community among OST educators and improve STEM facilitation skills—has benefited in-school educators who are also often isolated in their work. This includes educators teaching in remote or rural settings who are often the only teacher for a particular grade level or subject area and lack a built-in professional learning network. Broadly, we have noticed that several aspects of the Virtual Coaching PLC approach seem to be particularly influential in our work with in-school educators:

1. **Structure:** Starting with experiencing a skill or instructional strategy, progressing to analyzing the skill or strategy in context, and culminating in practicing the skill with youth and receiving feedback on it from peers is a powerful structure for both OST and in-school educators.
2. **Scheduling:** Shorter sessions scheduled over several weeks provides opportunities for educators to engage in frequent and ongoing professional learning that fits within their busy schedules for both OST and in-school educators.
3. **Situating Learning in Context:** Situating professional learning within educators' context by having educators practice skills or strategies in their own programs and bringing recordings back to the group for feedback allows for more personalized experiences.

Below, we expand on each of these aspects by providing contextualized examples of how we have translated the ACRES Virtual Coaching PLC approach back to in-school settings. Specifically, we showcase two professional learning experiences designed for in-school educators:

- *Case A: High School Mathematics* — A professional learning experience focused on "Asking Purposeful Questions" for high school mathematics teachers
- *Case B: K–12 Science* — A professional learning experience for K–12 educators focused on science storyline development designed for the Next Generation Science Standards (NGSS Lead States 2013)

Case A: High School Mathematics

The high school mathematics Virtual Coaching PLC had seven educators who made up one school's math department. The opportunity to gather for an ongoing series was initiated by the school administration in partnership with teachers who were interested in reflecting on their practice. Teachers were also incentivized to participate with professional development contact hours necessary for licensure, as well as with compensation for their time. The whole group met three times with approximately three to four weeks between each session. To participate fully, members needed an internet connection, a computer with a webcam, and a camera (or phone with a camera) to record their practice. The costs of running the Virtual Coaching PLC included the time of the facilitating coach, the time of the educators, and any additional technology.

Structure

The high school mathematics cohort was structured in a similar way to the ACRES cohorts (see Table 2). Cohort members spent the first Virtual Coaching PLC session immersed in the mathematics facilitation skill of Posing Purposeful Questions, one of the key mathematics practices (National Council of Teachers of Mathematics 2014). Cohort members first learned the skill, then experienced a mathematical modeling activity from the perspective of a learner, and discussed the role of particular types of questions within the task. "Assessing questions" are questions that have students clarify their thinking and give the teacher more information about student understanding. For example, "Explain why you chose to organize your result this way." Similarly, "advancing questions" are often used to propel students to think more deeply. For example, the question, "Does it always work that way?" might be used to help advance a student toward making generalizations based on repeated reasoning. Educators were then given a handout with concrete strategies and examples of Purposeful Questions that they could use in their high school mathematics classes. After the initial session, educators spent time practicing the skill, either by modifying their lesson plans or by trying the skill with the students. Educators uploaded either video recordings of themselves working with youth or revisions they had made to their own lesson plans. During the coaching session, educators shared their videos with peers and received feedback in the same way that ACRES PLCs do.

Scheduling

Informed by our work with OST educators, we scheduled only three cohort meetings, and each meeting lasted no more than two hours. Meetings were scheduled outside of the school day at a convenient time for educators, which allowed them to relax in their own homes and engage in professional learning as an ongoing process that fit within their busy schedules.

Situating Learning in Context

Just as ACRES participants film their own work with youth, participants in the high school mathematics professional learning focused on using the skill of Posing Purposeful Questions in their own contexts. This allowed teachers to work with timely and relevant lesson plans that had immediate impact on their classroom practice. For example, during the first coaching session, one teacher shared and received feedback on Artifact A, a task they had prepared for pre-calculus students (see Figure 2). The feedback focused on helping the teacher pose questions that were more purposeful. At the second coaching session, the teacher shared Artifact B, which represented a significant shift in posing purposeful questions, moving away from rote computational practice and toward student reasoning and discourse. These artifacts showcase the power of contextualizing professional learning within teachers' classrooms. While the artifacts are on different topics (because the class was studying different topics), the educator was nevertheless able to progress in the targeted skill.

Case B: K–12 Science

The K–12 Science Virtual Coaching PLC included approximately 40 educators who were subdivided into three PLCs of 8–15 people each. The educators came from four different school districts and seven different schools, and taught grade levels ranging from second grade to twelfth grade. The opportunity to gather for an ongoing series was initiated by Maine Mathematics and Science Alliance. Districts, schools, or individual teachers could choose to opt in to the program. Teachers were also incentivized to participate with professional development contact hours necessary for licensure. The whole group met for a weeklong professional learning workshop and then met every other week for a semester in virtual PLCs. To participate fully, members needed an internet connection, a computer with a webcam, and access to a virtual platform such as Google Docs to share their work. The costs of running the Virtual Coaching PLC included the time of the facilitating coach, the time of the educators, and any additional technology.

Structure

The K–12 science professional learning structure was similarly informed by the ACRES cohort structure, though it deviated somewhat more from the original structure than the high school mathematics cohort (see Table 3). After engaging nearly 40 teachers in a weeklong professional learning workshop, the smaller Virtual Coaching PLCs cohorts met every other week for 12 weeks. Because many of the teachers were in the early stages of transitioning to the NGSS, we focused efforts on supporting teachers as they planned for NGSS-designed instruction. On odd weeks (Weeks 1, 3, 5, 7, 9, and 11), we focused on developing teachers' knowledge of a particular instructional strategy (equivalent to the "facilitation skills" in the ACRES model). For instance, on Week 3, we focused on helping teachers understand how to plan using the Anchoring Phenomenon Routine. On even weeks (Weeks 2, 4, 6, 8, 10, and 12), teachers came prepared with their planning artifact. Planning artifacts were outlines, notes, or slides that teachers shared as evidence of their curricular planning. For instance, on Week 4, teachers came with an outline for their Anchoring Phenomenon lesson. During our Virtual Coaching PLC, cohort members examined each other's planning artifact and provided feedback to one another.

FIGURE 2

An artifact and a revised artifact shared during coaching sessions.

Pre-Calculus
Inverse Trigonometric Functions Exploration
Lesson 6-4

You will work in groups of 2 or 3. Find **ALL** possible answers in the domain $0 \le x < 360^\circ$ that make the following true.

1. $\sin(x) = \frac{1}{2}$
2. $\cos(x) = \frac{1}{2}$
3. $\tan(x) = 1$
4. $\sin(x) = -\frac{\sqrt{3}}{2}$
5. $\cos(x) = -\frac{\sqrt{3}}{2}$
6. $\sin(x) = \frac{\sqrt{2}}{2}$
7. $\tan(x) = -1$
8. $\sin(x) = -\frac{\sqrt{2}}{2}$

Artifact A

(x + 2)(y + 2) = xy + 4

Is this equation always true, never true or sometimes true? How do you know?

Artifact B

Scheduling

Originally, we planned to schedule our ongoing sessions for two hours to mirror our work in ACRES. After consulting the teachers in our cohorts, however, we learned that two-hour blocks of time were even more challenging for teachers, given various afterschool conflicts. As a result we limited meeting times to less than 90 minutes and held more of them over the course of several weeks. The shorter time frames were more manageable for participants and allowed us to focus on smaller, more digestible skills at each session. We scheduled one cohort after school and one in the evening (at 8 p.m.) to accommodate scheduling constraints that participants faced. This, too, mimicked the OST educators' patterns of scheduling availability, and in some cases the teachers were running afterschool programs, so this was not surprising.

Situating Learning in Context

Inspired by the immediate relevance and applicability of the skills in the virtual coaching PLCs in ACRES, we designed the K–12 science experience to be immediately applicable for teachers, without requiring an initial grounding in theory. Unlike the ACRES model, however, the teachers planned units that they expected to teach at the end of the entire professional learning experience, without the opportunity to practice them between PLC meetings. One drawback was that they weren't able to actually "test" any of their learning with youth to bring back to the group; however, benefits included teachers taking needed time to develop units in a supported way.

Part 3: Implications and Next Steps

We believe that there is great promise for both OST and in-school educators and professional learning facilitators to continue to reciprocally iterate on the ACRES Virtual Coaching PLC approach. From our experiences, we believe it is worthwhile to continue to use strategies that are productive for both in-school and OST educators. These strategies include

- structuring virtual sessions to include "skills" sessions followed by "coaching" sessions;
- scheduling ongoing professional learning in shorter, more manageable time frames; and
- situating professional learning in the educators' immediate context.

To establish this approach as an effective and needed practice for in-school educators, additional evaluative work is needed to document the ongoing changes in teacher thinking. A design-based research approach, iterating between the OST and in-school approaches, may reveal mutually beneficial strategies leading to key outcomes.

Overall, we are motivated by the prospect of continuing to improve on the in-school and OST adaptations and modifications to the Virtual Coaching PLC approach and the ways that the two worlds can mutually inform one another. In our case, this means having professional learning providers straddle both worlds as a way of "seeing into" each context to inform the other.

Lastly, we were struck by the overlap between the instructional practices of effective STEM teachers (National Council of Teachers of Mathematics 2014; NGSS Lead States 2013) and the recommended facilitation practices of effective afterschool providers characterized in frameworks such as Click2SciencePD, Dimensions of Success and STEM PQA. Skills such as asking purposeful questions, following up to understand student thinking, ensuring equitable participation by all youth, making time for reflection, and emphasizing relevance and connection-making are highly transferable skills that will support educators to be more effective for both in- and out-of-school settings.

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REFERENCES

Brasili, A., and S. Allen. 2019. Beyond the webinar: Dynamic online STEM professional development. *Afterschool Matters* 29, 9–16. https://eric.ed.gov/?id=EJ1208376

Desimone, L.M., and K. Pak. 2017. Instructional coaching as high-quality professional development. *Theory Into Practice* 56 (1): 3–12. https://doi.org/10.1080/00405841.2016.1241947

Gibbons, L.K., and P. Cobb. 2017. Focusing on teacher learning opportunities to identify potentially productive coaching activities. *Journal of Teacher Education* 68 (4): 411–425. https://doi.org/10.1177/0022487117702579

Martin, L.W., L.U. Tran, and D.B. Ash. 2019. *The reflective museum practitioner: Expanding practice in science museums*. Routledge. https://www.amazon.com/Reflective-Museum-Practitioner-Expanding-Practice/dp/1629582220

McConnell, T.J., J.M. Parker, J. Eberhardt, M.J. Koehler, and M.A. Lundeberg, 2013. Virtual professional learning communities: Teachers' perceptions of virtual versus face-to-face professional development. *Journal of Science Education and Technology* 22 (3): 267–277. https://doi.org/10.1007/s10956-012-9391-y

McKenzie, W. 2014. *The Guilded Age: Professional learning communities in education. ASCD Inservice.* https://inservice.ascd.org/the-guilded-age-professional-learning-communities-in-education/

National Council of Teachers of Mathematics. 2014. *Principles to actions: Ensuring mathematical success for all*. The National Council of Teachers of Mathematics.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington DC: National Academies Press. https://play.google.com/store/books/details?id=qfhhCwAAQBAJ

Sneider, C., and S. Allen. 2019. Formative assessment of STEM activities in afterschool and summer programs. *Connected Science Learning* 1 (11).

Vance, F., E. Salvaterra, J.A. Michelsen, and C. Newhouse. 2016. Getting the right fit: Designing a professional learning community for out-of-school time. *Afterschool Matters* 24: 21–32. https://eric.ed.gov/?id=EJ1120613

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Formative Assessment of STEM Activities in Afterschool and Summer Programs

BY CARY SNEIDER AND SUE ALLEN

The positive impacts of STEM (science, technology, engineering, and math) afterschool and summer programs have been well documented and summarized in a number of review papers and books (e.g., Allen, Noam, and Little 2017; Krishnamurthi and Bevan 2017; NRC 2015). Growing awareness of STEM's value in outside-of-school time (OST) has in recent years led education leaders to develop the STEM Ecosystem Movement, an effort to form collaborations among formal and informal educators with support from local businesses, universities, science centers, and other partners, with the goal of creating more effective ways of fostering student learning. At last count, 68 city and regional teams have joined StemEcosystems.org, a collaboration involving 1,870 school districts, 1,200 OST providers, and 4,350 philanthropic, business, and industry partners, serving more than 33 million preK–12 children and youth.

Of central importance in these new collaborations are partnerships between school teachers and facilitators of afterschool and summer programs. These partnerships have great potential to coordinate otherwise separate efforts in order to provide more engaging, meaningful, and educationally effective STEM experiences for youth. However, given the differences between the two distinct teaching environments, it is not always clear how teams can best collaborate. Preliminary evaluations have shown that one of the major challenges for these teams has been "finding time and trust to successfully navigate differences among formal and informal cultures, including language and terminology, education and experience, accountability and vision" (Traphagen and Trail 2014, p. 7).

In a nutshell, the idea is to engage formal and informal educators in collaborating on developing ways to use formative assessment—an instructional approach widely recognized for its value in schools—in afterschool and summer programs (Black et al. 2003; Black and Wiliam 2009; Yeiser and Sneider 2013). In formative assessment, teachers identify what they want their students to learn, and then provide activities to see which students are learning and who needs more help. Teachers can then adjust their instruction to achieve their goals. Formative assessment activities can range from quizzes to hands-on activities to group discussions—whatever helps the facilitator see whether students are learning the targeted concepts and skills.

We were initially concerned that classroom teachers would have a greater focus on concepts and skills, whereas afterschool and summer camp facilitators would place a higher value on fun and engagement. However, as illustrated in the three case studies reported in this article, that did not appear to be a problem because the classroom teachers in this study recognized the special nature of STEM outside-of-school time, and the OST facilitators wanted their students to develop knowledge and skills that would be valued in school. Although our sample is small, we expect that mutual understanding and trust are achievable for participants in many STEM ecosystems.

In early 2016 we had an opportunity to work with four citywide teams (Boston, Massachusetts; Providence, Rhode Island; New York, New York; and Nashville, Tennessee) through the efforts of Every Hour Counts, a national coalition of organizations representing cities and regions across the United States that have formed STEM ecosystems (Traphagen 2018). In the sections that follow, we summarize a one-day workshop we offered on formative assessment, and then report results from three of the pioneering teams that approached the task of developing and testing a formative assessment activity in different ways. In sharing the results, we have drawn heavily from reports written by the teams as part of their reflections on their learning experiences. To preserve the privacy of individuals and schools, we have assigned pseudonyms and acknowledged their assistance as a group at the end of this article.

FIGURE 1

The Puppy Tower Challenge.

Workshop: Formative Assessment in Afterschool and Summer Programs

Thirty-one educators from seven citywide STEM ecosystems participated in the workshop, including the four that subsequently worked with us to develop and test formative assessment activities. The workshop involved a series of practical activities on formative assessment. We defined formative assessment as gathering information on students' learning during instruction, and listed the many benefits of using it in informal as well as classroom learning settings. We then guided the participants through a simple hands-on activity intended to teach the distinction between criteria and constraints in the process of engineering design. The challenge was to build a tower to support a stuffed puppy (Figure 1). Participants were tasked to meet the criteria of height and stability and the constraint of using a given number of index cards as construction materials. Much like youth in afterschool and summer STEM programs, the participants engaged in the activity with enthusiasm.

During the activity, we modeled the following formative assessment strategies:

- asking youth to flash colored sticky notes to self-report their level of understanding;
- making discreet observations of youth at work;
- asking youth open-ended, purposeful questions about their activity; and
- using a simple rubric.

These strategies were integrated into the activity, did not take a lot of time, did not disrupt the experience, and gave the facilitator a rough sense of whether most of the group had met the goal of the activity—to meet the criteria and constraints of the task—or needed more help. Because the larger goal of the workshop was to demonstrate the use of formative assessment, we ended by asking participants to share their experiences, summarizing the four strategies we used during the activity, and leading a short discussion about the pros and cons of each strategy. We gave the participants a handout (Figure 2) as a take-home reminder of the strategies.

We also provided a brief review of the Next Generation Science Standards' science and engineering practices as a set of learning goals that would be of value to both formal and informal educators (NGSS Lead States 2013). Then, we assigned teams to select an activity they might do at their site that would align well with one or more NGSS practices, as if they were going to present the activity the next day. Teams left with the expectation that they would attempt to use formative assessment at their sites and report on their experiences. Although not all STEM ecosystems were able to commit to working with us to pilot this approach, four of the citywide STEM ecosystems did so, and we coordinated the work of eight teams (two teams in each of the four cities) of formal and informal educators via phone or Zoom videoconferencing. We selected three of the eight case studies for this article because they represent a diversity of OST settings.

FIGURE 2

Workshop handout showing four useful strategies for formative assessment in afterschool and summer programs.

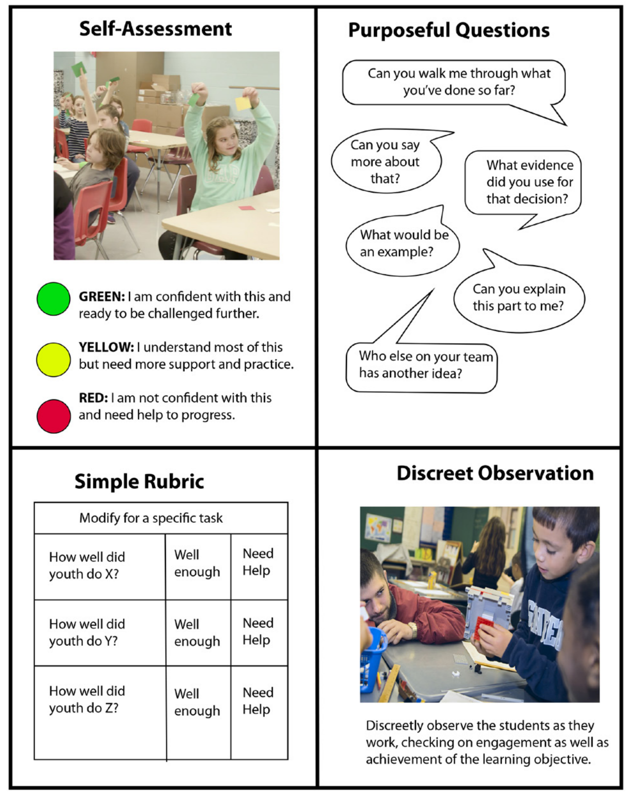


Image in upper left section provided by: Perrin Chick, Melissa Fenton, Cary Sneider, and Hannah Lakin. Image in lower right section provided by: Andrew Brilliant, courtesy of Museum of Science, Boston.

Case Study: Formative Assessment in a Summer School Program

In comparison to afterschool, summer programs provide much more time for students to engage in extended projects, and thereby develop deeper skills. That was the case with the middle school Fashion Futures summer program, which ran for five weeks, five days per week, for three and a half hours each day. Tracey, an informal educator, and Mariel, a formal educator, designed the course. Although fashion design was not in their state's standards, Tracey and Mariel recognized the value of the program for youth age 11–14 to learn physical science concepts (properties of materials), mathematics skills (measuring and scaling), and practices of science and engineering (solving problems and arguing from evidence). As Tracey and Mariel later reflected:

During the course of the 2017 Fashion Futures program, youth engaged in many hands-on activities where they learned to measure, scale, manipulate, and create full garments. [We] expected youth to learn how to do all the things listed above through models and hands-on activities. We used various forms of formative and informal assessment during our day-to-day activities to ensure youth understanding. One of the most important aspects of our program was to make sure all youth were proud of their outfits and they could explain and show off their hard work. We did this through a fashion show at the end of the program on the last day of camp.

We completed two activities where youth needed to provide evidence to support their claims. The first formative assessment task was when youth tested over 20 pieces of material that could be used for clothing. Based on their designs, they would need to decide which fabric they would choose and provide evidence as to why this worked. For example, if a youth was creating a rain jacket, they would need to use evidence to support their claim that a plastic bag would be a good material for a rain jacket, [as] opposed to a white, cloth material. Youth did this individually and handed in their reflections.

The youth completed the second activity toward the end of the summer. They were asked to independently reflect on their fashion designs, providing evidence in support of their decisions.

During the first of the two assessment activities, most of the youth did a great job [of] providing evidence to support their claims. Those who did not complete this efficiently discussed the assessment with one of us to make sure they understood what they were supposed to do to show that their claims and decisions were supported by evidence. We then followed up with those youth later on. By the time the second formative assessment activity was given, this was a much easier process for the youth because they were already exposed to it during the first round, so these discussions were beneficial.

During the course of the summer, we learned that the informal assessments don't have to be as thoughtfully planned as formal assessments. With this being said, it is important to make sure that [assessment] is happening continuously throughout class time in order to make sure all youth understand the concepts.

This example illustrates that the team did not have to change their planned activities. They ran their Fashion Futures class as they had in the past, but they shifted their thinking about the activities, seeing them not only as learning opportunities for students, but also as opportunities to learn about student thinking. They also thought differently about their learning goal. Arguing from evidence had always been an important goal, but as a focus of formative assessment, the teachers found ways to accomplish that goal through different means.

Case Study: Formative Assessment in a One-Day Field Trip

The setting of the second case study was a nature preserve that offers single-day field trip experiences for middle school students (grades 6–8) from the city. Senior staff developed the program, which was then delivered by more junior facilitators, few of whom had a background in teaching or science. The focus of this lesson was on the core ideas of adaptation and natural selection, and the practice of constructing explanations. The senior facilitators later reflected:

> The first lesson, Micro-wilderness, had the children find insects and describe their adaptations. The goal was for them to think purposefully about how structures and behaviors increase the [chances of] survival of the population. [Students] made claims about the function of an adaptation by recording evidence that they observed on worksheets and researching additional information about their insect. The worksheets had the following questions:
>
> - Name a physical and a behavioral adaptation, and explain how it helps your insect survive in its environment. What is your evidence?
> - Let's say in the next year, there's a new species of bird introduced to the island that eats your insect. Describe a new structure or a change in behavior your insect population could evolve and explain how it will help the population survive this new threat.
>
> Most students were able to name a physical and/or a behavioral adaptation correctly. While some students only named the adaptation, many were able to explain how that adaptation enabled the insect to survive. In the children's responses to the second question, about what would happen if a new species of bird were introduced to the island, many were able to name either a physical or behavioral adaptation, and some (but not all) were able to explain how the adaptation would help it survive.
>
> The students then presented their organism in a convention format, fostering discussion, questions, and idea-sharing amongst their peers. The objectives of this lesson were for the students to describe how specific features—structural or behavioral—provide advantages to an organism's survival, and to explain how environmental changes impact adaptations within a population over time. The (junior) facilitators had been coached to ask the following questions during the convention:

- Tell me about your insect's adaptation. What is your evidence?
- How will that adaptation help your organism survive the new bird species/predator?
- Is your adaptation structural or behavioral? How can you tell the difference?

Our formative assessment methods were purposeful questioning and direct observations. We provided the facilitators with instructions for what to do if their observations during the convention suggested that the class was having difficulty understanding the concepts of adaptation and natural selection. This took the form of open-ended questions that would encourage the students to construct these core ideas on their own:

- Can someone remind us what a physical or a behavioral adaptation is, or give us an example? What does your insect need to be able to survive?
- If you were being hunted by a pterodactyl, what behaviors or body parts would you like to have in order to not be eaten?
- Put yourself in your insect's place. What body part or behavior would help you survive if a bird were trying to eat you?

The facilitators interacted with the children while they were working on … responses, making observations and asking purposeful questions to provide guidance. In the future, we expect to ask our facilitators to model correct responses by sharing out loud some of the most interesting observations and ideas that they heard. This can help promote more and better responses from the group as a whole.

In summary, we learned the following about informal assessments in our particular setting:

Pros

- Formative assessments are useful to focus the facilitator on the major objective of the lesson.
- They provide the program with a closer look at the quality of the lesson in meeting [the] objective(s).
- They can serve as a tool to provide feedback to the facilitator.
- They can be used to scaffold student learning and guide them back on track.
- They can provide information as to how the lesson may be revised.

Cons

- The limited time we have with children allows little time for … modifications for those [who are] not ["getting" the lesson].
- We don't have the luxury of addressing what [students] didn't ["get"] since there is no follow-up lesson.
- Our facilitators do not necessarily have a background in teaching and/or science and therefore must undergo extensive training prior to the beginning of each season. Because of the nature of this industry, we have a high turnover of facilitators from season to season. We develop [in facilitators] the necessary skills over time to apply formative assessments, and then they move on and we must start over with new facilitators. For these reasons, it is imperative that we develop well thought-out scripted lessons that the facilitators can deliver in a timely fashion that leaves little margin for error during delivery.

This was a particularly interesting case because the "pro" bullets show that formative assessment can work in out-of-school settings, even with facilitators with little or no background in teaching or science. Regarding the first two "con" bullets, we note that this lesson plan had additional activities built into it to help children who were struggling. The third "con" bullet is also an important lesson for leaders of afterschool and summer programs. In this case, "scripted lessons" did not mean providing information to be memorized and delivered, but rather good questions to ask so as to determine how well students are learning.

Case Study: Formative Assessment in an Afterschool Program

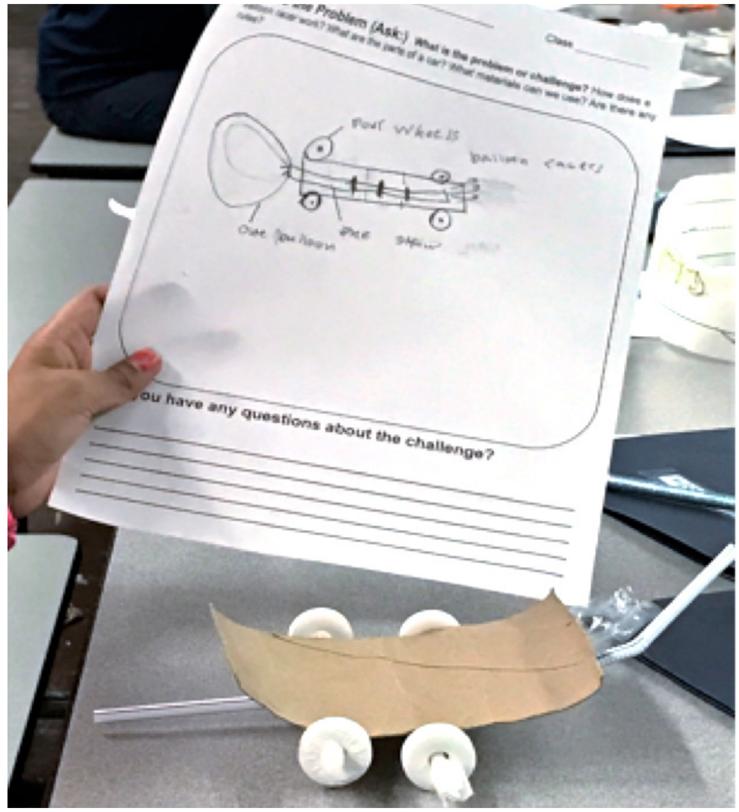
In our third case study, both formal and informal educators ran the afterschool program together, and both had considerable teaching experience. Louise taught all of the science classes in her urban elementary school of nearly 600 students. Her partner, Frances, taught preschool and afterschool.

In this case, the team decided to focus their afterschool program for grades 2–4 on a specific physical science standard—"Energy and matter interact through forces that result in changes in motion" (NGSS Lead States 2013)—rather than a more general science or engineering practice. Their plan was to provide experiences for their students to address this standard through three different activities that engaged students in applying the same core ideas. They also wanted to use formative assessment to determine how to modify each activity based on prior student performance. Each of the activities described below require approximately four one-hour lessons with youth (see Figure 3).

- **Balloon racer:** Our goal was to support the learning that goes on during the day by challenging students to use their understanding of concepts taught in school to solve real-life problems. The first challenge was to build a balloon racer that would use air in a balloon to push the racer forward. The first step was to have students do a 30-minute investigation pushing a toy car around the room, and make observations. Next, the students researched air-powered cars to draw inspiration for their own racer. Then they built and tested their racers. We had to stop at one point when we realized they had trouble with wheels and axles. They were taping the wheels to the racer, so they were not turning … [and] were sliding [instead of] spinning. Once the students solved the problem with the wheels, they discussed other ways to improve their designs. These discussions among the students served as our formative assessment. Some suggested having two straws from the balloon to the racer would let more air flow. Others thought a bigger balloon would give them more force. They also learned that heavier racers required a greater force than lighter racers. In the end 50% of the racers were successful, but all of the students appeared to understand the idea that more force gets the cars to go further, and many also realized that heavier cars require more force than lighter cars to go the same distance.
- **Catapult:** The children designed a catapult from rubber bands and spoons to hurl a marshmallow as far and accurately as possible. This second challenge helped them become more independent builders, so that we didn't have to troubleshoot as often.
- **Playground slide:** The third activity was to plan and conduct experiments with a playground slide to see how the force of gravity affects objects of different weights.

FIGURE 3

Two afterschool activities designed to help students develop understanding of force and motion.



Balloon racer

Slide activities

TABLE 1

Continuum of formative assessment methods.

More Whole-Group	More Individualized
Discreetly observing the group as a whole, checking on engagement as well as achievement of the learning objective (e.g., content or practices)	Using checklists in observations, checking to see not only whether students are engaged in and achieving objectives, but also who may be having difficulties
Asking purposeful questions verbally, but not necessarily systematically	Asking purposeful questions systematically on handouts to determine each youth's understanding of key ideas
Drawing conclusions about the effectiveness of the activity for the group, based on how well the majority of youth appear to understand concepts and carry out practices	Drawing conclusions about the effectiveness of the activity for individual youth, based on observations and written answers to questions or other clues
Developing ideas to modify activities to provide scaffolding so more youth will achieve the intended outcomes	Developing ideas to provide differentiated instruction during activities, so students who are achieving the objectives can expand their capabilities, whereas students who are not can receive assistance
Modifying subsequent activities for the current group of youth (or future groups)	Providing differentiated instruction during activities so students who are struggling get further help, whereas those who are doing well have further challenges

My partner and I learned several things about ourselves and our students from these afterschool activities. One is that kids have comments and questions that are completely unpredictable and catch you off guard. Second, we really love creating a fun, interactive place to learn about science. We are very supportive of one another.

Keeping in mind that the purpose of these activities was for students to learn that "Energy and matter interact through forces that result in changes in motion," the teachers' deliberate attention to students' discussions as they tested and redesigned their balloon racers led the teachers to conclude that "all of the students appeared to understand the idea that more force gets the cars to go farther, and many also realized that heavier cars require more force than lighter cars to go the same distance."

For a teacher in the formal school system, this may not provide sufficient evidence that all students were taking important steps toward achieving the standard. However, this was not a science class in school, and requiring each learner to respond to a written quiz could easily have dampened any enthusiasm students had developed for experimenting with force and motion. What is most important in this setting is that by listening to their youth talk with each other, the educators became attuned to what to emphasize in the two subsequent activities, which ideas to reinforce, and how to deepen children's understanding of the relationships among energy, matter, force, and motion.

Conclusion: What We Learned About Formative Assessment in Out-of-School Time

Although the STEM ecosystem movement is still young, a survey of ecosystem leaders revealed some of the challenges of forming partnerships between classroom teachers and afterschool and summer program providers. The study found a common desire among leaders to encourage assessments for continuous improvement but difficulties achieving a common vision of what that means.

"In the words of one leader: 'Useful assessment and evaluation always require a stable environment in which to assess[;] agreement on important goals, methods and techniques of assessment[;] carefully selected instruments upon which the various constituencies agree and approve[;] and the development of a common language/purpose of assessment'" (Allen and Noam 2016, p. 9).

The goal of engaging classroom teachers and OST facilitators in working together to develop formative assessments has been to help them achieve agreement on important goals, methods, and techniques of assessment that work in both environments, as well as a common language. In the afterschool and summer environment, that has meant teaching and assessing STEM more systematically, without losing the fun and engaging quality of STEM outside of school—some call it the "special sauce"—that has inspired so many of today's scientists and engineers. Although we do not claim this should be the only approach to assessment, we did find that it is one way to help formal–informal educator teams work together to improve STEM education.

Looking across all eight of the case studies (three of which are reported above), we saw a continuum of approaches, ranging from a more whole-group focus to a sharper focus on individual youth. Table 1 illustrates these differences. These are emphases rather than distinct differences. Both extremes begin by specifying a clear and specific learning objective, and engaging youth in activities that can reveal their thinking. Which approach to emphasize depends on the setting, the number of youth, the experience of the facilitators, and the particular activity, including its learning goals and structure.

We commend the participants who designed and carried out these case studies for their willingness to explore new formative assessment approaches and share their experiences with us. We hope these examples will inspire readers to collaborate with their colleagues, take a fresh look at their lesson plans for the coming months—whether in school, afterschool, or summer—and design new ways of understanding how students are thinking and leaning so that you can continually adjust your teaching to meet their needs.

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The handouts shown in Figures 1 and 2 were created as part of the ACRES project, supported by grants from the National Science Foundation and STEM Next Opportunity Fund, which offers coaching and professional development materials to afterschool educators in rural settings. You can find more information about the ACRES project online.

REFERENCES

Allen, P.J., and G.G. Noam. 2016. *STEM learning ecosystems: Evaluation and assessment findings*. Cleveland Heights, OH: Teaching Institute for Excellence in STEM.

Allen, P.J., G.G. Noam, and T.D. Little. 2017. Multi-state evaluation finds evidence that investment in afterschool STEM works. In *STEM ready America*, ed. R. Ottinger. http://stemreadyamerica.org/multi-state-evaluation-finds-evidence-that-investment-in-afterschool-stem-works.

Black, P., C. Harrison, C. Lee, B. Marshall, and D. Wiliam. 2003. *Assessment for learning: Putting it into practice*. London: Open University Press.

Black, P., and D. Wiliam. 2009. Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability* 21 (1): 1–31.

Krishnamurthi, A., and B. Bevan. 2017. From evidence to policy: The case for STEM in afterschool. In *STEM ready America*, ed. R. Ottinger. http://stemreadyamerica.org/article-evidence-to-policy.

National Research Council (NRC). 2015. *Identifying and supporting productive programs in out-of-school settings*. Washington, DC: National Academies Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press. www.nextgenscience.org/next-generation-science-standards.

Traphagen, K. 2018. *From niche to necessary: Scale and sustainability lessons from the Frontiers in Urban Science Education (FUSE) initiative*. San Diego, CA: STEM Next Opportunity Fund. http://bit.ly/2SaaddN.

Traphagen, K., and S. Trail. 2014. How cross-sector collaborations are advancing STEM learning: Working paper. Report to The Noyce Foundation.

Yeiser, L., and C. Sneider. 2013. Formative assessment: Attending to the substance of student thinking. In *Opening the door to physics through formative assessment*, ed. C. Sneider and B. Wojnowski. Aurora, CO: National Science Education Leadership Association.

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5

STEM ENGAGEMENT

THE POWER OF FAMILIES

INTRODUCTION

The Power of Families in STEM Learning

BY BETH MURPHY, Field Editor, *Connected Science Learning*

While the focus is most often on the role educators and educational institutions play in STEM education, we also know that the network of significant adults in a young person's world plays a critical role in supporting their STEM access, opportunity, engagement, participation, and learning. There are many different roles that these grown-ups can play, for example: facilitator, collaborator, advisor, facilitator, coach, advocate, connector, and even co-learner. Parents and caregivers can and do support young people in developing their STEM identities by exposing them to STEM and STEM role models, affirming their STEM interest, providing access to STEM-related learning experiences, and connecting them with STEM-related resources. Many educational initiatives that invite and welcome parents and caregivers into these roles have been shown to be impactful—everyone benefits when they are involved partners in STEM learning. Learning is a cultural experience that incorporates multiple ways of knowing and grows out of the lives of learners. Families themselves are learning systems and thus a holistic and inclusive ecosystem-focused approach can make a difference.

Articles in this chapter reflect on program designs and research about the role parents, caregivers, and other significant adults play in developing the STEM-related dispositions, interests, aspirations, and knowledge of young people—exploring questions such as:

- What goals are shared by STEM education organizations and families for their children, and how can we work together to achieve them?
- How can STEM programs benefit from the assets and funds of knowledge within families?
- What are effective strategies for building authentic and purposeful connections with parents and caregivers?
- What are some successful models for collaboration, especially with communities that have historically been marginalized or overlooked by and within STEM?
- How do we know what success looks like for family engagement in STEM learning?

Young Mathematicians

A Successful Model of a Family Math Community

BY KRISTEN REED AND JESSICA MERCER YOUNG

Children are born with mathematical minds. Even before children enter kindergarten, they engage in mathematical ways of thinking that help them make sense of the world around them. When children have opportunities to engage in meaningful mathematical interactions, it supports cognitive development, builds brain architecture, and develops skills such as problem-solving and persevering. Providing these mathematics learning opportunities is critically important, given that mathematical knowledge in early childhood is strongly predictive of children's future success in school (Claessens, Duncan, and Engel 2009). Indeed, at kindergarten entry, mathematics skills predict mathematics achievement through high school (Watts et al. 2014), with kindergarteners' early mathematics skills building a foundation not only for advanced mathematical knowledge, but also for achievement in science and engineering (Claessens and Engel 2013; National Mathematics Advisory Panel 2008).

However, systemic opportunity gaps create unequal access to high-quality mathematics learning experiences. Analysis of education gaps in the U.S. have shown that young children with limited access to economic resources may start kindergarten with mathematics skills that are up to a full year behind their more economically advantaged peers (DeFlorio and Beliakoff 2015; Garcia and Weiss 2015), and these gaps in mathematics outcomes persist or even increase as children proceed through school (Cross et al. 2009). Research has shown that investing in early childhood education programs and supporting families as education partners can help narrow the gaps between students at the start of school (Bivens et al. 2016; Garcia and Weiss 2017). Here, we explore how we took a community-based partnership approach to align enriching mathematics experiences to create a web of opportunity that ultimately supports children's school readiness and success.

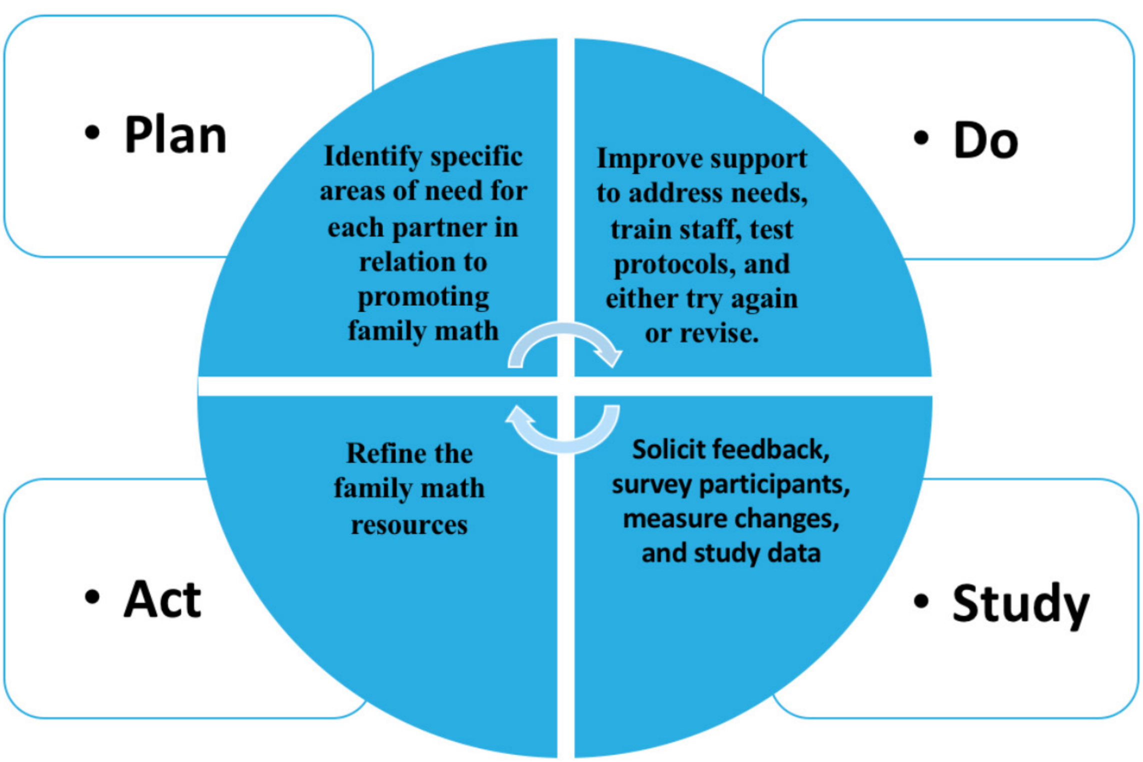
Young Mathematicians in Worcester Family Math Partnership

The Young Mathematicians (YM) program, developed by the Education Development Center (EDC), has partnered with early childhood programs for almost a decade to research and develop early childhood mathematics games and educator professional development. The YM intervention program aims to promote the mathematics skills of young children from under-resourced communities through games and short problem-solving stories. In 2015 YM added a family mathematics component designed to support mathematics learning across home and school environments. Grounded in Bronfenbrenner's (1986) ecological systems theory, YM capitalizes on the interconnectedness of children s environments by infusing each level of the ecosystem with positive attitudes toward mathematics and opportunities for children to engage in meaningful early mathematics practices.

With the success of this design, the YM team sought to engage additional early childhood stakeholders and form a networked community improvement model. In 2019, with support from Overdeck Family Foundation and Heising-Simons Foundation, the Young Mathematicians in Worcester (YM-W) initiative was established to support preschoolers whose communities have historically been denied access and equitable opportunities to engage in high-quality mathematics experiences. The partnership among early childhood education agencies, families, educators, librarians, and researchers has the goal to establish a "web of opportunity" that breaks down the silos of school, home, and the broader community and aligns

FIGURE 1

Plan-Do-Study-Act cycle.



Classroom game boards 1–5.

1–12 number path outside with family.

Classroom butterfly path.

Number path family kitchen floor.

Classroom floor number path.

Library summer reading kickoff.

Number line in the park.

young children's mathematics learning experiences across contexts by providing greater access to high-quality mathematics learning opportunities.

The partnership is based in Worcester, Massachusetts—a unique and richly diverse city, which is the second largest city in New England and a leading refugee resettlement community. Seventy-four languages are represented in the public schools, and 59% of students speak a first language other than English. More than 80% of public-school students are designated as "high need" by the state, and in 2021 only 15% of Worcester's third-graders met grade-level expectations in mathematics (Massachusetts Department of Elementary and Secondary Education 2021). While there are challenges, Worcester is fortunate to have a highly networked and coop-

TABLE 1

Retrospective pre-changes in educators' attitudes toward mathematics.

	Year 1 (N = 59)		Year 2 (N = 57)	
	Mean Before YM	Mean End of Year 1	Mean Before YM	Mean End of Year 2
Understanding importance of family math and early math learning***	4.05	5.51	3.96	5.60
Interest in early math activities and early math learning***	3.98	5.29	4.07	5.42
Comfort engaging in math with young children***	4.10	5.32	4.12	5.33
Comfort supporting families in early math***	3.47	4.88	3.30	4.77
Avoidance of math activities*** (Year 2; Not Significant in Year 1)	2.31	1.91	2.28	1.58

* p < .05; ** p < .01; *** p < .001.

erative community of early childhood organizations that are committed to empowering the community and supporting their needs (see Table 1 in Supplemental Resources).

Partnership Activities

To enact change in the community, a key activity of YM-W was the formation of a partnership among Early Childhood Education (ECE) programs and stakeholders. YM-W built upon EDC's Young Mathematicians program to strengthen and extend its family math component through collaborations among partners and in iterative cycles of improvement that included feedback from key stakeholders— children, families, educators, and ECE community partners. We convened regular leadership board meetings to support communication and capacity building to reach educators and families by providing educator workshops and family math leader meetings. In addition, using the YM program as a prototype, we co-designed with YM-W families and educators a broad collection of family and classroom instructional resources, including early mathematics games with easy-to-use instructions, videos, and a robust website with resources available in English, Spanish, and Portuguese. The main partnership activities were leadership board discussions, educator workshops, family math leader meetings, and resource development.

YM-W Leadership Board. The YM-W leadership board, along with the external evaluator, met monthly to evaluate progress, respond to challenges, and adapt the program in a cycle of continuous quality improvement. Following a networked community improvement model (Bryk et al. 2015), the board comprised leaders from each of the partner organizations plus two parents who were also family math leaders. Most meetings had a similar structure: (1) updates about successes and challenges over the past month; (2) review of qualitative or quantitative data collected by the external evaluator; (3) discussion of modifications to make based on that data and the partners' observations; and (4) preparing for next steps, including revising the implementation plan as needed. This networked community improvement model and regular cycle of Plan-Do-Study-Act contributed to the overall success of the project (see Figure 1).

Educator workshops. Educators from Worcester Family Partnership (WFP) and Worcester Child Development (WCD) Head Start wanted to learn more about early mathematics content and age-appropriate activities for home and school. In Year 1 (2019–2020), EDC staff facilitated professional learning sessions focused on number and operations (these were in-person at first but when the pandemic began in March 2020 the workshops were provided online). In Year 2 (2020–2021), we explored different topics in early mathematics including geometry, patterns, and spatial relationships. During each session, we discussed children's early mathematics development, addressed modifications for different-age children, and discussed the influence of positive attitudes toward mathematics. Educators received materials related to the topic of the session, such as game boards, cards, dice, and other materials; game instructions; related math mini-books; and suggestions for related picture books. When educators were teaching virtually, we provided virtual game ideas as well as materials to send home to families.

Importantly, each session provided time for educators to reflect on their own practice, share their reflections with colleagues, and think together what strategies they might incorporate to improve their practice and enhance their support of children and families. These sessions were a critical tool to align formal education settings such as Head Start with the work of informal education settings such as WFP.

Family Math Leaders. Families from WFP and Worcester Head Start were recruited to learn more about early mathematics and help co-design the family math activities and materials. Beginning in October 2019, a group of families met in-person monthly with EDC staff to learn about ways to engage in fun and playful mathematics, explore what they were already doing at home that supported children's mathematics learning, learn about the mathematics learning happening in preschool classrooms, and brainstorm ways to connect informal and formal learning environments. Parents and caregivers contributed to the design process, helping us revise existing games and materials and create new ones. Importantly, the family math leaders reached out to other families to share their enthusiasm for the project and were inspired to make new connections to local community organizations.

Resource development. Using the original YM activities as prototypes, we co-designed with families and educators a collection of family math games with directions, videos, and other resources available in English, Spanish, and Portuguese. In addition, we focused on creating games and resources that would meet the needs of children at different developmental stages, and could be implemented in classrooms, homes, virtually, and in home-visiting contexts.

The Young Mathematicians in Worcester Approach to Family Math

The YM-W project uses games and problem-solving activities to support young children's foundational mathematics development in number sense, number operations, geometry, patterns, data, and spatial reasoning. Mathematics games provide the perfect context for these objectives as play can spark children's interest in mathematics, enhance their skills, and extend their conceptual understandings. In this way, we provided educators and families from WCD Head Start and WFP with concrete examples of the mathematics that children can learn through daily activities and deepened educators' and families' understanding of early mathematics concepts, emphasizing the similarities between early mathematics and language development.

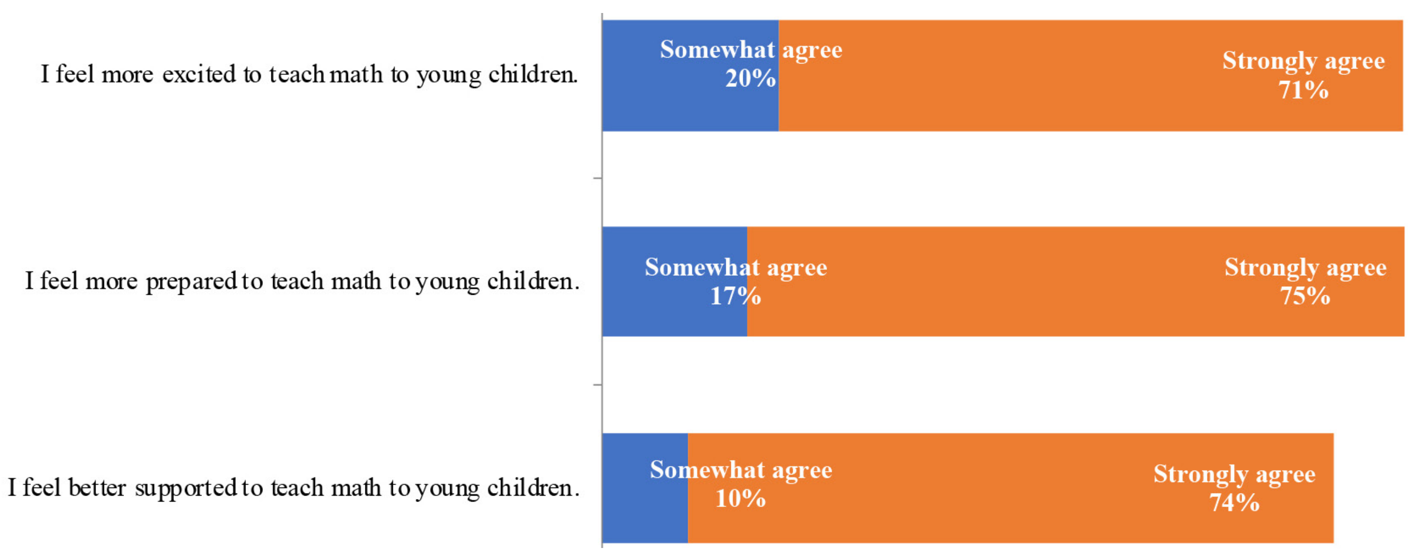
Through this approach we were able to successfully create a model with resources and supports that: (1) addressed the need for high-quality mathematics instructional materials for educators and families; (2) broadened participation for families traditionally underrepresented in STEM; and (3) addressed educators' and families' attitudes toward mathematics.

Mathematics Games Spread Across the Community

Below we illustrate how one of the YM games—a number path game—was adapted with input from families and educators. During the professional learning sessions and family math workshops, educators and families played a tabletop version of *Jumping on the Lilypads*. This game was originally designed with Head Start teachers (see *Play Games, Learn Math! Number Path Games)* to include children ranging in age from 2.9 to 5 years old. After playing the game, educators and families discussed the mathematics they noticed while playing and watched a video of children playing the game. All the families and educators took these ideas and tried them out, modified them as needed to fit their context, and then discussed their experience at our next meeting. Below we provide some examples of how the game was successfully adapted to be played in a range of contexts across Worcester, including home, school, and community. We believe that this helps illustrate the "web of opportunity" provided for children as they engaged in joyful mathematics learning opportunities that supported their school readiness skills.

FIGURE 2

Educator attitudes about teaching math.



N = 59–61. Scale: Strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, or strongly disagree

Preschool Classrooms

Head Start teachers incorporated the game into small groups, classroom math centers, and gross motor activities, and they sent materials home for families to use. Teachers made different number paths depending on the classroom theme for the month (e.g., frogs on lilypads, butterflies on path of flowers, and dinosaurs walking on dinosaur prints).

Family Playgroups and Family Literacy Night

WFP hosts family playgroups and literacy nights, and most of the families who attend have two- and three-year-olds. WFP educators focused on making the number path game engaging for toddlers.

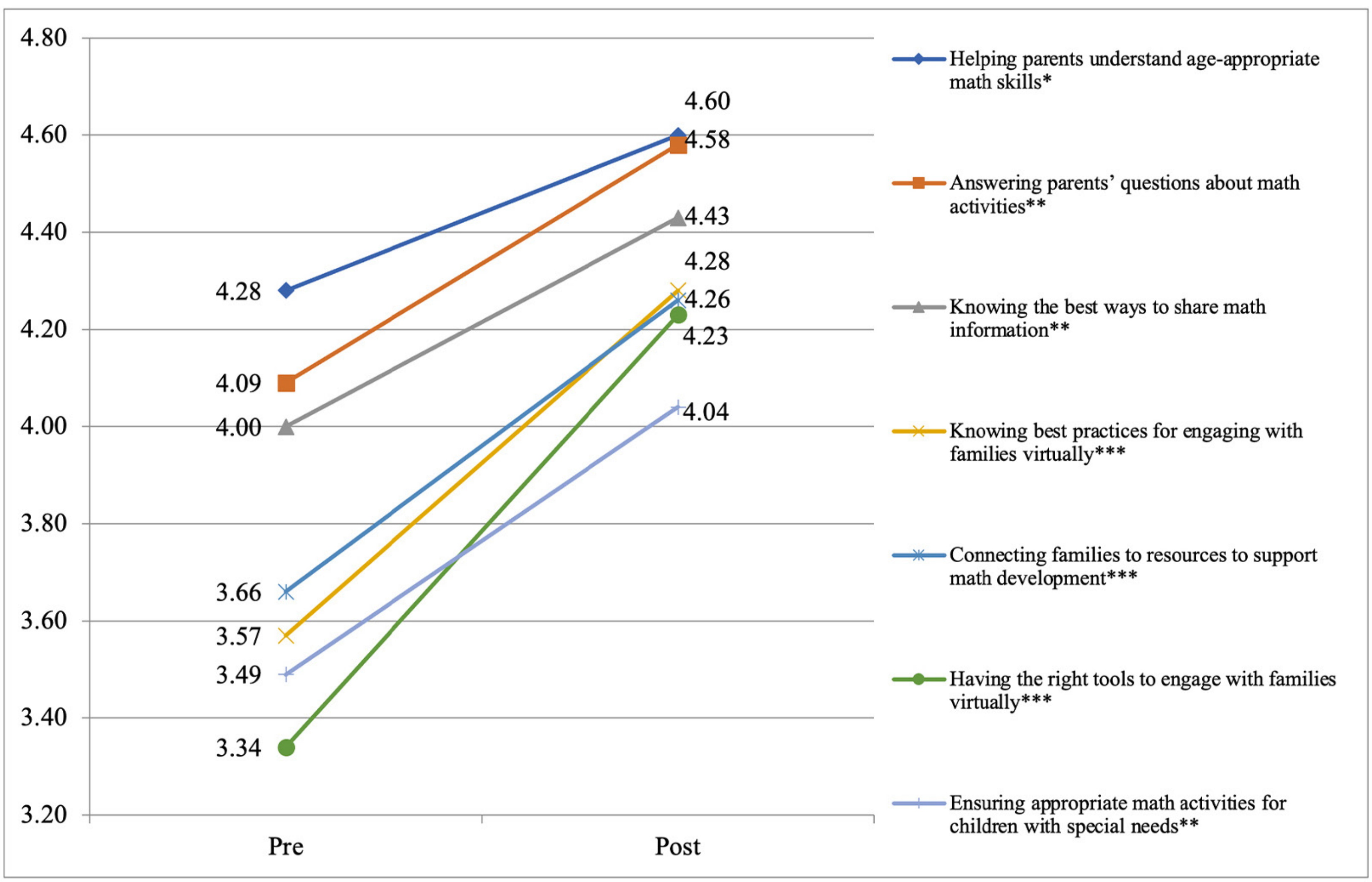
They made a number path on the floor and had children roll dice to move. They held potato sack races on the number path and used the number path to play hopscotch. Playing with the number path in a variety of ways gave children lots of opportunities to practice the number concepts while continuing to maintain high engagement. All the while, WFP educators made sure to discuss with parents why it's important for children to practice these skills and how they can incorporate math talk and math games into their own routines at home.

At Home

After being introduced to mathematics games, parents implemented them in a variety of ways. For the number path game, one family drew a number path on the floor of their kitchen (with washable markers). Another family drew a number

FIGURE 3

Changes in educators' confidence supporting families to engage in mathematics.



N = 52–53. * p < .05, ** p < .01, *** p < .001

path in chalk outside on the sidewalk. Some families used dice, some made spinners, and some drew numeral cards to play with. Families with elementary school–age children made longer number paths, and the older siblings often helped the younger ones. Some families played cooperatively so that each player jumped the same number each time rather than competing to see who would get to the end first.

At the Library

The Worcester Public Library (WPL) incorporated family math kits into their in-person and online summer reading events. The kits included *Jumping on the Lily Pads* game boards, directions for how to play, and a math "mini-book" about jumping to 10. The *Jump to 10* mini-book is available in English, Spanish, and Portuguese.

TABLE 2

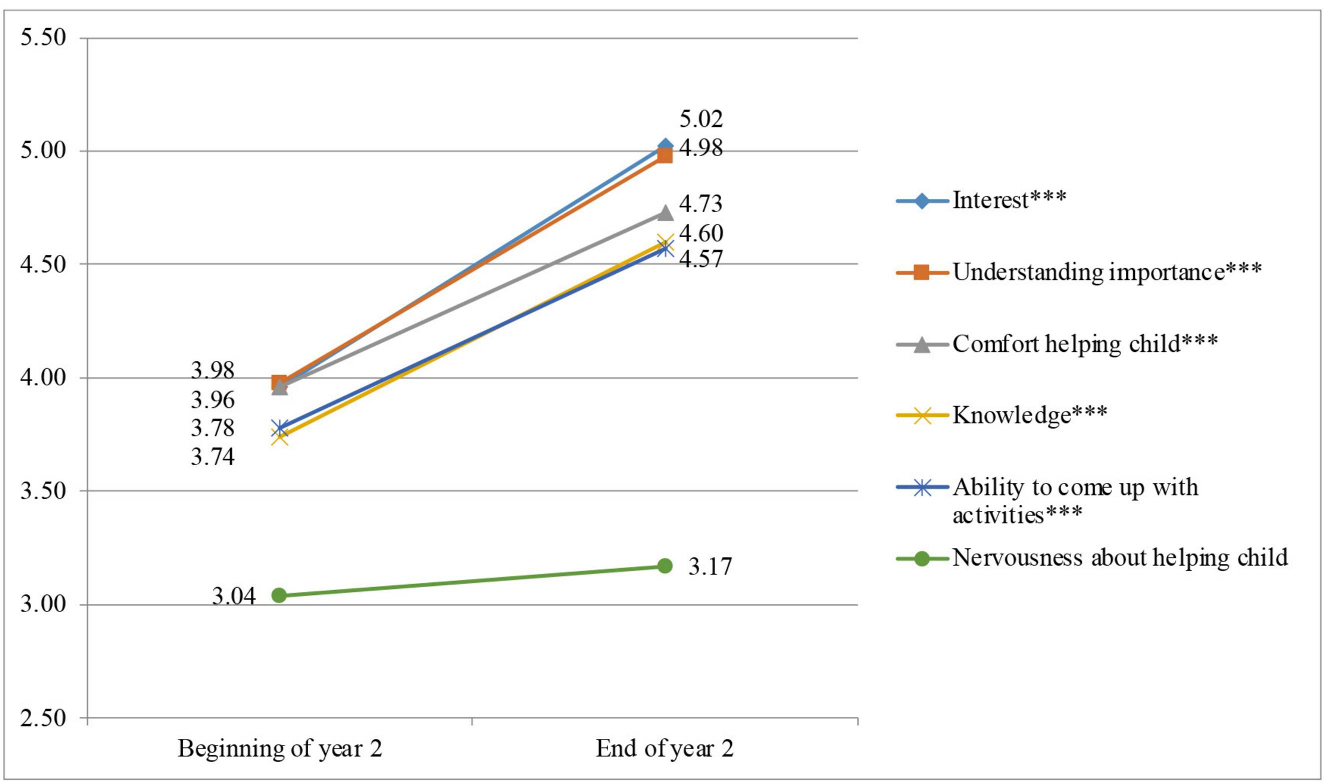
Frequency with which responding families used YM-W materials.

	Frequency of use	% of respondents
Used materials (82%)	Almost every day	8% (n = 4)
	2–4 times a week	32% (n = 16)
	Once a week	34% (n = 17)
	Less than once a week	8% (n = 4)
Had not (yet) used materials (18%)	Planned to use	12% (n = 6)
	Did not use	6% (n = 3)

N = 50 (who responded and recalled receiving the materials)

FIGURE 4

Retrospective pre-changes in families' attitudes toward mathematics.



N = 48–50. *** p < .001.

In the Park

The number path idea extended beyond the partnership members. Worcester's Recreation Department; Pow! Wow! Worcester; a community development organization; and WFP partnered with MathTalk to design and install a giant number path in a local park. The number path included family math signage with QR codes to bring families to apps and websites with more information.

Evaluation and Findings

During the 2019–20 and 2020–21 school years, an external evaluator administered surveys and conducted focus groups and interviews with families, educators, and project leadership (Manning 2022).

Educator Surveys

Educators were surveyed at the beginning and end of each year. Nearly half of the educators had more than 10 years of experience in early childhood education. Sixty-four percent of the educators were White, 11% were Latino, 7% were Black, 5% were Asian, and 9% did not report. Thirty-one percent of educators were bilingual, most commonly Spanish and English.

Educators' Attitudes Toward Mathematics

On the end-of-year surveys, educators rated their current math attitudes and reflected back to their math attitudes at the beginning of the year. As you can see in Table 2, educators showed statistically significant increases in their positive attitudes toward mathematics. Reflecting on teachers' experience in the program, the education manager said that the professional development allowed teachers to easily understand the mathematics concepts children are learning and they left each session feeling like they could "Do Math" themselves and with their students.

Educator Attitudes Toward Teaching Mathematics

In addition to having a positive effect on educators' attitudes toward mathematics, their attitudes about *teaching* mathematics also improved, as shown in Figure 2.

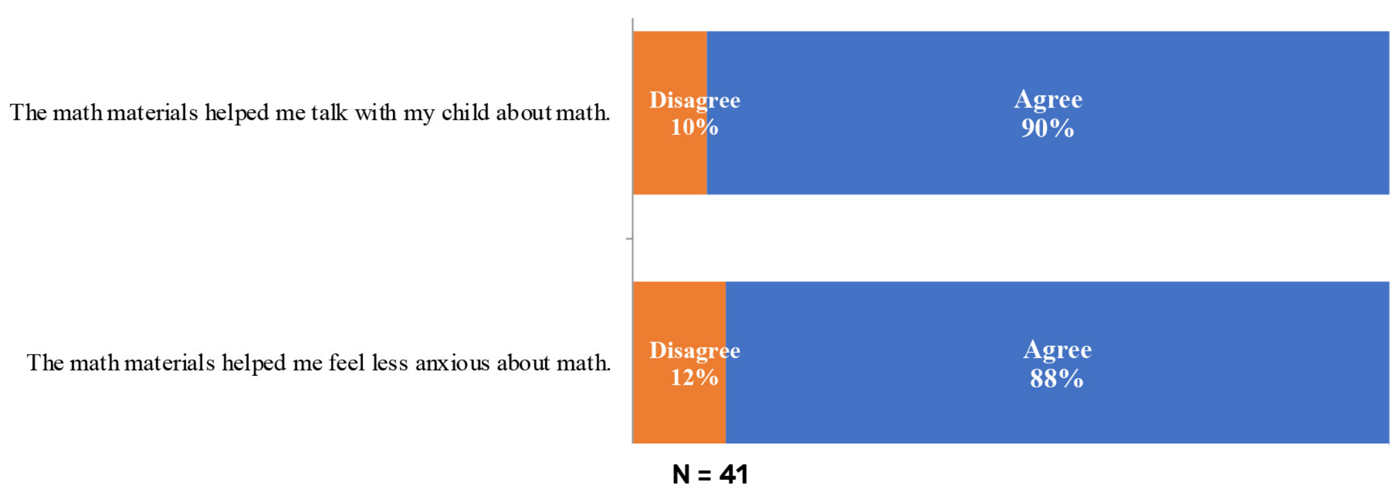
Educator Confidence in Supporting Family Math

Educators also reported statistically significant increases in their confidence to support families in early mathematics (see Figure 3).

The project leadership board unanimously agreed that there was a positive cumulative effect of the PD provided to educators, which also supported children and families' understanding of children's early math knowledge and the

FIGURE 5

Families' assessment of the impact of the YM-W materials.



importance of engaging them in playful math activities to support school readiness.

> *We have had richer conversations amongst staff, and this has translated directly into our work with families. We have had more intentional conversations with caregivers and play with children.*

These data provide promising evidence that this type of program can have significant positive effects on educators' attitudes toward math, attitudes toward teaching math, and confidence supporting fam-ilies to engage in math with young children.

Family Survey

To capture the experience of families involved with the partnership, we administered a survey at the end of each year. The data presented here is from the survey administered spring 2021 at the end of Year 2. It was available in English and Spanish. Of the 59 parents who responded, three-quarters of respondents were people of color and about half spoke a language other than English at home (17% Spanish; 5% Arabic; 5% Twi; 3% Albanian; 3% Urdu; and 2% for Bengali, French, Haitian Creole, Japanese, Mandarin, and Portuguese). More than two-thirds had children entering kindergarten in fall 2021; the rest were either entering public preK or continuing in Head Start or WFP.

Families' Attitudes Toward Mathematics

On the end-of-year family survey, families rated their math attitudes and reflected on their feelings about math at the beginning of the year. Findings showed significant positive increases in families' mathematics attitudes on all questions but one, *nervousness about helping their child with mathematics* (see Figure 4). While parents' nervousness went up slightly, it was not a significant change, and it could be explained by children having spent a year in remote or hybrid instruction during the pandemic. Many parents were feeling more nervous about their children's mathematics learning after a year and half of the pandemic.

Family Use of YM-W Games and Materials

Families were asked about their use of the YM-W games and materials as well as about the impact of the materials (Table 3). Of families who responded to the Year 2 survey, 82% used the YM materials that they received, and 74% of parents used them once a week or more.

As shown in Figure 5, nearly all the parent survey respondents (90%) who used the materials agreed that the materials helped them talk with their children about math, while 88% also agreed that the games and books helped them feel less anxious about math.

These findings provide evidence that the partnership promoted an increased understanding of the importance of early mathematics among educators and families and an increase in positive attitudes toward mathematics. Importantly, these findings help illustrate that a family math learning community can spark adults' interest in early mathematics and increase adults' comfort and knowledge of how to help young children learn math. In addition, the results suggest that playful early mathematics learning materials can support families' math talk with children, while also reducing families' math anxiety. The program supports the adults in children's lives to see the mathematics in everyday life and intentionally capitalize on these "math moments" to support children's learning.

Lessons Learned From a Successful Family Math Community

In this section, we discuss some of the key lessons we have learned from this partnership.

Responding and Adapting

A key component of the success of the partnership was our willingness to quickly change strategies in response to data and the ever changing COVID-19 crisis while keeping a clear focus on the overall mission. The leadership team met monthly to review qualitative and quantitative data from families and educators and revised our plans based on their needs. For example, when in-person classroom instruction for Worcester Head Start Programs and playgroups for the Worcester Family Partnership were shut down in March 2020 due to the COVID-19 pandemic, educators were concerned about how to work remotely with families who depend on their programs. Within a few weeks, we began virtual PD sessions and shared and discussed virtual mathematics instructional strategies and practices to keep children and families learning math at home. We used a web-based Learning Management System to provide online access to resources, discussion forums, and recordings of PD sessions.

Family-School-Community Triangle of Support

The partnership aligned children's informal and formal environments by recognizing the importance of their interconnectedness and building on each other's strengths. This teacher from Head Start recognized the key role that families play in children's learning and how teachers can provide the needed ingredients:

> *Families are fundamental in shaping children's interest and skills in math…We can give families ingredients, and motivation to support their young children's mathematical development effectively. Families can… provid[e] environments that are rich in learning. Families can teach children to see and name small quantities, count, add, subtract, and point out shapes.*

By strengthening the connections between home, school, and community learning environments, we can provide a more robust learning ecosystem for children.

Accessible and Engaging Mathematics for a Wide Range of Ages

Early in the partnership, we learned that for mathematics games to be engaging and easy to implement for families, they must be accessible and engaging for *all* members of the family—toddlers, preschoolers, elementary school–age children, caregivers, and grandparents—who want to play together. This was a design challenge that the members of the family math leaders and WFP educators were eager to take on. Starting with a prototype, they redesigned games to work better in multi-age environments. Learning from these lessons, we improved our design strategies with a focus on accessibility and adaptability. In addition, we found that playing mathematics games with adults can support their understanding of important foundational mathematics. For example, playful mathematics resources can remove some of the pressure of "doing it right" that teachers and families often feel about mathematics and provides an intuitive way of understanding and engaging children with mathematics. Mathematics games can also spark families' interest and enjoyment of mathematics and we noticed that they played an important role in helping families to see and intentionally capitalize on the mathematics in everyday moments, such as noticing shapes and patterns on a walk, using spatial language at the playground, or sharing treats fairly among friends.

Equitable Access to Mathematics for All Families

The partnership has worked on many strategies to provide access to more families. The Young Mathematicians website has game direction sheets and how-to-play videos in English, Spanish, and Portuguese, as well as other resources that visitors can browse and download at no cost. We are expanding a collection of family math text messages that provide family math ideas on a weekly basis. WFP and Head Start send home family math kits that are aligned with the scope and sequence of what they are teaching. In addition, based on their experience during the pandemic, they will continue to offer a mix of online and in-person learning opportunities to make it easier for families to attend.

The model we have developed supports adult learning about important early mathematical ideas through mathematics games and can be replicated by other programs. When thoughtfully implemented, mathematics games can provide a context for educative materials that provide a context for educators and families to practice and learn more about children's mathematical thinking.

Next Steps

The partnership has entered Year 3, and we are focused on sustainability and expansion. Two of the key components of sustainability are (1) including family math in curriculum planning throughout the school year and (2) coaching current and new staff. Both WFP and Head Start have included family math in their scope and sequence for the year and are planning family math kits to align with their lessons. We are working together to design a coaching program that can continue to be used once the project is over.

In terms of expansion, the partnership is going through a planning process to hear from families about the supports, tools, and touchpoints they currently engage with or would like to engage with to support their children's early mathematics learning. Expanding our work with the public school is a particular priority that we have identified.

Concluding Thoughts

As a family math community, we set a goal to foster positive attitudes toward mathematics and transform the way that families engage with their children around mathematics—making it a common and doable family activity, so that *all* children see themselves as STEM learners. The achievement of this goal may be best illustrated by one of our parent participants, Shemekia Pearson, who said as she reflected on her experience with Young Mathematicians:

> *Playing these games was quality time with my child, but it was quality time that I felt was beneficial to his todayandto his future… I see how confident he is in math, and it makes me feel proud.*

The YM-Worcester family math learning community exemplifies our strong belief in the benefit of bringing early childhood programs and families together in partnership so that all children have the opportunity to engage in meaningful mathematics across home, school, and community contexts. We hope that the model we have created can be useful to other communities seeking to promote these connections and increase learning opportunities for all children.

AUTHOR NOTE

For the sake of brevity, we sometimes use the word *parent* to refer to children's primary caregivers, but we recognize families come in many configurations, and the primary caregivers may be grandparents, aunts, uncles, older siblings, other family members, or guardians.

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REFERENCES

Bivens, J., E. García, E. Gould, E. Weiss, and V. Wilson. 2016. *It's Time for an Ambitious National Investment in America's Children: Investments in Early Childhood Care and Education Would Have Enormous Benefits for Children, Families, Society, and the Economy.* Economic Policy Institute.

Bronfenbrenner, U. 1986. Ecology of the family as a context for human development: Research perspectives. *Developmental Psychology* 22: 723–742.

Bryk, A.S., L.M. Gomez, A. Grunow, and P.G. LeMahieu. 2015. *Learning to improve: How America's schools can get better at getting better*. Harvard Education Press.

Claessens, A., G. Duncan, and M. Engel. 2009. Kindergarten skills and fifth-grade achievement: Evidence from the ECLS-K. *Economics of Education Review* 28 (4): 415–427.

Claessens, A., and M. Engel. 2013. How important is where you start? Early mathematics knowledge and later school success. *Teachers College Record* 115 (6).

Cross, C.T., T.A. Woods, and H.A. Schweingruber. Eds. 2009. *Mathematics learning in early childhood: Paths toward excellence and equity*. National Academies Press.

DeFlorio, L., and A. Beliakoff. 2015. Socioeconomic status and preschoolers' mathematical knowledge: The contribution of home activities and parent beliefs. *Early Education and Development* 26 (3): 319–341.

Friedman-Krauss, A.H., S. Barnett, K.A. Garver, K.S. Hodges, G.G. Weisenfeld, and B.A. Gardiner. 2020. *The state of preschool yearbook 2020*. National Institute for Early Education Research. https:/nieer.org/wpcontent/uploads/2021/08/YB2020_Full_Report_080521.pdf

García, E., and E. Weiss. 2015. *Early education gaps by social class and race start US children out on unequal footing*. Economic Policy Institute. https: /www.epi.org/publication/early-education-gaps-by-social-class-and-race-start-us-children-out-on-unequal-footing-a-summary-of-the-major-findings-in-inequalities-at-the-starting-gate/

García, E., and E. Weiss. 2017, Sept. 27. *Education inequalities at the school starting gate: Gaps, trends, and strategies to address them*. Economic Policy Institute. https: /www.epi.org/publication/education-inequalities-at-the-schoolstarting-gate/

Kurtz, H. 2020, April 10. National Survey Tracks Impact of Coronavirus on Schools: 10 Key Findings. Education Week. https: /www.edweek.org/teaching-learning/national-survey-tracks-impact-of-coronavirus-on-schools-10-key-findings/2020/04

Manning, C.F. 2022. *Young Mathematicians-Worcester* Final Evaluation Report. Cambridge, MA: Goodman Research Group, Inc.

Massachusetts Department of Elementary and Secondary Education. 2021. *School and district profiles: Worcester public schools*. https: /profiles.doe.mass.edu/general/general.aspx? topNavID=1andleftNavId=100andorgcode=03480000andorgtypecode=5

National Mathematics Advisory Panel. 2008. *Foundations for success: The final report of the National Mathematics Advisory Panel*. U.S. Department of Education.

Watts, T.W., G.J. Duncan, R.S. Siegler, and P.E. Davis-Kean. 2014. What's past is prologue: Relations between early mathematics knowledge and high school achievement. *Educational Researcher* 43 (7): 352–360.DOI: 10.3102/0013189X14553660

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Re-imagining the Role of Families as Equal Partners in STEM Learning

BY TARANA KHAN AND SUSANA BELTRAN GRIMM

Family engagement has been a focus for many programs largely due to children spending more time with their families during the first 10 years of life than in any other social context (Dotti Sani and Treas 2016). Families can set the tone for how children learn, which is especially true when learning about STEM. Just as family participation in early reading skills and exposure to books at a young age positively impacts the development of reading skills, early exposure to STEM concepts and activities for children through family STEM programs can be an important contributor to children's successful STEM learning outcomes (Haden et al. 2016). This is especially important because proficiency in some STEM skills, such as mathematics, predicts lifelong achievement (Hadani et al. 2018; Watts et al. 2018).

For example, children with a strong start in mathematics by age 5 have more tools available to them to problem solve and think critically—and are more likely to have a bright future ahead of them (Claessens and Engel 2013). However, the early mathematics knowledge gap is also most pronounced in children living in low-income neighborhoods, which are faced with low-quality formal school instruction, lack of parental education, and limited access to educational resources (Gandara and Contreras 2009; Lee and Bowen 2006; Rivas and Olmsted 2013; Suarez-Orozco 2013).

Effective and high-quality STEM family engagement should allow families to draw connections between their personal histories and everyday experiences. To do this, families should be included in the co-design process to have a voice and develop an identity as doers of STEM. PBS SoCal, Southern California's local public broadcasting station, started the Compton Family Math program, which was designed to support mathematics learning at home and was informed by families' needs and desires. Family Math, as defined by the emergent field of Family Math (Eason et al. 2020), is families' awareness of mathematical concepts in everyday contexts, enthusiasm for doing and learning math, and access to resources that support this engagement.

PBS SoCal Family Math Program

The PBS SoCal Family Math program encompasses a broad range of content, resources, and services aimed at changing neighborhoods through family engagement. The services and curriculum include introductory Family Math workshops, a Family Math Parent Academy, Family Math Learning Community Workshops, and digital bilingual videos and articles featuring math activities, recipes, and resources. The program aims to ensure access to culturally responsive math opportunities through physical and digital public media spaces available to all families.

One of the major tenants of our Family Math work is using co-design methodologies to integrate caregivers into their children's learning community and increase child and family mathematics positivity by offering fun learning opportunities and family workshops. Specifically, PBS SoCal aims to help families tie their understanding of math to their practice of math in the home. Families are central to supporting children's learning (Mapp and Kuttner 2013), yet creators of family engagement programs often fail to see their unique capabilities, specifically overlooking the contributions of disenfranchised Latino and Black families (Gonzalez et al. 2006; Nasir 2000; Taylor 2000). Many family engagement programs are designed without considering what families and children need and want (Jay et al. 2017; Marsh and Turner-Vorbeck 2010). Simply put, families often do not have a seat at the table.

PBS SoCal wanted to give families a voice by applying co-design principles to the development of the Family Math Parent Academy Curriculum to understand how families in Compton experienced teaching mathematics to their children. Borrowing ideas from the "Whole Teacher Approach" (designed by Dr. Jie-Qi Chen, founder of the Early Math Collaborative), the PBS SoCal Parent Academy sought to create a "Whole Home Approach." This approach uses clear, simple language to identify and explain math topics that are essential for kindergarten readiness, such as cardinality, spatial sense, and patterns. The "Whole Home Approach" allows families to discover that math-learning opportunities are everywhere in their homes, daily routines, and local communities, illustrating that math can be easy and accessible. With this in mind, PBS SoCal partnered with The Early Learning Lab to better understand which learning opportunities would be fun, easy, and engaging for Compton families to do at home to create a Family Math curriculum that resonates with diverse families in Compton.

Co-Design Thinking Process

Originally developed by the Stanford University Design School, co-design thinking focuses on understanding the needs of a person who experiences a problem, focusing on whether the proposed solution is effectively meeting their needs. Co-design approaches center user's voices—in this instance, families' voices (needs, wants, emotions, and values)—as experts to help co-create and co-design meaningful solutions to an issue (Fuad-Luke et al. 2015; Kang et al. 2015).

The approach is most effective when the person experiencing the issue becomes a part of the co-design process. This approach also seeks to challenge the imbalance of power often held within select groups of individuals by giving individuals a space to voice their concerns, build relationships, and encourage creativity (Gutiérrez and Jurow 2016), which is why a primary goal of the Family Math co-design process was to understand the barriers that prevent families from engaging with their children's learning at home. Co-design approaches with and for families can offer an opportunity for collaboration between schools, programs, and organizations to help create a meaningful and sustainable change in family engagement programs.

Family Math Activities

The ongoing partnership between PBS SoCal and Compton Unified School District was instrumental in recruiting families who were interested in participating in the co-design sessions. Community Resource Specialists at Compton Elementary schools helped recruit families and allowed the sessions to be hosted in a familiar and comfortable space for families that were located within their child's school. Participants were all mothers from Compton elementary schools, 88% Hispanic/Latino, 12% Black, and mostly bilingual or Spanish-only speakers. PBS SoCal staff developed the activities, which were designed to be culturally resonant with families and informed by their prior experience working with Latino and Black families. During the session, families tested prototypes of hands-on Family Math activities and provided their feedback.

Given that the majority of the Compton families that PBS SoCal connects with are Latino, many of the Family Math activities were designed to resonate with Latino or Spanish-speaking culture. In addition, the City of Compton is also home to a large percentage of Black families, making it essential that the Family Math activities are inclusive for families of all backgrounds. For example, families engaged with a modified *lotería* activity to explore concepts of counting and cardinality. *Lotería* is a traditional Mexican game of chance that is similar to the American game Bingo. Each parent received a colorfully illustrated game card that displayed 10 sets of traditional *lotería* images, such as trees, sunflowers, and watermelons, in quantities from 1 to 10. The object of the game was to count out loud while marking the spaces on the board with dry beans by finding the corresponding set of images that matched the number announced by the caller. Parents were encouraged to practice cardinality by emphasizing the last number to indicate the total number of items represented in the image.

Three mothers participate in a discussion with their table facilitator about how Family Math activities could fit into their busy schedules and routines. They also talk about various challenges to teaching math at home.

Feedback and Findings

Feedback from parents suggested that they enjoyed the competitive aspect of the game and believed it could be a fun way to practice basic counting skills with their children; however, they thought the game could benefit from some extra features. Parents enjoyed emphasizing the final number as a way to cue children to understand that was representative of the total number of objects. Many parents who had played *lotería* or Bingo appreciated the familiarity of the game and were genuinely pleased that a game that was already part of their culture could be adapted to help their child practice counting. Deeper discussions with parents and facilitators revealed that parents needed a better understanding of the learning objective prior to the start of the game so that they would remember that the focus of the game was to practice counting and cardinality. Some parents asked for additional options on how to make the game more challenging for older children. Families believed that the *lotería* activity could easily fit into busy schedules because it could be played on-the-go or at home because the materials were accessible and easy to carry. Overall, the *lotería* activity met all design principles because it

- helped parents become a curiosity guide,
- embedded "class-to-home" cues,
- helped parents understand how their child can learn the math concept,
- embedded cultural resonance for parents,
- was easy and simple enough for parents to understand and implement at home, and
- modeled playfulness for families (The Early Learning Lab 2020).

Overall findings from two design sessions, eight interviews, and follow-up surveys indicated that families enjoyed exploring culturally relevant, authentic, and meaningful math learning experiences along with their children. After delving into how families' culture, traditions, and everyday routines could become mathematics opportunities, findings showed that families were already practicing math-related activities at home, suggesting that existing routines and tasks could be incorporated into the Family Math curriculum.

It became clear that the success of the Family Math curriculum depended on the program's ability to help families overcome daily challenges. Examples of common barriers to helping their children with mathematics in the ways that they wanted included lack of time and energy, balancing multiple children's needs, finding ways to be creative with teaching, parent struggles with mathematics knowledge and confidence, and language barriers.

Follow-up interviews suggested that the Family Math design sessions may have helped families address some of the challenges they experience when teaching math at home to their children. Parents reported feeling confident in their ability to have math conversations at home after attending the design sessions. One mother described how the activities helped her talk to her children about doing math in less complicated and less stressful ways at home, implying that making math more fun could lessen anxiety some families feel about math (Herts et al. 2019). Parents were motivated to talk about how math can be used in several different aspects of life, suggesting that the design sessions helped families see the universal relevance of math. Simply having the materials to complete the activities allowed families to create space in their busy lives to learn and play with math. Parents enjoyed learning a variety of techniques to introduce math concepts, such as 3D shapes and counting, to their children. Parents found creative ways to include the materials provided by PBS SoCal or their own household objects in their math lessons, illustrating that the ingenuity of the design sessions inspired parents to feel more confident teaching math at home.

Family engagement programs like Family Math can mitigate barriers by inspiring families to see that learning opportunities exist all around them. By integrating co-design thinking methodologies, program providers and family engagement practitioners can engage in social design experimentation to develop family engagement programs that encourage social transformation for underserved families. Having Latino and Black families become co-creators of the family engagement programs will help amplify their voices as not only consumers of STEM but creators of STEM practices.

Five Steps to Implementing Family Design Sessions

Teachers, program providers, and family engagement practitioners can develop and implement hands-on design sessions that center around families' voices. Use the following five steps from The Early Learning Lab to co-design family engagement programs with families (The Early Learning Lab 2020). Read the full brief by The Early Learning Lab for more information.

Step 1: Define your inquiry

Figure out why a design session will be useful for your program by brainstorming a list of questions that build on the frame of inquiry. What do you want to know more about? How will this session help you learn this information? These questions should inspire the design team and open up possibilities for exploration. It is often helpful to visualize your questions using a whiteboard, flipchart, or shared document.

Step 2: Plan your design session

Assign roles for who will be responsible for each aspect of the design session, including project managers and design session facilitators. Project managers recruit, schedule interviews, gather consent forms, collect and synthesize data, and manage communication with facilitators. Facilitators design the activities, conduct interviews, and facilitate the sessions. Assistant facilitators take photographs, capture audio recordings, and help with other session logistics such as food, classroom arrangement, and technology issues.

Step 3: Develop Curriculum and Prototypes

Begin developing prototypes that will help you answer the inquiries established in Step 1. PBS SoCal sought to design a curriculum that builds on early math concepts and skills, takes advantage of children's natural curiosity, and is developmentally appropriate for early math learners. PBS SoCal designed four math activities that met the aforementioned criteria based on staff's prior experience working in communities that were made up of predominantly Latino and Black families. Efforts were made to make sure the curriculum resonated with family traditions and culture when possible.

Step 4: Create and execute a recruitment plan

Figure out which members in your community can help you best address your frame of inquiry. Identify participants that have varying perspectives regarding the focus of your design session. For Family Math design sessions, PBS SoCal sent parents a brief survey evaluating their confidence about teaching their child mathematics at home. We selected parents who had high, medium, and low levels of confidence to capture many different perspectives. Use connections with partner organizations to find participants who are the best match for the project because established networks usually result in more reliable recruitment and participation. Schedule brief phone conversations with parents in their preferred language before the design sessions to start building a relationship with them.

Step 5: Implement and follow up

Have multiple people assigned to observe and take detailed notes. Collect data from parents immediately and at least one week after participating in the design session. During the two-week follow-up, PBS SoCal asked parents how their conversations and activities changed at home since participating in the workshop. Other follow-up questions included whether participating in the workshop changed parents' views of how they can teach their child math at home and if they were able to try any of the activities at home. After participating in the workshop, 96% of mothers reported feeling very comfortable adapting the math activities for at-home use, suggesting that families saw the ease and potential for including the activities in their everyday lives. All parents reported trying at least one of the Family Math activities two weeks after the design sessions were completed. One mother reported that having the educational math materials from the session inspired her to help her son with his homework. Another parent discussed how the design session motivated her to do more math-related arts and crafts activities with her child using Family Math resources she took home.

Recommendations for Co-Designing Family Engagement Programs

Using a co-design approach to designing family engagement programs can help families feel supported and empowered to become leaders in their child's mathematics education. Provided are a few recommendations and guidelines based on PBS SoCal's co-design experience and The Early Learning Lab's core design principles that communities can use when designing family engagement programs (The Early Learning Lab 2020).

Listen to Family's Voices, Routines, and Culture

- When working with diverse communities, ensure that equity is at the center of designing culturally resonant family engagement to be inclusive of all families. Listen to families' concerns to design programs that break down the barriers that they face in supporting their child's learning at home.
- Families are busy! Carefully deconstruct and evaluate what families are already doing in their everyday routines to figure out how to inspire them with new ways to build in at-home learning experiences into the tasks they do on a daily basis.

Ensure Ease and Accessibility in Content for At-Home Use

- Make it easy and tangible for families to translate classroom lessons to home lessons by designing cues, tools, and activities to help them see the mathematics opportunities in what they are already doing at home with their children, such as when cooking or doing laundry together. Encourage families to be curiosity guides for their children by modeling how to integrate early mathematics talk and concepts into everyday activities.
- Ensure that the mathematics content and learning objectives are simplified for families so they can take the activity home and easily teach the same concept to their children. Model playfulness for parents so that they are inspired to bring the same energy at home.

Create Spaces for Communication and Collaboration

- Build spaces for peer-to-peer relationships through conversations and sharing of ideas and resources. Families enjoyed and benefited from the social and community aspect of the design session, suggesting that they love learning from one another.
- Develop supportive partnerships with school districts and other community organizations, such as nonprofit childcare centers or public libraries. Because these are institutions that families already trust, hosting workshops and parent design sessions within familiar spaces allow families to feel comfortable and safe and attend family engagement events at their convenience. Host sessions at different times in the day to accommodate different work and home schedules.

Concluding Thoughts

STEM programs, at present, tend to be conceived of and entrenched in silos of youth engagement, college and career readiness, and teaching improvement. However, several studies, including Rivas and Olmstead (2013), support the theory that family engagement is an essential tool for children's STEM success. Although there are several family engagement programs and resources to support early literacy skills (YaeBin and Teresa 2016), there is limited research on Family Math engagement (Eason et al. 2020). Most of the research so far has been about children's early math cognition instead of how low-income families can support and encourage these skills (Gibson et al. 2019; Holland et al. 2020). As a public media station, PBS SoCal is uniquely positioned to widely disseminate Family Math resources within the communities that helped us design our program and to organizations and practitioners who design family engagement programs for other low-income and ethnically diverse communities. Program providers and family engagement specialists can use these findings and co-design approaches to center family collaboration to transform children's learning. Being intentional in engaging families—especially those from different cultural backgrounds—can be the new solution.

AUTHOR NOTE

The authors of this article use the term *Latino* because the families in Compton choose to identify as Latino, rather than Latinx. Therefore, the term Latino is used to be more inclusive of the families PBS SoCal connects with through their family engagement services.

REFERENCES

Banse, H.W., D.H. Clements, C. Day-Hess, J. Sarama, M. Simoni, and J. Ratchford. 2020. Teaching moves and preschoolers' arithmetical accuracy. *The Journal of Educational Research*, DOI: https://doi.org/10.1080/00220671.2020.1846484

Children Now. 2018. https://www.childrennow.org/portfolio-posts/18reportcard/

Claessens, A., and M. Engel. 2013. How important is where you start? Early mathematics knowledge and later school success. *Teachers College Record* 115 (6): 1–29. http://www.tcrecord.org/Content.asp?ContentId=16980

Dotti Sani, G.M., and J. Treas. 2016. Educational gradients in parents' child-care time across countries, 1965–2012. *Journal of Marriage and Family* 78 (4): 1083–1096. https://doi.org/10.1111/jomf.12305

The Early Learning Lab. 2020. *Designing family math: A case study*. Published online July 2020. https://earlylearninglab.org/designing-family-math-pbssocal-case-study/

Eason, H.S., N.R. Scalise, T. Berkowitz, B.G. Ramani, and C.S. Levine. 2020. *Reviewing the family math literature: Recommendations for practice, policy, and research*. Purdue University. https://educationfirst.com/wpcontent/uploads/2020/06/FamilyMathReview_WhitePaper.pdf

Fuad-Luke, A., A.-L. Hirscher, and K. Moebus. 2015. *Agents of alternatives: Re-designing our realities*. Berlin: Agents of alternatives e.v. http://www.otherspaces.net/wp-content/uploads/pdf/TPSB_AgentsOfAlternatives.pdf

Gándara P., and F. Contreras. 2009. *The Latino education crisis: The consequences of failed social policies*. Cambridge, MA: Harvard University Press.

Gibson, D., T. Berkowitz, and S.C. Levine. 2019. Designing effective number input: Lessons from cognitive science. In *Learning in the Digital Age: Towards a Science of Learning for 21st Century Education*, eds., P.K. Kuhl, S.-S. Lim, S. Guerriero, and D. van Damme. 2019. Educational Research and Innovation, OECD Publishing, Paris. https://doi.org/10.1787/562a8659-en

González, N., L.C. Moll, and C. Amanti, Eds. 2006. *Funds of knowledge: Theorizing practices in households, communities, and classrooms*. New York, NY: Routledge.

Gutiérrez, K.D., and A.S. Jurow. 2016. Social design experiments: Toward equity by design. *The Journal of the Learning Sciences* 25 (4): 565–598.

Hadani, H.S., E. Rood, A. Eisenmann, R. Foushee, Garrett Jaeger, Gina Jaeger, J. Kauffmann, K. Kennedy, and L. Regalla. 2018. *The roots of STEM success: Changing early learning experiences to build lifelong thinking skills*. Bay Area Discovery Museum.

Haden, C.A., E.A. Jant, P.C. Hoffman, M. Marcus, J.R. Geddes, and S. Gaskins. 2016. Supporting family conversations and children's STEM learning in a children's museum. *Early Childhood Research Quarterly* 29 (3): 333–344.

Herts, J.B., S.L. Beilock, and S.C. Levine. 2019. The role of parents' and teachers' math anxiety in children's math learning and attitudes. In *Mathematics anxiety: What is known and what is still to be understood*, eds. I.C. Mammarella, S. Caviola, and A. Dowker, 190–210. London and New York: Routledge.

Jay, T., J. Rose, and B. Simmons. 2017. Finding "mathematics": Parents questioning school-centered approaches to involvement in children's mathematics learning. *School Community Journal* 27 (1): 201–230.

Kang, M., P. Choo, and C.E. Watters. 2015. Design for experiencing: Participatory design approach with multidisciplinary perspectives. *Procedia - Social and Behavioral Sciences*, 174, 830–833. https://doi.org/10.1016/j.sbspro.2015.01.676

Lee, J.-S., and N.K. Bowen. 2006. Parent involvement, cultural capital, and the achievement gap among elementary school children. *American Educational Research Journal* 43 (2): 193–218.

Mapp, K.L., and P.J. Kuttner. 2013. *Partners in education: A dual capacity-building framework for family-school partnerships. US Department of Education & SEDL*. Retrieved from https://www2.ed.gov/documents/family-community/partners-education.pdf

Marsh, M.M., and T. Turner-Vorbeck. 2010. *(Mis)Understanding families: Learning from real families in our schools*. New York: Teachers College Press.

Nasir, N.I.S. 2000. "Points ain't everything": Emergent goals and average and percent understandings in the play of basketball among African American students. *Anthropology & Education Quarterly* 31 (3): 283–305.

Rivas, L.M., and D. Olmsted. 2013. Be a scientist: Family science for minorities. Paper presented at 2013 ASEE Annual Conference. The Nation's Report Card. 2011. https://nces.ed.gov/nationsreportcard/pdf/main2011/2012457.pdf

Suarez-Orozco, C., and M. Suarez-Orozco. 2013. Transnationalism of the heart: Familyhood across borders. In *What is parenthood?* eds, D. Cere, and L. McClain, 279–298. New York: New York University Press.

Taylor, E.V. 2000. Multi-unit conceptual understanding in low-income African-American first and second grade students: The influence of currency knowledge. In annual meeting of the American Educational Research Association, New Orleans, LA.

Watts, T.W., G.J. Duncan, D.H. Clements, and J. Sarama. 2018. What is the long-run impact of learning mathematics during preschool? *Child Development* 89 (2): 539–555.

YaeBin, K., and B. Teresa. 2016. Community-based family literacy program: Comparing different durations and family characteristics. *Child Development Research*, 2016. https://doi.org/10.1155/2016/4593167

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Creating Pathways for Equity in STEM Through Family Engagement

Highlighting the Experiences of Hispanic/Latine Youths

BY REMY DOU AND HEIDI CIAN

"La historia de uno mismo no es autorreferencial ni autónoma, sino dada a través de la comunidad y la relación con los otros.

[An individual's personal story is neither self-referential nor autonomous but given through their community and relationship with others.]"

– José Francisco Zárate Ortiz

As social creatures, we develop a sense of who we are by interacting with others. This self-perception can change as our social settings change. At home we might see ourselves as parents, at work we might play the role of a technical expert, and when listening to friends we might see ourselves as advisors. Quite often we juggle our various identities at the same time, each of which is in a dynamic, never-ending process of change and development. Challenges arise when our multiple ways of being conflict as a result of social pressures—for instance, when a doctor has religious misgivings about performing certain procedures or when someone with a male gender identity wants to enter a career historically perceived as feminine, such as early childhood education. In situations like these, identifying as a member of one community could make it hard to feel welcome in another. These "rules" of what kind of person belongs in a particular community are typically established by its existing members and communicated through their interactions with outsiders, often leading to a cycle where the same kinds of people are accepted by the community and the "rules" become more entrenched.

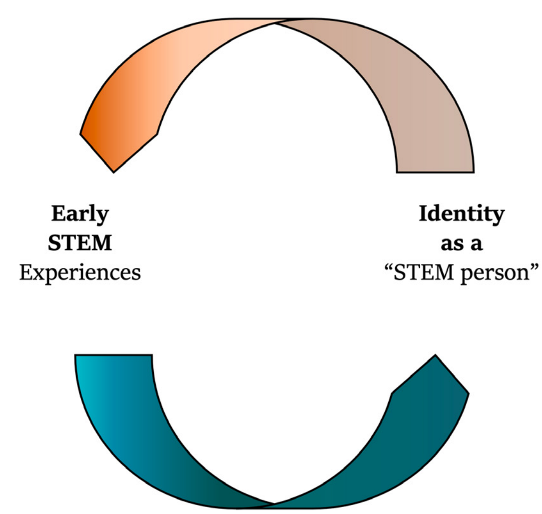
In STEM fields in the United States, this challenge of being seen as "one of the group" faces many individuals—particularly women and people of color—who have a hard time seeing STEM as a place where they belong. There are several reasons for this, including the way we highlight "heroes" of science and mathematics, typically praising the accomplishments of white men and suppressing the contributions of others. Simply ask a group of youths or adults to name a scientist or mathematician to reveal their unconscious perceptions of the ideal archetypes in these fields; many will likely name Einstein, Tesla, Newton, Pascal, and (occasionally) Marie Curie. Although some of these famous individuals faced challenges of their own, this list fails to reflect the important STEM contributions of Latin American, Black or Afro-Caribbean, Asian, and other ethnic groups. These false ideals of what a STEM person "looks like" (i.e., white and male) further extend into recreational settings, including the way the media portrays STEM professionals. Inequities observed in popular culture reflect deeper issues of prejudice and racism that have plagued specific STEM fields, keeping women and people of color from participating equitably despite national attention on these problems (National Science Board 2020). Some researchers and practitioners are considering new ways to highlight unequal distributions of power in STEM contexts by exploring how individuals come to see themselves as science and/or math people—ultimately aiming to use what they learn to redesign STEM programs to be more inclusive of individuals who do not identify as male or white.

Though the important role that parents play in children's STEM learning is broadly appreciated, the unique ways parents of minoritized youths encourage the development of their children's STEM identity is largely under-realized. Given the relationship between how we are socialized and the development of our identities, the value of parental contributions makes intuitive sense—most children interact with their parents more frequently and intimately than anyone else. Thus, children's earliest sense of who they are is constructed through parental interactions, like when a parent expresses delight in seeing their child's artwork and recognizes their artistic traits or places books prominently in their child's bedroom, implicitly communicating family values around literacy. Because families necessarily share many identities with their children (e.g., ethnic, cultural, religious), they can authentically communicate to their children that someone "like them" could participate in STEM. In the safe space of the home, parents can provide children the ability to explore identities that they may not be able to elsewhere, such as a Hispanic/Latine physicist or a gender non-binary biologist. In other words, family members have the power to affirm and reinforce minoritized children's sense that they can meaningfully participate in STEM by providing a space where their diverse identities can coexist and be recognized as legitimate. As we discuss in this article, parents can (and do) create these spaces and experiences regardless of their education, economic status, and immigration status.

To make this case, we draw from our research project, "Talking Science," which explores Latine parents' everyday science talk with their children to highlight how parents work to make STEM "normal" in their homes (i.e., establish STEM *dispositions*), as well as give and acquire STEM resources (i.e., *capital*) to support their children's identification with STEM (see Figure 1). We make the case that understanding how parents do these things is essential to our efforts as practitioners to dismantle structures and

FIGURE 1

Relationship between experiences and identity. Early experiences contribute to STEM identity, which in turn leads to more STEM experiences.



systems that perpetuate racial and ethnic inequalities in STEM. We also offer some recommendations for how this information can be put to use.

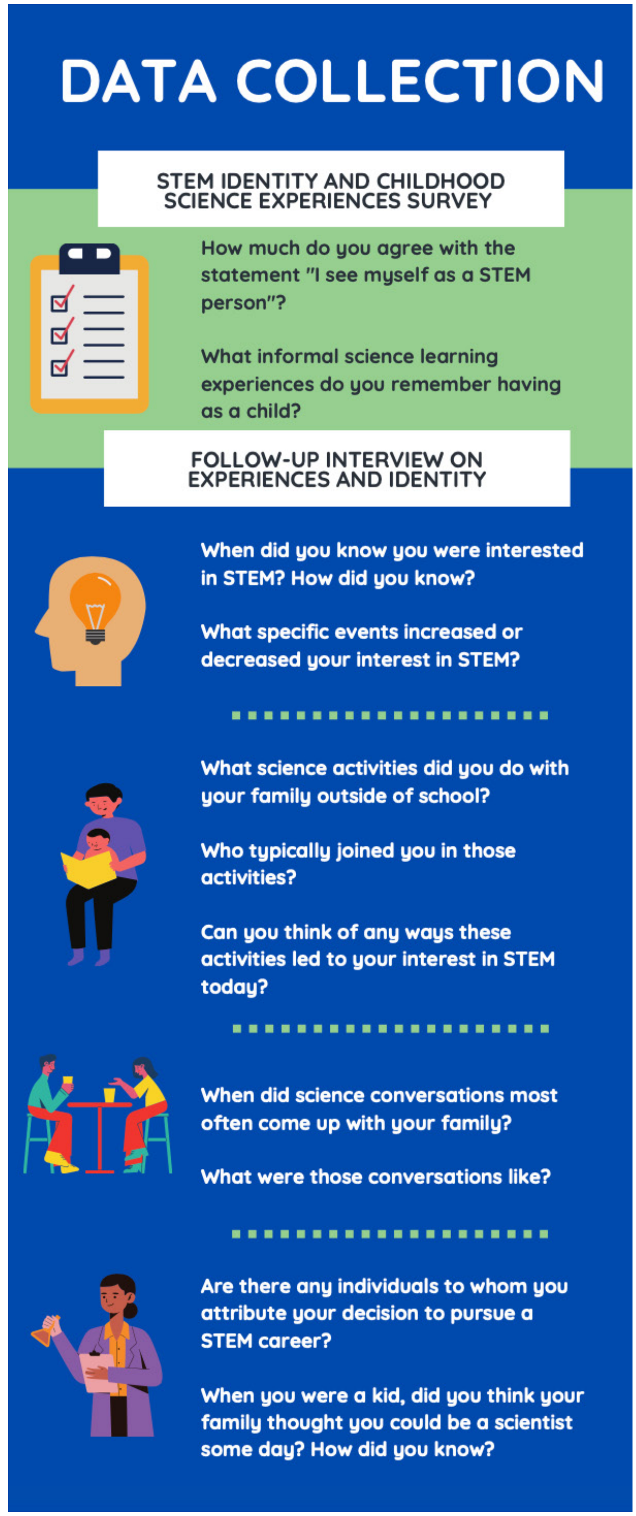
A Little Bit of the Past

"Talking Science" was born out of an exploration of the links between informal STEM learning experiences and STEM identity. Our interest in these topics was predicated upon findings that college students who identify as a STEM person have a 21.7 times higher odds of pursuing a career in STEM than students who do not see themselves that way (Dou et al. 2019). Drawing from awareness that STEM identity can be developed outside of school, Dou and his colleagues wanted to explore how much certain kinds of childhood experiences (i.e., those that took place between the ages of 5 and 9) may have contributed to college students' self-perceptions within STEM (see Figure 1). To do this, they analyzed survey data from over 15,000 college students across the country—representing a variety of contexts and majors—asking them to select from a list the kinds of STEM experiences they had as children, including tinkering with electronics, mixing chemicals, participating in science camps or competitions, taking care of animals, and talking with friends or family about science. When they reviewed the responses, they noticed that none of the experiences they asked about related significantly to STEM identity except talking with friends or family about science.

According to this finding, individuals who thought of themselves as STEM people in college—regardless of their gender, race, ethnicity, family support, prior interests, and even secondary math and science performance—were also likely to have recalled talking to friends and family about science when they were children. Although this relationship does not necessarily mean that talking about science at home causes increases in STEM identity, practical interventions that are aimed at identity-related outcomes have endorsed the possibility that promoting family talk around STEM topics could be an important contributor. For instance, the STEM Next Opportunity Fund encourages program developers and practitioners they work with to think about how to foster STEM-related conversations within families both at their institutions and in the home (Kekelis and Sammet 2019). Yet, more needed to be learned about what effective conversations sound like and whether specific conversational characteristics stand out as meaningful in children's development, especially children who come from Hispanic/Latine households. This population faces unique

FIGURE 2

Sample of data collection items. Survey items were forced-choice and interview questions were open-ended.



barriers to participation in STEM in the United States due to inequitable access to quality education and systemic structures designed to exclusively promote the knowledge and values of the dominant culture (Flores 2008).

With this objective in mind and funding from the National Science Foundation, our five-year "Talking Science" project kicked off. The focus of "Talking Science" is neither school experiences nor informal learning environments, like science centers or makerspaces, but rather the learning setting children encounter the most: the home, where children learn many of their values, dispositions, and attitudes (Archer et al. 2015). Its aim is to explore the context, content, and structure of childhood conversations that contribute to young people's STEM identity development—particularly those who identify as Hispanic/Latine. In 2019 we began our work to get to know the family STEM experiences of Hispanic/Latine college STEM students (Figure 2), as well as elementary school–age children. Here, we focus primarily on what we learned from talking with college STEM students, which has informed our interviews with young children, and make recommendations for how those formative experiences can be made available through programming.

Some Important Context

Before we share our findings and recommendations, it is important to understand more about who our participants were in relation to the ideas we are exploring. Over 65% identified as female and Hispanic/Latine; 47% grew up in Spanish-speaking homes, and many described having recent family immigration histories (i.e., first, second, or third generation). Nearly all respondents were STEM majors, most of whom were successful STEM majors who had completed their first college year and were still pursuing a STEM degree; many Hispanic/Latine individuals who start college as STEM majors end up switching majors (Riegle-Crumb et al. 2019). Many (almost 70%) also came from homes supportive of science. Though here we categorize these individuals under a single banner, "Hispanic" or "Latine," we are careful to keep in mind the cultural differences both across and within Hispanic/Latine communities. For example, since our research took place in South Florida where most of our participants grew up, it is important to note that the experiences of Cuban-Americans will generally differ from those of other groups given the sociopolitical and historical factors that have shaped Cuban communities in South Florida. It is in this acute awareness of the differences between our participants that we situate the significance of the shared experiences of most—if not all—who sat down to talk with us.

What Have We Learned So Far?

Data for our study come from surveys of over 500 students and follow-up interviews with 20 students. Figure 2 shows sample items and Figure 3 outlines the process of data collection and analysis.

FIGURE 3

Sequence of data collection and analysis. Surveys were used to identify interview participants.

STAGES OF RESEARCH

Survey sent to students

STEM identity survey sent to over 5,000 students majoring in STEM fields

Examined responses

Looked for experiences closely associated with STEM identity

Identified interviewees

Invited respondents with diverse experiences to interview

Conducted interviews

Asked interviewees to reflect on how their interest in STEM developed

Analyzed interviews

Focused our analysis primarily on family-child interactions

Drawing from these data, we describe three relevant factors that stand out as ways that parents facilitate access to STEM for their children and support the development of their STEM identities:

1. Parents *transfer* STEM capital.
2. Parents *convert* general capital to acquire STEM capital.
3. Parents *establish* STEM dispositions within the household.

By "capital" we mean the tangible and intangible resources that individuals, including parents, draw upon to interact with the world in desired ways. Capital includes various forms of knowledge, financial, and social resources (Bourdieu 1986). "STEM capital" refers to these resources as they relate to STEM, such as knowledge about STEM topics, access to spaces like science centers, and relationships with people who work in STEM (Archer et al. 2015).

1. Parents transfer STEM capital.

One of the most obvious ways parents support their children's STEM engagement is by directly providing STEM-related resources. For many of our participants this came in the form of knowledge—one or both parents directly sharing information they knew about a STEM topic. This happened even when neither parent held a STEM degree or worked in STEM, suggesting that outside of traditional schooling or training parents picked up STEM knowledge relevant to family conversations. Many participants recalled parents enthusiastically expounding on their knowledge of specific topics when opportunities arose through everyday events like watching a science or science fiction television program, going to the beach, completing homework, or experiencing a thunderstorm. Participants recalled their parents not only sharing what they knew but also engaging with them by asking questions or encouraging them to find more information. While all our interviewees, regardless of gender identity, recalled having these kinds of conversations, their stories almost always attributed the role of STEM-knowledge expert to their fathers or paternal guardians, even in cases where parents had separated.

2. Parents convert general capital to acquire STEM capital.

Parents find ways to leverage the general forms of capital they possess (e.g., finances, friends, understandings of the education system) to gain access to and transfer STEM capital to their children. We heard many stories of how parents used money to support or encourage STEM interests by buying tangible materials, such as science activity kits and books, or purchasing admission to informal STEM learning institutions like museums. Participants also described many cases in which their parents contacted friends or relatives in STEM careers—some of whom lived outside the United States—to ask for guidance on science and math homework or STEM career pathways. For example, Allie, a second generation Mexican-American and aspiring dentist, remembered a time when her mother used personal connections to get her an internship at a dental office. Others vividly recalled their mothers' persistence in fighting for them to have access to high-quality education by researching area schools or advocating for their access to advanced courses. Saffi, a student whose family had moved to South Florida from Puerto Rico, recounted that her mother did a lot of research and reflected on her older children's academic experiences to identify the right schools for her. As evident in Allie and Saffi's experiences, the role of converting existing capital (e.g., financial, social) into STEM-related resources also tended to fall along gender-based patterns, with most of this work being done by maternal caregivers.

3. Parents establish STEM dispositions within the household.

Through various means parents establish household "dispositions," or ways of thinking, behaving, and sense-making (Archer et al. 2015). Family STEM dispositions are these norms in relation to STEM fields, such as tendencies to want to explore scientific questions or consideration of visiting a science museum as a fun way for the family to spend a Saturday. Many of our participants' childhood stories suggested their parents communicated these dispositions implicitly by encouraging them to talk about what they learned in their STEM classes, expressing wonder at what they knew, and/or asking questions to encourage them to share more. Selena, a first-generation Cuban American, reflected how doing STEM activities with her mother and grandmother, like watching science movies, influenced her affinity toward STEM, commenting, "Since I saw that all people who I love were interested in it, it made me also be like, 'Oh, this is normal, like, this is what's expected of me.'"

In some cases, parents were more direct. Mary remembered being encouraged by her parents when she became frustrated with her STEM studies to the point that she wondered whether she should quit her career pursuits. She specifically remembered her parents verbally affirming her strengths and reminding her of past success, telling her, "You're already doing it and you're doing well ... Of course you can keep going. What is going to stop you?" Mary attributed that message, at least in part, to her parents' own history, reflecting, "They like science so much and they liked medicine but they were never able to pursue it themselves."

Capital and Immigration

Given that many of our participants also described themselves as first- or second-generation migrants, we must consider how this context contributed to the ways parents transfer or leverage their capital. As evidenced in the narratives of our participants, especially those with recent immigration histories, their families held forms of capital valued in their home countries, such as dominance of the Spanish language or STEM degrees, but many found that those were not valued the same way in the United States. Thus, some struggled to find jobs because of their inability to speak English fluently, encountered professional systems that refused to recognize their education credentials, or struggled to support their children's studies even when they knew the material because their strategies differed from the way their children were being taught. Our participants recalled how these types of obstacles hindered their parents' ability to transfer or convert capital. Yet, they also recalled finding other forms of support to participate in STEM from another parent, a caregiver, family friend, or teacher—a luxury not all young people have.

We must also account for the sociopolitical forces that can shape migrant families' abilities to mobilize their resources. Building off our earlier example, the 50-year-plus history of US-Cuban affairs has contributed to a large and growing population of Cuban Americans such that recent migrants often find communities with shared values or family with resources they can leverage. The recent influx of families fleeing the economic and political turmoil facing Venezuelan nationals has generated similar support communities in Florida (Noe-Bustamante et al. 2019). This is not the case for all Hispanic/Latine families, nor does being a Cuban or Venezuelan national guarantee these forms of support.

The multiple recollections of our college-age Hispanic/Latine participants impress upon us that regardless of their parents' facility with the English language, their STEM education history, or their professions, one or both parents found ways to further their children's STEM interests and pursuits. They did so in the midst of challenging circumstances, and their college-age children attributed their place within STEM—at least in part—to the conversations and experiences they had with their parents during childhood. This insight gives us reason to believe that pathways exist that invite Hispanic/Latine youth to participate in STEM through family engagement.

Practical Recommendations

The ways parents transfer and convert capital, as well as communicate family dispositions and values, play important roles in the development of their children's STEM identity. In doing so parents

- expose children to STEM and STEM role models;
- affirm their children's interests in STEM while reinforcing their own;
- provide access to settings where children can develop their STEM knowledge, skills, and confidence;
- positively recognize their children's engagement; and
- connect children with resources that increase their sense of agency within STEM—all of which are direct and indirect shapers of STEM identity.

When we think about engaging families to promote these efforts—particularly when working with families from minoritized groups—ideas often center on how to more equitably distribute certain prized forms of capital. However, that is only part of the problem and overlooks some ways that access to STEM can be expanded by understanding how families are using capital they have. With this in mind, we can begin to identify a few important recommendations for practitioners to consider, especially when developing programming aimed at supporting STEM identification for Hispanic/Latine children: (1) account for the different ways that maternal and paternal caregivers tend to engage with their children, (2) recognize and avoid a deficit capital mindset, and (3) extend programmatic goals to include influence on family dispositions.

1. Account for the different ways that maternal and paternal caregivers tend to engage with their children.

Although we did not directly ask participants whether their maternal caregivers interacted with them differently than their paternal caregivers, these gender-based differences stood out in their responses to our questions and sometimes extended to other family members, as well. Specifically, maternal caregivers were more likely to engage in capital conversion—using one form of capital to gain access to STEM capital, like buying a book or asking a friend who is a STEM professional to talk to their child about career pathways. Paternal caregivers were more likely to transfer STEM capital by answering questions using information they already knew about topics their children were curious about. Knowing this, programs aimed at increasing parental participation in children's STEM engagement should consider creating opportunities that cater to these two different approaches. While avoiding stereotypes, family engagement programs should include activities that both invite caregivers to contribute their existing knowledge and connect them to resources they could turn to when seeking STEM-related experiences for their children (e.g., scholarships, homework help, additional programming). These activities need not address both approaches simultaneously, but may be part of a suite of activities.

2. *Recognize and avoid a deficit capital mindset.*

In general, when thinking about creating opportunities for underserved or marginalized groups, we tend to think of ways to reduce costs or other barriers that we believe limit their participation. If we stop here without reflecting on differences in community and institutional capital, we run the risk of growing frustrated when, in spite of accommodations, these communities do not engage with our programming. Even when these approaches are successful, they are not always sustainable; more importantly, they fail to take into account existing capital in these communities. Instead, we should make efforts to recognize and leverage forms of capital valued within those communities. A simple approach might include embracing satellite programming that takes place at local schools, libraries, or community centers that families are already familiar with and whose staff they trust. A more involved approach could include grassroots program development where developers work with community leaders to better understand the types of STEM topics and issues the families they serve engage with on a day-to-day basis. In doing so, developers can gain insight for designing activities that are not only relevant but also allow families to contribute (and build upon) the STEM knowledge they have gained through their own lived experiences. This insight can also be applied to exhibit development, such that exhibit themes can reflect the topics, issues, perspectives, and languages relevant to and inclusive of families in those communities.

3. *Extend programmatic goals to include influence on family dispositions.*

If a child is interested in STEM but is only able to explore that interest in institutional settings, engagement may wane, especially if experiencing STEM in informal learning spaces is a rare treat (e.g., on a school trip or through exceptional admission fee waivers). When thinking about how to sustain children's interest and engagement in STEM—which are critical for developing a positive STEM identity—it is essential to include the family context. The development of interest in STEM, particularly for young children, is not an individualistic process but rather a family affair (Pattison and Dierking 2019). Outreach aimed at promoting STEM identity in underserved youths should not limit itself to inspiring STEM engagement with children alone. Parents should also be involved, and programs should aim to not only motivate (and evaluate) children's STEM interest and identity but also their parents'. This may require accounting for the demands placed on parents and how those demands may make involvement difficult if involvement is only possible in the traditional sense (e.g., during work hours). For instance, families can be presented with activities to do at home that leverage topics that resonate with family values while extending what their children learn through programming.

Conclusion

Every day we see the joy that individuals of all ages and backgrounds experience when they are able to explore the natural world in ways that inspire wonder. We see it as our responsibility to make sure these types of experiences are available to everyone in our community, and perhaps especially accessible to those who do not often see themselves represented in STEM. Though it can be difficult to figure out how to do this, the findings from our research—which we are beginning to see reaffirmed through our interviews with elementary-age children—show that STEM identity is supported in cases where parents are willing and able to transfer or convert their resources to support their children's STEM-related experiences. This should urge us as practitioners to critically examine how we design and evaluate our programs by accounting for family capital and dispositions. While we may assess program outcomes and find positive changes in children's attitudes toward STEM and skills or interest in STEM topics, long-term sustainment must involve engaging and exciting parents in ways that embrace their values and the goals they envision for their children. These efforts, which entail more than quick-fix solutions, such as lowered admission cost, require out-of-the-box, collaborative thinking that involves community members and organizations.

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AUTHOR NOTE

Here the term "Latine" (la-ti-ne) is used as a gender-neutral reference to individuals who identify primarily with Spanish-speaking cultures of Latin America, including the Caribbean. We recognize that in practice this may include individuals who identify only as "Hispanic" or those who speak Brazilian Portuguese. While no term is perfect, unlike the terms "Latinx" and "Latin@", the origins of the term "Latine" are rooted in Latin American social movements and its use is more congruent with a Spanish-language pronunciation.

REFERENCES

Archer, L., E. Dawson, J. DeWitt, A. Seakins, and B. Wong. 2015. "Science capital": A conceptual, methodological, and empirical argument for extending bourdieusian notions of capital beyond the arts. Journal of Research in Science Teaching 52 (7): 922–948.

Bourdieu, P. 1986. The forms of capital. In: Richardson, J., Ed. Handbook of Theory and Research for the Sociology of Education, pp. 241–258. Greenwood.

Dou, R., Z. Hazari, K. Dabney, G. Sonnert, and P. Sadler. 2019. Early informal STEM experiences and STEM identity: The importance of talking science. Science Education 103 (3): 623–637.

Erel, U. 2010. Migrating cultural capital: Bourdieu in migration studies. Sociology 44 (4): 642–660.

Flores, G.M. 2008. America's competitiveness, Hispanic participation in technology careers summit report: Increasing Latino participation in science, technology, engineering and mathematics (STEM) Careers. Armonk, NY: IBM Corporation.

Kekelis, L., and K. Sammet. 2019. Family engagement: Taking it to the next level. STEM Next Opportunity Fund. Retrieved from https://stemnext.org/wp-content/uploads/2018/07/Case-Study-Taking-it-to-the-Next-Level-1.pdf

National Science Board. 2020. The State of US Science and Engineering 2020. National Science Foundation, January, 15.

Noe-Bustamante, L., A. Flores, and S. Shah. 2019. Facts on Hispanics of Venezuelan origin in the United States, 2017. Pew Research Center. Retrieved from https://www.pewresearch.org/hispanic/fact-sheet/u-s-hispanics-facts-on-venezuelan-origin-latinos/

Pattison, S.A., and L.D. Dierking. 2019. Early childhood science interest development: Variation in interest patterns and parent–child interactions among low-income families. Science Education 103 (2): 362–388.

Riegle-Crumb, C., B. King and Y. Irizarry. 2019. Does STEM stand out? Examining racial/ethnic gaps in persistence across postsecondary fields. Educational Researcher 48 (3): 133–144.

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