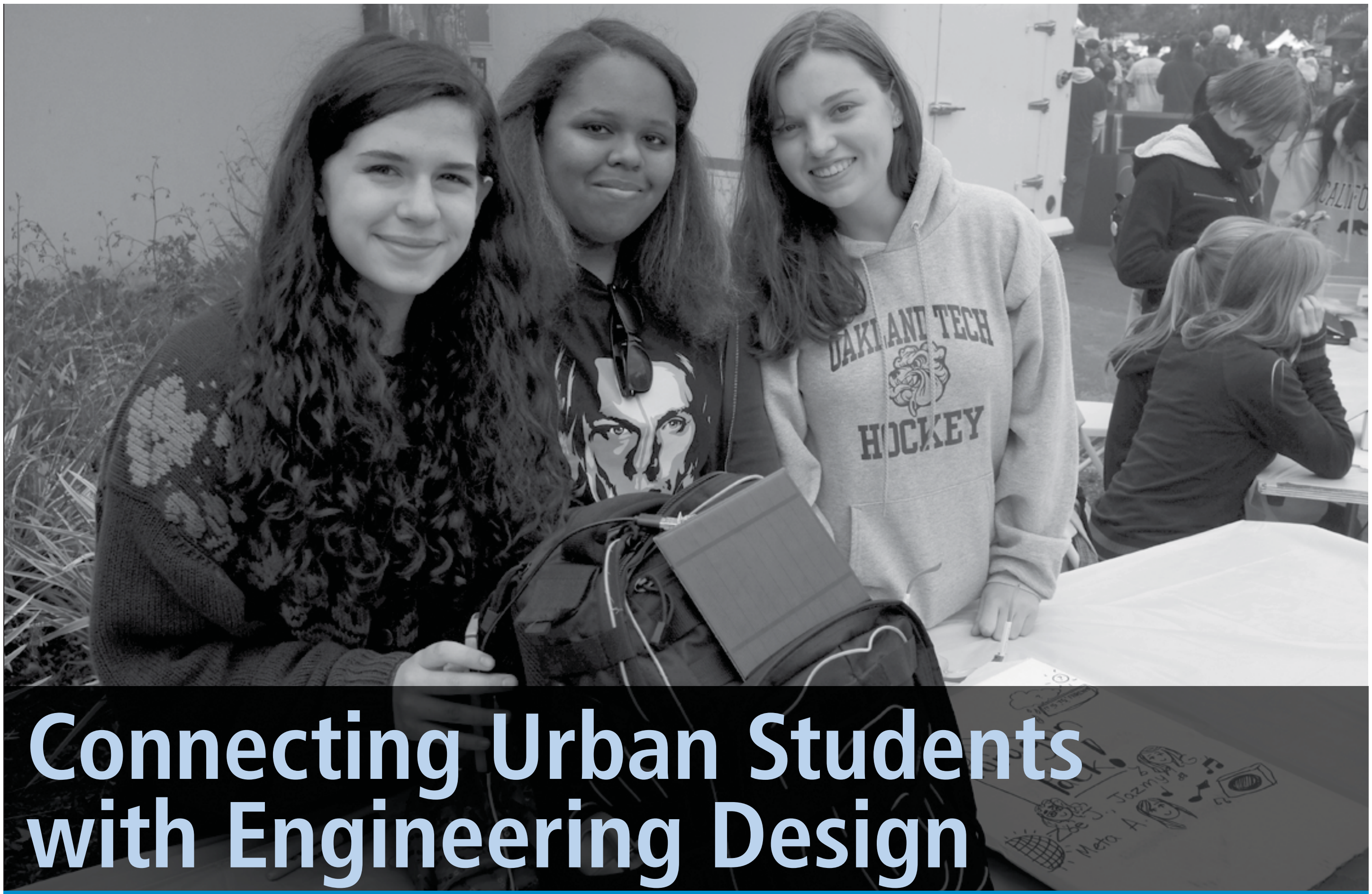

Connecting Urban Students with Engineering Design

Community-Focused, Student-Driven Projects

Carolyn Parker, Catherine Kruchten, and Audrey Moshfeghian

> "Test it, and you gotta figure out what's the problem, like, if I build the rain barrel, … and I test it out with the filter, … and then see if … the polluted water comes down and see if it can works, turn it to clean water. And if we see it does not … I gotta figure out, "What's the main problem?" So I gotta think that, it's the filter's problem, or just the water's problem…. So I gotta check the filter. And then you take it out and then see what's wrong with it, and then figure out and then can improve it."

Tamitha, a fifth grader, explains engineering concepts after participating in the out-of-school time (OST) part of STEM Achievement in Baltimore Elementary Schools (SABES) for two years. Other participants offered similar ideas. Our study of this OST program, focused on science, technology, engineering, and mathematics (STEM), suggests that community-focused student-driven projects can help low-income urban elementary students develop an understanding of the engineering design process (EDP). OST STEM programs have been found to engage students and enhance interest in the

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STEM fields (Dynarski et al., 2004; James-Burdumy, Dynarski, Deke, Mansfield, & Pistorino, 2005). STEM-focused OST programs often support student-centered learning more than does in-school education, which is often driven by national or state standards and assessment requirements (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003; Rennie, 2007).

Student-Driven Projects

Rennie (2007) notes that OST environments provide learning opportunities in which the curriculum is student-centered, attendance and involvement are voluntary, and program activities are not evaluative or competitive. The informal setting "is learner-led and intrinsically motivated, rather than teacher-led and extrinsically motivated" (Rennie, 2007, p. 127). The student-centered, voluntary, nonevaluative nature of OST settings can make them better able than schools to bring the product and processes of STEM learning to students and to integrate STEM into their lives.

This integration is particularly important in low-income urban settings, where many students perceive STEM as disconnected from their own experiences (Basu & Barton, 2007). Brickhouse (1994) attributed the disconnect to a narrowly defined scientific way of knowing that separates science from students' personal experience. Seiler (2001) characterized the disconnect this way: "We were battling our own and others' perceptions that science is a collection of facts laid out in a book and not a collection of topics connected to everyday lived experiences" (p. 1007). To resolve this disconnect, Roth and Lee (2004) suggest that educators "organize learning environments that allow students to become knowledgeable by participating in and contributing to the life of their community, which has the potential to lead to lifelong participation and learning" (p. 264). In particular, Basu and Barton (2007) found that when low-income urban "students encountered science classrooms in which they could choose and engage in activities connected to their visions of the future . . . they developed a strong, long-term commitment to pursuing science" (p. 487).

When they start early with engineering practices and design process thinking, students develop important skills—such as communication, collaboration, inquiry, problem solving, and flexibility—that form the foundation for their educational and professional lives.

Engineering Design

Historically, engineering has not been a prominent component of K–12 education. The Next Generation Science Standards (NGSS Lead States, 2013) are seeking to change this reality by introducing an integrated approach to STEM learning. In the new framework, engineering and design constitute one of the four disciplinary core ideas, along with Earth and space science, life science, and physical science. The practice of engineering, with explicit connections to professional engineering practice, is likewise emphasized. The crosscutting concepts in NGSS enable students to integrate the sciences and engineering, reinforcing the close relationships between the disciplines and providing context for problem-based learning. The goal is to develop an integrated understanding of science and engineering over time (NGSS Lead States, 2013).

The NGSS promotion of engineering design as a critical element of K–12 education is in keeping with the recent trend of promoting design process skills in college engineering programs (Doppelt, Mehalik, Schunn, Silk, & Krysinski, 2008). When they start early with engineering practices and design process thinking, students develop important skills—such as communication, collaboration, inquiry, problem solving, and flexibility—that form the foundation for their educational and professional lives (Doppelt et al., 2008; NGSS Lead States, 2013).

STEM Achievement in Baltimore Elementary Schools

In 2012, Johns Hopkins University and Baltimore City School District formalized the SABES project. SABES is a community partnership initiative that includes both in-school and afterschool STEM education for grades 3–5. It was designed to broaden participation and achievement in STEM education by bringing science and engineering to the lives of low-income urban elementary school children. With the support of community-based organizations that provide afterschool programming, SABES serves families and children in three Baltimore City neighborhoods.

SABES engages directly with students in three ways:

1. During the school day, students are taught with a curriculum aligned to the NGSS (2013) that challenges them to draw their own conclusions about science concepts through hands-on investigations.
2. Community-based organizations help facilitate local STEM events that bring together teachers, students, families, other community members, and university-based partners to learn collaboratively about STEM topics, engage in hands-on activities, and celebrate student projects.
3. Community afterschool providers help SABES staff offer the OST program, which is organized around community-focused, student-driven projects, explored through problem-based learning and the EDP.

> Examples of student-driven projects undertaken in SABES programs during the 2014–2015 school year include exploring vacuum technology to clean up a littered playground; developing inexpensive, sustainable shelters for Baltimore's homeless population; and exploring ways to decrease the amount of lead in Baltimore's drinking water.

Problem-based learning takes place when "students encounter carefully selected, but ill-structured problems before they experience any instruction in the particular focus area" (Bridges & Hallinger, 1997, pp. 5–6). The essence of ill-structured problems is their open-endedness; problem-based learning does not direct students toward a determined path. Using ill-structured problems in STEM education gives students the autonomy to define a problem they want to address and to develop the process they will use to work toward a solution. The literature often confuses *problem-based* learning with *project-based* learning, *inquiry-based* learning, or *expeditionary* learning. The feature that distinguishes problem-based learning in SABES is the centrality of the ill-structured problem identified by students and explored through the EDP.

The SABES OST program meets for four hours each week, led by facilitators who are either teachers in the host school or individuals hired by the partner community-based program. Twice a semester, facilitators receive professional development designed to support implementation of student-driven projects.

The student-driven projects emphasize the relevance of STEM in the children's neighborhoods. Accompanied by their facilitators, students from each site complete a community walk-through. As a group, they identify a problem or dilemma in their community. Once the group has chosen a problem, the facilitators help the students view that problem through the lens of problem-based learning. In alignment with the problem-based learning approach (Bridges & Hallinger, 1997), students are responsible for everything from defining the problem to researching appropriate content and developing a solution. This process connects students with the engineering process by giving them complete ownership of their project through its entire lifespan. By choosing projects that are directly relevant to their lives and developing real-world solutions, the students experience first-hand that STEM, far from being merely a decontextualized school subject, can be used to improve their community.

Once the students identify their problem-based project, the facilitators guide their exploration of the project using the five-step EDP for elementary-age children outlined by Engineering Is Elementary (2016):

1. **Ask.** What is the problem? How have others approached it? What are your constraints?
2. **Imagine.** What are some solutions? Brainstorm ideas. Choose the best one.
3. **Plan.** Draw a diagram. Make lists of materials you will need.
4. **Create.** Follow your plan and create something. Test it out!
5. **Improve.** What works? What doesn't? What could work better? Modify your design to make it better. Test it out! (Engineering Is Elementary, 2016)

STEM mentors from the Johns Hopkins Whiting School of Engineering volunteer to work with students to develop their projects. The volunteers include university faculty, postdoctoral fellows, and students from several departments, including computer science, mechanical engineering, civil engineering, materials science and engineering, and geography and environmental engineering. The Johns Hopkins mentors, along with site facilitators, support the use of the EDP as the students develop their problem-based projects. Working with the university mentors also exposes students to engineers in a variety of fields.

Examples of student-driven projects undertaken in SABES programs during the 2014–2015 school year include exploring vacuum technology to clean up a littered playground; developing inexpensive, sustainable shelters for Baltimore's homeless population; and exploring ways to decrease the amount of lead in Baltimore's drinking water. By creating projects that have personal significance, students develop a rich experiential understanding of the EDP. Creating projects that align with the values of their communities bridges students' academic lives and their environment beyond the school walls. Research suggests that basing STEM projects in students' communities is crucial in meeting the needs of low-income students and in developing their long-term engagement with STEM (Basu & Barton, 2007; Bouillion & Gomez, 2001; Roth & Lee, 2004).

Building Understanding of the Engineering Design Process

To understand how the SABES approach influences students' understanding of the EDP, we adopted a validated instrument developed by Hsu, Cardella, and Purzer (2012). The instrument uses an illustration of a student's design process for a specific assignment—an egg drop contest—to structure one-on-one interviews that probe the student's understanding of the EDP. We chose the instrument because it is an age-appropriate, validated instrument that shows promise in capturing a student's knowledge of the EDP.

Using the protocol established by Hsu, Cardella, and Purzer (2012), interviewers used the instrument to frame individual interviews with 12 students who had participated in the SABES OST program for two years. All 12 came from a site that had been assessed by SABES staff as having a well-implemented program. The SABES research and evaluation team completes regular visits at each site during which we document facilitator and student attendance, note the general instructional climate, observe the engagement of the facilitators and students, and assess instruction. This site was determined to have the best-run OST program of the three sites because students attended regularly, the climate was positive, and almost all students were engaged in the day's activities during the site visits.

Ten girls and two boys were interviewed. Nine of the girls identified as African American, one girl identified as Asian, and both boys identified as African American. All 12 students were in fifth grade. Each interview was video recorded, transcribed, and analyzed by two independent coders. The two coders worked together to develop consensus on the assertions developed for each interview. The coding process allowed us to identify themes and draw conclusions about the students' understanding of the EDP.

The analysis of the interviews and the themes that emerged revealed that the SABES OST program supported students in developing an understanding of the EDP. The interviewed students recognized the EDP and could describe it in detail. Moreover, the students described the importance of community-focused, student-driven projects in supporting their understanding and application of the EDP. Our assertions support and extend findings from earlier studies focused on the importance of integrating students' communities in STEM learning (Basu & Barton, 2007; Bouillion & Gomez, 2001; Roth & Lee, 2004).

Highlighting the Importance of Iteration in the Engineering Design Process

When we interviewed the 12 students, four of them recognized the EDP and described it in detail without any prompting. Six others recognized that the instrument depicted the EDP, but, unprompted, gave much more limited explanations. When these six students were prompted about how the EDP diagram in the instrument was related to their experiences in the SABES OST program, they explained the EDP in detail without additional prompting. All 12 students remembered the "imagine" and "plan" components of the EDP, and no student forgot more than one EDP component.

We are experienced educators who have taught STEM both in school and in OST. We were pleasantly surprised, yet intrigued, by the students' emphasis on how the iteration step improves the design of a product.

What we found most intriguing was that 11 of the 12 students were able to articulate the "improve" phase in great detail. Students were quite articulate about the notion that the EDP is a cycle that may need to be repeated, especially to improve on the project; that is, they understood the iterative nature of the EDP. Kaiya shared her understanding of the improve phase:

> And improve … if you test your model and … if it falls or the head falls off or the tape wasn't strong enough, you could remove the tape and put new tape on or change the position.

Nevette shared the importance of improving a design: “When you test it and it don’t work, you gotta improve it to make it better.”

We are experienced educators who have taught STEM both in school and in OST. We were pleasantly surprised, yet intrigued, by the students’ emphasis on how the iteration step improves the design of a product. In the age of No Child Left Behind (NCLB) and now Every Student Succeeds, STEM education is often pushed aside, particularly in the elementary grades. In a survey of 164 elementary teachers, more than half indicated that they had cut time from science instruction since NCLB became law (Griffith & Scharmann, 2008). The main reason they gave was the need to increase time for mathematics and reading instruction. This perception is not surprising: Reading and mathematics are the most commonly assessed subjects, and educators’ careers can be determined by their students’ assessment results. However, the focus on reading and math to the exclusion of science may be shortsighted: Some evidence suggests that science learning can promote student achievement in math and reading (Milner, Sondergeld, Demir, Johnson, & Czerniak, 2012).

The students who grounded the EDP in contexts to which they could relate in personal and meaningful ways showed greater understanding of the EDP and of engineering in general. Furthermore, the students we worked with were able to articulate how engineering applied to their lives beyond the confines of school.

Although they may understand the benefit of making science relevant, teachers cite lack of time, resources, and professional development as impediments to teaching science (Milner et al., 2012). Marx and Harris (2006) state that contemporary elementary students are missing out on what many adult scientists experienced when they themselves were in elementary and middle school: science instruction and experiences that sparked their interest, curiosity, and imagination. Teachers are often forced to move through STEM content quickly, perpetually chased by the high-stakes assessment at the end of the year. Students are not given time to explore processes or revise their answers. There is an overemphasis on finding the “right” answer.

SABES aims to address these issues by leveraging the flexibility of the OST environment, which allows time to explore science and engineering content. SABES also provides support and professional development to allow facilitators to meet the challenge of leading problem-based learning through student-driven projects. Our student interviews suggest that this approach was working: Almost all of the students understood that revision was an important step of the EDP and that one answer, developed after a brief struggle with the material, was not necessarily the most appropriate or “right” answer.

Bridging STEM Learning with Students’ Community

In their study of a community-based education partnership, Bouillion and Gomez (2001) found that solving real-world, community-based problems enhanced student learning. Students were more interested in science and expanded their understanding of the nature of science (Bouillion & Gomez, 2001).

Our work with community-focused, student-driven projects extends this work from the domain of science to the domain of engineering design. The students we interviewed were able to contextualize the importance of using the EDP in their projects to help their communities. For example, Raushaun said that the steps of the EDP “will make you more to be an engineer and more to make the structure better to help the people.” The students who grounded the EDP in contexts to which they could relate in personal and meaningful ways showed greater understanding of the EDP and of engineering in general. Furthermore, the students we worked with were able to articulate how engineering applied to their lives beyond the confines of school. Alisha related her work in the OST to her community:

> [The site facilitator] took us on a community walk. We try to solve—we could try to list out all the things that we had problems during the community … brainstorm many ideas and then choose one best idea. So then we list a whole bunch of problems and then we discuss, and then each group select one topic. And then they gonna do some research ... about that and see … how many affect the environment and how we can make this better.

Our work contributes to the body of literature on the value of community-focused, student-driven projects. Moreover, our work highlights the need to provide context for STEM content, allowing students to develop understanding of how engineering and design processes are valuable outside the classroom.

This need to allow students to connect with their projects has several implications for STEM teaching and learning. Educators must not only be well versed in the STEM content that supports student projects but also be able to show students how their projects have value beyond their performance in school. Facilitators need to spend time explicitly on the "big picture" of the EDP in order to mitigate students' tendencies to look for the "right" answer or get caught up in the details of executing individual steps. The need to improve designs and to repeat the EDP cycle should be emphasized. Educators need to help students see the societal value not only of their specific projects but also of engineering generally and of the use of a design process to solve problems.

Implications for Practice

Encouraged by how students articulated the importance of the student-driven projects in their developing understanding of engineering and the EDP, we interviewed the two facilitators of the OST site attended by the 12 interviewees. Both facilitators were teachers at the host school, one in fourth grade and one in fifth. Our interview questions focused on what improvements could be made in the implementation of the OST STEM program and in the support of the student-driven projects.

These facilitator interviews led to several modifications to the SABES OST program. For example, because the community walk-throughs are such an important component of the student-driven projects, we have given the students guiding questions to focus their observations, providing a bit more structure to maintain their attention.

Another improvement was to reach out to more community members and businesses who could support deeper community connections, strengthening the students' projects. Consequently, student-driven projects now include awareness campaigns designed to engage community partners. Students create flyers, attend events, visit local businesses and organizations, and speak to the public about the problem they are addressing and their proposed solutions.

One of the facilitators' biggest concerns was the need for professional development regarding community-focused, student-driven projects. Rather than providing answers to students, SABES OST facilitators have learned to guide students by asking questions and coaching independent exploration—the approach advocated in the NGSS. The facilitators we interviewed said that they required time to become comfortable in this role and that they needed professional development to become comfortable redirecting questions back to the students and asking them to explain their answers.

Finally, we used the interview feedback of students and facilitators to revise the process for the next cycle of projects. OST STEM programs that want to implement community-focused, problem-based student-driven projects might consider implementing these steps.

1. **Arrange community walk-throughs.** Take students on a walk through the school's neighborhood, asking them to take note of particulars. Use a handout with specific questions to focus students on community issues for which STEM can be used to create a solution. Have STEM mentors—for example, university students or mentors from area STEM-focused businesses—help the students develop and refine the questions.
2. **Identify potential neighborhood partners.** Recruit local businesses, schools, and other organizations that can provide resources to help students better understand community issues. Focus on organizations that will provide different perspectives on the same community issue.
3. **Narrow down issues.** Discuss with students the issues they identified, examining how these problems affect the neighborhood. Help students narrow the list to the most problematic. Discuss which students are qualified to tackle these issues.
4. **Formulate solutions.** Help students conceptualize three possible STEM solutions to the issue or issues they have chosen. STEM mentors, if available, can help the students narrow down the choices by discussing which solution is the most feasible and affordable. Students may split into groups and try different solutions, if they want, as long as the process is coherent.
5. **Create a preliminary supply list.** Disclose the operating budget to students and give them responsibility of creating an initial supply list. Supervise them closely to avoid going over budget.
6. **Perform background research.** While supplies are being ordered, have students conduct research on the topic. Research can include interviewing community members or reading about the topic in print or internet sources.
7. **Create a campaign.** During the research phase, have students design a small-scale community awareness campaign. For example, they could create a brochure featuring the community problem and how the students intend to solve it.
8. **Arrange field trips and invite guest speakers.** Identify local organizations and projects that students can visit or invite guest speakers to discuss the topic. Outside input can shed light on the issue or the proposed solution.

9. **Model and test.** Have facilitators and STEM mentors work with the students to create a preliminary model of a proposed solution. Then have students test their first model.
10. **Improve.** Once students test their first model, lead them to modify and improve the model.
11. **Launch.** Sponsor a recognition event at which students can present their projects to their families and community members. Support the students to prepare a presentation of their project. This event helps student develop public presentation skills.
12. **Initiate next steps**. Finally, encourage students to continually refine and improve their model.

Finally, every student should have a project notebook in which to document the group's models, tests, findings, and improvements.

Applying what we learned by observing one site and interviewing 12 students and two site facilitators, we have scaled SABES to nine elementary schools. Other OST programs may be able to build on our work to provide elementary students with community-based, student-driven programming that helps them learn the engineering design process.

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