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Teaching Engineering Practices

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Abstract Engineering is featured prominently in the Next Generation Science Standards (NGSS) and related reform documents, but how its nature and methods are described is problematic. This paper is a systematic review and critique of that representation, and proposes that the disciplinary core ideas of engineering (as described in the NGSS) can be disregarded safely if the practices of engineering are better articulated and modeled through student engagement in engineering projects. A clearer distinction between science and engineering practices is outlined, and prior research is described that suggests that precollege engineering design can strengthen children's understandings about scientific concepts. However, a piecemeal approach to teaching engineering practices is unlikely to result in students understanding engineering as a discipline. The implications for science teacher education are supplemented with lessons learned from a number of engineering education professional development projects.

Keywords Engineering education · Engineering practices · Next Generation Science Standards (NGSS)

The 2012 NRC *Framework* boldly advocated a prominent position for engineering in new science standards. It also proposed a structure for those standards, distinguishing between *practices, disciplinary core ideas*, and *cross-cutting concepts*. That curricular structure offered a consistent way of thinking about—

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and across–the various school science subjects. Furthermore, it raised the visibility of engineering as it relates to science, and advocated its greater emphasis in the school curriculum (National Research Council [NRC], 2012). These were worthwhile goals.

However, consider the stated rationale for including engineering:

> Engineering and technology…are included in the framework for several reasons. First, the committee thinks it is important for students to explore the practical use of science… Second,…these topics typically do not appear elsewhere in the curriculum and thus are neglected if not included in science instruction….Finally, engineering and technology provide a context in which students can test their own developing scientific knowledge and apply it to practical problems; doing so enhances their understanding of science—and, for many, their interest in science—as they recognize the interplay among science, engineering, and technology. (*Framework*, p. 12)
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> Engineering and technology are included as they relate to the applications of science, and in so doing they offer students a path to strengthen their understanding of the role of sciences. (*Framework*, p. 11)

On the one hand, language like this suggests that engineering is an *application* of science. On the other hand, engineering would soon be described in the *Next Generation Science Standards* (NGSS Lead States, 2013) using three disciplinary core ideas (DCIs), implying a distinct disciplinary identity. To further complicate things, a careful reader of both documents might note that, whereas the other 38 DCIs and all seven cross-cutting concepts were described using nouns (e.g., "Forces and motion," "Natural selection"), the engineering DCIs used verbs: "Defining and delimiting an engineering problem," "Developing possible solutions," and "Optimizing the design solution." The core ideas of engineering here sound like activities, not concepts, principles, or theories.

In this paper, we try to shed light on puzzles like this, explore some implications of a new emphasis on engineering practices, and suggest why this emphasis may be useful for teaching science. We also share some lessons learned from previous work on teaching teachers about engineering.

Engineering Practices

If one uses Schwab's (1964) familiar description of disciplines as having characteristic substantive (conceptual) and syntactic (epistemic) dimensions, then the three NGSS engineering "core ideas" appear to be mislabeled syntactic structures: They are actually statements of *practices*. This misclassification is understandable: To the extent that engineering *has* unique core ideas that would be intelligible to children, they had been used elsewhere in the document, and were thus unavailable as distinctive substantive structures of engineering. "Systems and system models," for example, are conceptually central to engineering, but the term was in use elsewhere as a "crosscutting concept." Bundling practices as core ideas may have been a well-intentioned effort by the *Framework's* authors to make sure that engineering wouldn't fall off the radar as new curricula are designed and standardized tests are developed. However, it is unnecessarily confusing. It also opens the door to the psychometric trivialization of engineering into knowing the definitions of terms like “optimization,” or being able to “order the steps of the engineering design process.”

To make sense of engineering and its place in the science curriculum, we suggest that it may be helpful to simply disregard the three proposed engineering DCIs and focus on *engineering practices* as the distinguishing feature of precollege engineering. The disciplinary core ideas of engineering that are of concern in science teaching (such as “systems”) exist already elsewhere in the standards. What distinguishes chemical engineering from chemistry is not a unique set of core ideas; it is how those ideas are used in productive, professional work. However, the Framework’s description of engineering practices is also problematic.

How the *Framework* Misrepresents Engineering Practices

In the NRC manifesto, the work of science and engineering was described using a single set of eight practices, and although the document offered some discussion of how the practices vary by field, only two were substantively differentiated: #1: *Asking questions (science) and defining problems (engineering)*; and #6: *Constructing explanations (science) and designing solutions (engineering)*. Many essential disciplinary differences weren’t mentioned. For example, in describing “Engaging in argument from evidence” (#7), the reader was left with the impression that engineering solutions are evaluated through scientific peer review. Almost 400 pages in length, the *Framework* contained only a single use of the word “client,” and nothing to suggest that the evaluation of engineering work involves non-scientists. For science and engineering, the *Framework’s* starting and finish lines were different, but what happens in between was largely “of a kind.” Our practice-by-practice review of a number of disciplinary differences is summarized in Table 1 and detailed elsewhere (Cunningham & Carlsen, 2014). Representations like this table may be useful in teacher education as a way of better clarifying how science and engineering differ, especially for the overwhelming majority of teachers who have never formally studied engineering.

From an educational perspective, one unintended consequence of conflating the practices of science and engineering is that distinctive features of engineering work may be overlooked as unique educational resources. For example, the NRC discussion of practices begins by pointing out that science “asks questions” and engineering “defines problems” (Practice #1). This choice of words usefully acknowledges the importance of language in these fields, but it also suggests that the goals of science and engineering are “answers” and “solutions.” It’s worth noting that in the school context, “answers” and “solutions” are interchangeable terms. But in science and engineering there are important differences: A scientific answer represents *conceptual progress*, and an engineering solution entails applying concepts in the production of a *useful technology*. From an educational perspective, both are important, but there may be times when there are advantages to organizing instruction with the material goal of producing a technology. This may be especially

Table 1 Differences in the practices of science and engineering (based on Cunningham & Carlsen, 2014)

Practice [from NRC (2012)]	Relative emphasis in science	Relative emphasis in engineering
1. Asking questions and defining problems	Goal is theoretical/conceptual progress	Goal is a useful, novel technology
2. Developing and using models	Explanation and prediction	Analysis and evaluation
3. Planning and carrying out investigations	Hypothesis-testing, may be sequential	Evaluation, usually iterative
4. Analyzing and interpreting data	Attention to measurable aspects of the found, natural world	Attention to diverse criteria: scientific (e.g., material properties) and other (e.g., cost, risk of failure)
5. Using mathematics and computational thinking	Testing conceptual models with real data	Designing concrete things, using both real and simulated data
6. Constructing explanations and designing solutions	Objective is a single "best explanation"	Objective is a preferred design, selected from among alternatives, with explicit consideration of tradeoffs
7. Engaging in argument from evidence	Goal is to persuade scientific peers	Goal is to satisfy a client
8. Obtaining, evaluating, and communicating information	Free exchange of information is an important norm	Products are often legally proprietary, and information guarded

important when working with young children; we will return to this point in the next section.

Engineering solutions (a.k.a., useful technologies) are evaluated using a wide range of both scientific and non-scientific criteria (Practice #4), and, as noted above, evaluation typically involves individuals who are not scientists (Practice #7). Considerations of convenience, cost, and taste are not irrational; they're a valued part of the routine problem-solving space. In the educational context, a child who has not yet studied advanced mathematics or science can still evaluate a design, especially if the engineering problem is relevant to the child. By legitimating more diverse evaluative criteria, we invite engagement by students with varied knowledge and abilities, including scientific novices. Another distinctive feature of engineering is that the work usually entails cycles of iterative activity (Practices #2–5). Iteration is necessary because the product of engineering work is not a claim; it is an optimization (Practice #6). Although a scientific outcome might be reducible to the statistical rejection of a null hypothesis (e.g., "X has no effect on Y under condition Z"), engineering solutions are typically optimized on multiple dimensions. To engineer a model bridge, students must engage in cycles of design and testing to find the best balance between cost, strength, and other criteria: one cannot optimize with a single test. From an educational perspective, the process offers opportunities for student self-regulation and learning from mistakes: Students don't need a teacher to see that their bridge collapsed, and they rarely require an invitation to try again! Iteration and productive failure provide both informative feedback and concrete challenges to students–features that help account for the high levels of student engagement that design projects often stimulate (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kolodner, 2006).

The structure of the *Next Generation Science Standards* potentially distorts engineering in one other important way. The standards are defined in terms of intersections between discrete science and engineering practices, disciplinary core ideas, and cross-cutting concepts. In simplified form, a single standard might be visualized using the analogy of a slide rule (Fig. 1). Although this approach works (perhaps awkwardly) to specify science curricular content, it distorts the very nature of engineering. The practices of engineering are meaningless outside of the context of the entire problem-solving process. Consider again Practice #7, "*Engaging in argument from evidence.*" General norms provide clear guidance for many scientific problems, such as, "What is the solubility of NaCl in water at 25 °C?" or "How does the gravitational potential energy of a mass change as a function of its distance from the surface of the Earth?" They provide little guidance, however, for engineering problems like, "What's the best design for a bridge to go over this river, here?" The nature of the building site, the preferences of the client, the projected amount of future traffic, the amount of risk that is deemed acceptable, and the availability of materials are among the myriad factors that must be considered and measured, simulated, haggled over, prototyped, and tested. Then repeat. In other words, the effectiveness of an *argument from evidence* (Practice #7) can only be evaluated from within the context of an episode of engineering. The solubility of NaCl does not depend on the location of the experiment, or the identities of one's peer reviewers. But an elegant, expensive bridge is the right solution only if aesthetics are a top priority for the client, and cost is not.

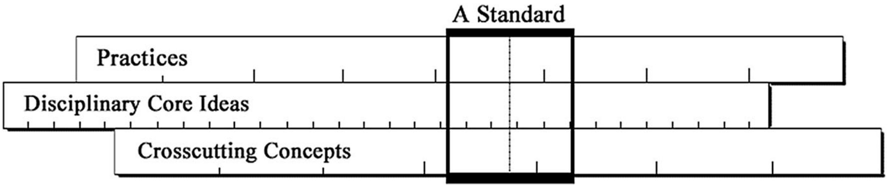

Fig. 1 "Slide rule" representation of an NGSS science standard

Of course, a teacher could always reduce an engineering problem to the point that contextual elements and their history were unimportant, but at that point, it would likely look like a science problem, not an engineering problem!

Why Engineering Practices Should Matter to Science Teachers

Engineering has an identity that is distinct from science, and "slipping in a little engineering" here and there is unlikely to result in science students developing a coherent view of engineering as a discipline and a profession. If "understanding engineering" is to be an educational goal, students will need experience doing complete engineering projects. In many middle schools, such projects are already carried out in standalone technology or even engineering classes, which often do a good job of emphasizing the iterative, product-oriented, material features of engineering problem-solving. However, in our experience, these classes rarely dig very deeply into the substantive, conceptual terrain that is shared by science and engineering. (To be fair, the same critique applies to many engineering projects done in science classrooms). Science teachers should be concerned with how engineering is represented in the curriculum, because so much of the conceptual landscape is shared. On the positive side, engineering design projects offers many potential cognitive opportunities for teaching scientific concepts better. Two examples follow.

The first example is from a study by Levy (2013) of fifteen 5–6 year olds. This fascinating project engaged children individually in four engineering challenges related to distributing water, such as designing and building a system to deliver equal amounts of water to two "apartments," one higher than the other. To control for maturation, testing, and other factors, a control group was also studied. Levy documented substantial treatment effects on children's understanding of several physical concepts, such as the effects on flow rate of differences in reservoir elevation and pipe diameter. Furthermore, the children were able to solve problems that appeared to be beyond their predictive ability, by spontaneously decomposing complex challenges into system components and addressing them individually. Levy credited several features of the design process for the outcomes, including the use of physical components as external memory to reduce cognitive load, sensorimotor feedback that reinforced visual observations, and the opportunity to backtrack and redo partial solutions manifested as subsystems.

The second example concerns disciplinary differences in how models are used. Schauble, Klopfer, and Raghavan (1991) compared the experiences of elementary students who worked with identical models, but in a different order. Students completed both a science problem (examining and explaining the effects of various mechanical factors on spring length) and a conceptually related engineering problem (increasing the speed of model boats being pulled through a canal system). Outcomes were superior for the group that conducted the engineering challenge first. To explain this finding, the authors pointed all the way back to John Dewey's (1913) observation that children often benefit from ends-oriented, practical activity prior to means-oriented science study. The authors also noted that when children are asked to determine causes and effects, they prefer to engage instead in optimizing for a desired outcome (e.g., Kuhn & Phelps, 1982).

Engineering is a new priority in precollege science education, and there is a small but growing literature on science learning in the context of engineering activity. This new research emphasis will offer new perspectives and new opportunities for science education, with implications for both curriculum and—critically—teacher education.

Teaching Engineering Practices to Teachers

We now turn to the specific challenge of teacher education. Several recent reports identify serious shortcomings in teachers' preparation for teaching engineering, and a dearth of opportunities for preservice and inservice education related to engineering (Committee on Integrated STEM Education, 2014; Katehi, Pearson, & Feder, 2009; Trygstad, 2013; Weis, 2013). How can we promote teacher familiarity, facility, and—eventually—fluency with engineering practices? In what follows, our comments are informed to some degree by the research literature, but to an even larger extent by our practical work. Over the last dozen years, the first author and her colleagues have offered over 400 inservice and preservice engineering education courses and professional development workshops to elementary, middle, and high school teachers, through projects like *Pre-College Engineering for Teachers* (PCET: Cunningham, Knight, Carlsen, & Kelly, 2007) and *Engineering is Elementary* (EiE: Cunningham, 2009; Lachapelle & Cunningham, 2014). In addition, both authors have served as external evaluators for professional development projects run by others, such as the NSF-supported *Engineering Concepts for the High School Classroom* program offered by the Thayer School of Engineering at Dartmouth College (Carlsen, 1998). One of the most useful aspects of this work has been the opportunity to follow teachers back to classrooms all over the country and see teachers' subsequent work in a wide range of settings.

The creation and refinement of teacher professional development looks a lot like engineering design itself: a highly iterative process that produces tangible products, is concerned with analysis and evaluation, and attends to the diverse needs and interests of its clients: schools, teachers, and students. In considering our own PD experiences and those of a number of other K-12 engineering programs such as

Engineering the Future, Project Lead the Way, INSPIRES (Increasing Student Participation, Interest, and Recruitment in Engineering and Science), and City Technology, we suggest that the following guiding principles have emerged as durable “design criteria,” and are reviewed in sequence below:

- Engage teachers in engineering practices.
- Model pedagogies that support those practices.
- Give teachers experience as both learners and teachers.
- Develop teachers’ understanding of the fundamentals of and interconnections between science and engineering, and
- Help teachers to understand engineering as a social practice.

Engage Teachers in Engineering Practices

To understand engineering, one needs to engineer. For most teachers, this is unfamiliar terrain, work that they have not experienced at all in prior schooling. To develop familiarity and facility with engineering, teachers need to engage with engineering practices. They don’t readily learn the practices or how to teach them by reading or watching others engage—they have to dive in. This usually includes an engineering design challenge so the work actually models the cycle of design (Daugherty & Custer, 2012). Effective activities tend to be hands-on, materials-intensive, and learner-driven.

In preservice and inservice professional development programs, teachers should use the engineering design process to generate solutions to a specified design challenge. The engineering challenge can be tailored to the appropriate grade level and, when possible, to the science content that the participants actually teach. For example, elementary teachers who study insects with their students might engage in a challenge to design a hand pollinator for a model flower. High school environmental science teachers might be asked to invent a device that allows them to collect a water sample from the middle of a stream. As they work through the challenge, the teachers redefine the problem, consider the criteria and constraints they must address, and establish what they know and what they need to learn. They brainstorm and evaluate possible designs and select one design for initial construction. They identify the materials they’ll need (from a range of materials that are on hand), and plan the construction, often using diagrams and models. Then they build their original technology, test it, and gather data about its performance. They analyze and interpret their data as a group and with the larger class, and reflect upon how they might improve the design so it better meets the criteria. Then they redesign the technology, engaging in the practices again. If the design challenge is appropriate for the group and a range of appropriate materials is on hand, this entire process can be modeled in as little as an hour.

As teachers engineer, they construct more than a technology—they also build their personal understanding of the engineering practices that together constitute design. Meanwhile, workshop or course facilitators ask participants to reflect upon the engineering practices that they are utilizing. Teachers may wish to consider how their students might react to an engineering experience—what will be new for students and where might students need scaffolding or support?

Teachers value the opportunity to design. In response to an open-ended evaluation question that EiE uses routinely at the end of workshops–which asks participants to identify the most helpful or effective aspect of engineering professional development workshop–comments like these are common:

> The opportunities we were given to actually complete the activities because it gave us a sense of what our students will be going through. Also, we were able to get a sense of what challenges our students might face.
> Actually doing the activities to see what the kids will be doing. It helps to know what the end-product is and to know all the steps and challenges along the way.
> Trying the experiments (i.e., design challenge) helped me think of what would be challenging to my students. It also helped me consider extension options.
> I felt that engaging in (the engineering activities) prepared me for teaching it in the classroom. While engaging in the material, I saw how the teacher should present the material and how the students would react to the learning.

Note that while teachers value the opportunity to carry out the full engineering design process, they typically express that value not in terms of disciplinary authenticity, but in terms of how that process will be experienced by students.

Model Pedagogies that Support Engineering Practices

When engineering is introduced to teachers, there is an opportunity to model unfamiliar pedagogies, approaches that may be at odds with current educational fashion. Meaningful engineering problems offer multiple solution paths and multiple *solutions*: If there is only a single "correct answer" for a problem, engineering isn't needed. And failure *is* an option; in fact it is usually essential. If an engineering challenge is too easy, it is unlikely to sustain student interest or lead to a meaningful sense of accomplishment.

The goal of engineering instruction is to structure the problem solving process, not to lead students inexorably to a predetermined conclusion. Challenges should require that participants produce solutions within specified constraints. For example, in designing a hand pollinator, the multiplicity of solutions that teachers and students create invites scrutiny of which properties of materials are best suited for pollen transfer, and opens discussion of the relationship between flower shape and pollinator shape (the two must be coordinated for the design to work). Design challenges focus participants on doing engineering; to help participants attend to the larger, overarching engineering and science principles that underlay the designs, facilitators should manage the activity, the discussion, and the variety of solutions.

It can be intimidating for many teachers to plan complicated activities in which students explore relatively open-ended problems. Professional development needs to model tested pedagogies and strategies that teachers can use to scaffold students as they develop familiarity and facility with engineering tasks.

What types of pedagogies should professional development demonstrate? Perhaps the most important is that teachers assume the role of teacher-as-facilitator. In professional development, as in the classroom, an instructor needs to envision her role as guiding or supporting student learning. This is accomplished by eliciting learners' ideas and reflections. Instead of passing judgment on students' designs or offering input for "better" next steps, the goal should be guiding student learning through open-ended questions or other prompts: "Why do you think that?" "I wonder how you might improve the design." "What are you trying to optimize?" "Why do you think it didn't work as you expected?" Note that these are not questions for which the instructor already knows the answer. Effective prompts help children to think about their own thinking, ask their own productive questions, generate a variety of strategies to pursue, or determine what data they need. Teachers benefit from observing and reflecting upon how instructors employ questions to focus learner efforts.

As they engineer, students need to learn not only from their own designs, but also to work in groups and to learn with and from the efforts of others—practices that engineers engage in as well. In professional development, as in the classroom, participants benefit from working in groups, later sharing their designs and their data with everyone. As learners analyze and reflect upon their results, facilitators actively guide the discussions with skillful questioning and model how to present arguments and evidence that are supported by data.

It is often easiest to teach as we are taught. Carefully designed professional development workshops model strategies for effective questioning, group work, and communication, and provide participants with models to use with their own students. Design challenges, social processes for deliberation and evaluation of designs, and opportunities to engage in an iterative failures and successes make learning to teach engineering unique, but also exciting.

Give Teachers Experience as Both Learners and Teachers

When teachers engage with colleagues in engineering activity, they are always eager to connect what they are doing with their experiences and goals as teachers. In other words, as learners, they tend to have trouble staying in role. That is problematic because, in the professional development context, it can fragment the systemic nature of engineering work that we hope to model. We've found that it is helpful to explicitly discuss both this tension and the workshop's goal of providing experience from two perspectives. In addition to doing the activities as a learner and processing experiences from a learner's perspective (the "student hat"), teachers also benefit from the opportunity to reflect upon what the instructor is doing, why, and how those *pedagogical* practices might play out in their own classrooms (the "teacher hat"). We have found that workshops are most effective when they provide time for participants to don each hat during a given activity and make clear which hat participants should "wear" during each part of the workshop. When they are wearing their teacher hats, participants spend time discussing issues such as what the activity might look like in the classroom; what misconceptions students might have about the concepts involved; where students might struggle with materials, concepts, or ideas; materials management; how to differentiate the lesson for learners of different abilities or backgrounds; and which engineering practices they used during the lesson. Course instructors and facilitators plan and manage such conversations carefully to help teachers gather additional pedagogical tips and strategies that they might employ.

Develop Teachers' Understandings of the Fundamentals of and Connections Between Science, Engineering, and Technology

Because engineering and technology are new content areas for most teachers, it is useful to work to strengthen teachers' understandings of foundational aspects of technology, engineering, and the engineering design process. We begin teacher workshops with two introductory activities: "What is technology?" and "What is engineering?" We use simple, everyday objects and materials in the activities to make these terms more accessible and familiar to participants, and also to draw out the ideas that technology is all around us, and that the engineering design process is a problem solving process that everyone uses. During a debriefing afterward, participants use what they discovered and experienced to construct definitions of technology and the engineering design process. Later on, when participants engage in engineering design challenges, the facilitator will refer to what participants did during the introductory activity to help frame and support teachers' thinking. Teachers usually introduce technology and engineering to their students using the same activities.

Science, engineering, and technology interact; discussion and reflection that invites teachers to clarify the boundaries and overlaps is helpful. Similarly, the practices and habits of mind of science and engineering also intersect. Surfacing the similarities is useful, but also important is clarifying the differences.

Help Teachers to Understand Engineering as a Social Practice

Engineering is a social enterprise. Engineers usually work in teams. Children in classrooms and teachers in professional development need to engage in engineering practices in groups. Teacher education workshops can model strategies for working in teams that are age-appropriate. Also, the technologies that engineers create are usually developed for a client. Thus, the need to design to meet the specifications of other people, groups, or societies should also be communicated and practiced as part of engineering activities.

Finally, engineering solutions are situated in a larger context. Determining the "best" design for a technology usually requires engineers to balance scientific, economic, political, environmental, cultural, ethical, and aesthetic considerations. In addition to considering practices on a micro-level, professional development should also expose teachers to engineering practices at a macro-level.

In exploring the nature of engineering with teachers, it is important to recognize that fidelity to real-world engineering practices is not always possible or desirable. For example, in the real world, engineering requires collaboration, but it also often entails competition, sometimes cutthroat competition. In teacher workshops, EiE instructors make special efforts to emphasize the collaborative nature of engineering, and we discourage the use of competitions in the operationalization of EiE design challenges (Cunningham & Lachapelle, 2014). Nevertheless, many student engineering challenges, like those sponsored by the Technology Student Association (http://www.tsaweb.org), use competition to good effect. Some, like First Robotics (http://www.usfirst.org), formally emphasize and reward both competition and active collaboration. On matters like this, there is room for diverse approaches.

Infusion of Engineering Practices into Teacher Education

How might engineering be incorporated into teacher education? Preservice teachers can sharpen their understanding of engineering practices through the integration of engineering into their programs of study. This may entail adding engineering into science education methods courses, incorporating engineering design and activities into core science courses for teachers, offering content courses that focus explicitly on teaching engineering to preservice teachers, or requiring mainstream engineering coursework (the latter probably feasible only for preservice secondary teachers, because of extensive prerequisites).

Since the 1990s, preservice elementary educators at Penn State have been able to enroll in engineering courses that are developed specifically to address their needs, through a collaboration between the Colleges of Engineering and Education (Taylor, Lunetta, Dana, & Tasar, 2002). These are science courses, not teaching methods courses, but the instruction models effective pedagogical *and* engineering practices. At the State University of New York, Oneonta, students in an elementary science methods course regularly engage in engineering challenges that build upon the science concepts they have studied. These preservice teachers engage in the activities that their own students will do, and then debrief extensively.

As part of the *Advancing Technological Literacy and Skills of Elementary Educators (ATLAS)* and *Bridging Engineering, Science, and Technology (BEST) for Elementary Educators* projects, science and education faculty who teach college classes for preservice students worked to introduce engineering concepts and practices. Education faculty redesigned curriculum and methods courses to include engineering. Science faculty redesigned the core science classes required of all students, including preservice teachers, so students not only engaged in science laboratory investigations, but also tackled an engineering design challenge. The benefits to the students were so apparent that participating faculty now include engineering in 20 % of the lessons they teach (Davis Square Research Associates, 2012).

Currently practicing classroom teachers also need education to develop their engineering fluency. Professional development of teachers must take a variety of forms—in part because of the limited time that is currently available for engineering or STEM professional development. Teachers report that face-to-face opportunities to engage in engineering activities are extremely valuable. They appreciate the opportunity to manipulate materials, engage in and reflect upon activities with colleagues, and interact with instructors. However, reaching all teachers through face-to-face workshops is simply not feasible. For some teachers it will always be difficult to attend professional development workshops, because of geographic or time constraints. Furthermore, the development of engineering education expertise is a process that occurs little by little over time. Ideally educators can focus on a few new aspects, then try them out, engage in further reflection, and move to the next focal area. We've found that most teachers begin by focusing on the logistical aspects of managing multiple materials and designs. Once they become comfortable with these logistics, they can begin to focus on elicitation strategies. Online professional development programs and resources may help teacher gain familiarity with engineering and its practices, and many groups are currently exploring these approaches, online video resources, and other experiments. Our experience suggests that it can take three to six years before teachers are genuinely comfortable engaging in engineering practices with their students. This is not a challenge amenable to a quick fix!

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