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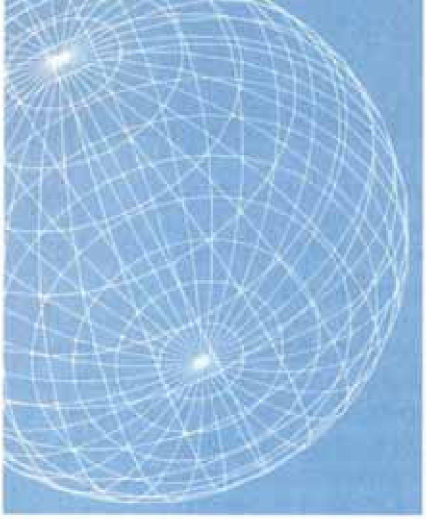

STEM FOR ALL

DECEMBER 2014/
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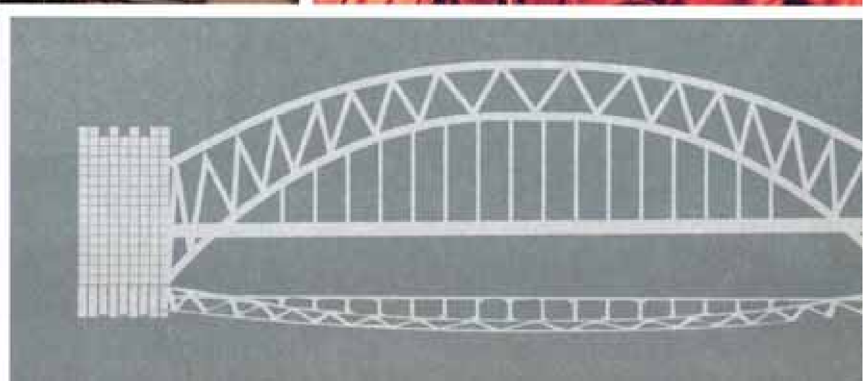

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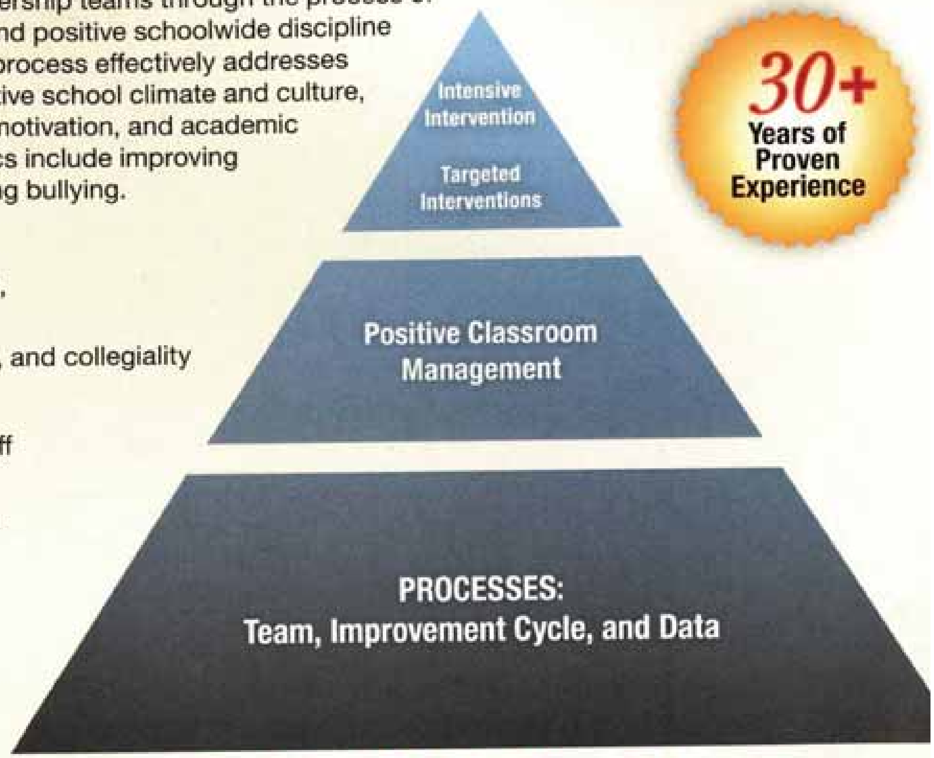

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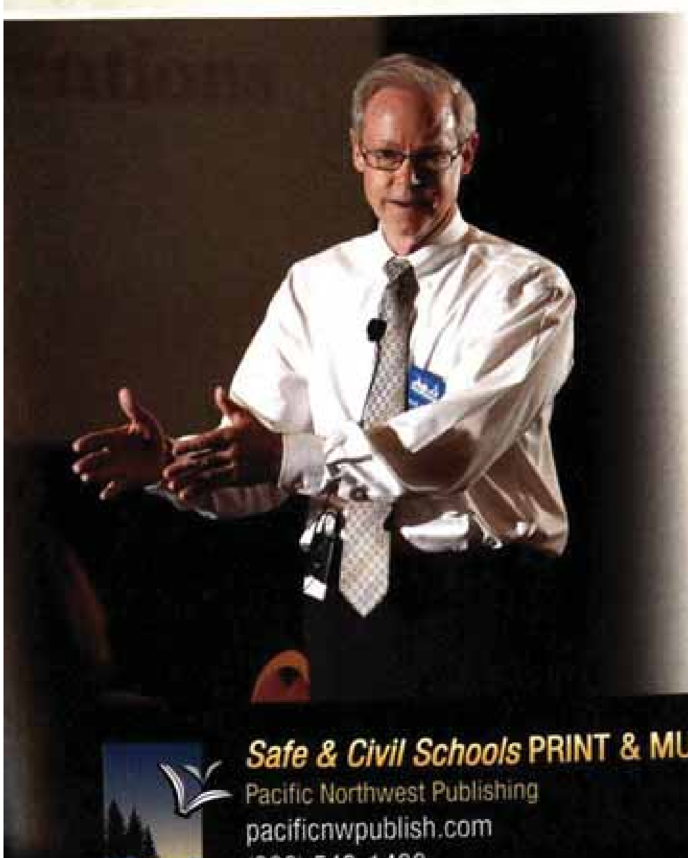

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STEM for All


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EL Study Guide

Teresa Preston

InService Guest Bloggers

Bronwyn Bevan and Melissa Higgins

Watch This Spot

With the help of high-powered equipment, students barcode the DNA in pet hair and food samples. This month's video comes from the DVD *The Innovators: Project Based Learning and the 21st Century.*

Close-to-Practice Learning

Bradley A. Ermeling and Ronald Gallimore

Which professional development practice shows promise for improving science teaching?

Beyond Computation

Deborah Schifter and Susan Jo Russell

How to identify and avoid persistent errors in arithmetic.

Literacy and Science: Better Together

Terry Shiverdecker and Jessica Fries-Gaither

Why you should use nonfiction texts to support science learning.

How to Engage More Students of Color in Math

Erica N. Walker

Peer tutors contribute to the success of students from underserved backgrounds.

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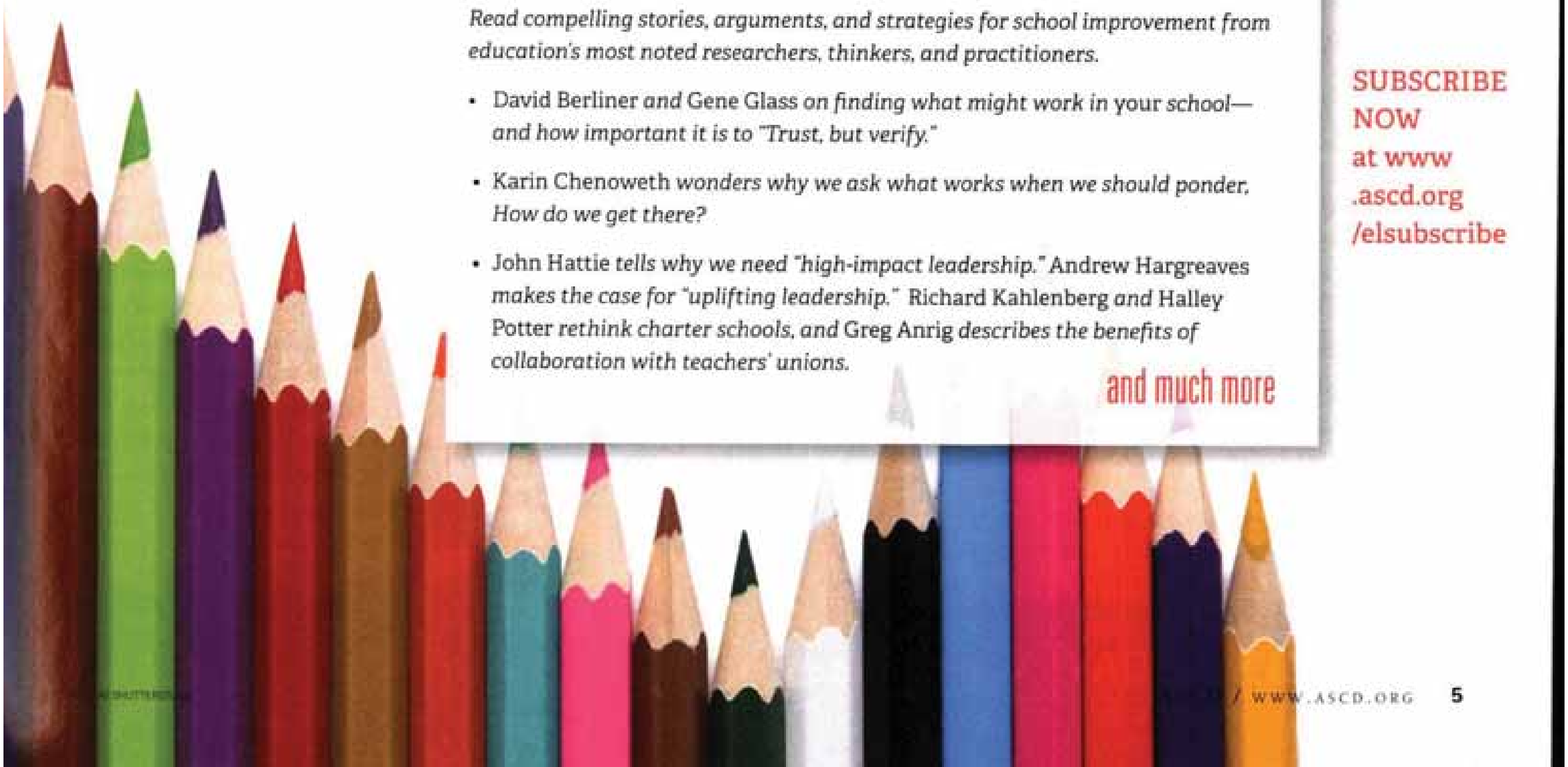

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- David Berliner *and* Gene Glass *on finding what might work in your school—and how important it is to "Trust, but verify."*
- Karin Chenoweth *wonders why we ask what works when we should ponder, How do we get there?*
- John Hattie *tells why we need "high-impact leadership."* Andrew Hargreaves *makes the case for "uplifting leadership."* Richard Kahlenberg *and* Halley Potter *rethink charter schools, and* Greg Anrig *describes the benefits of collaboration with teachers' unions.*

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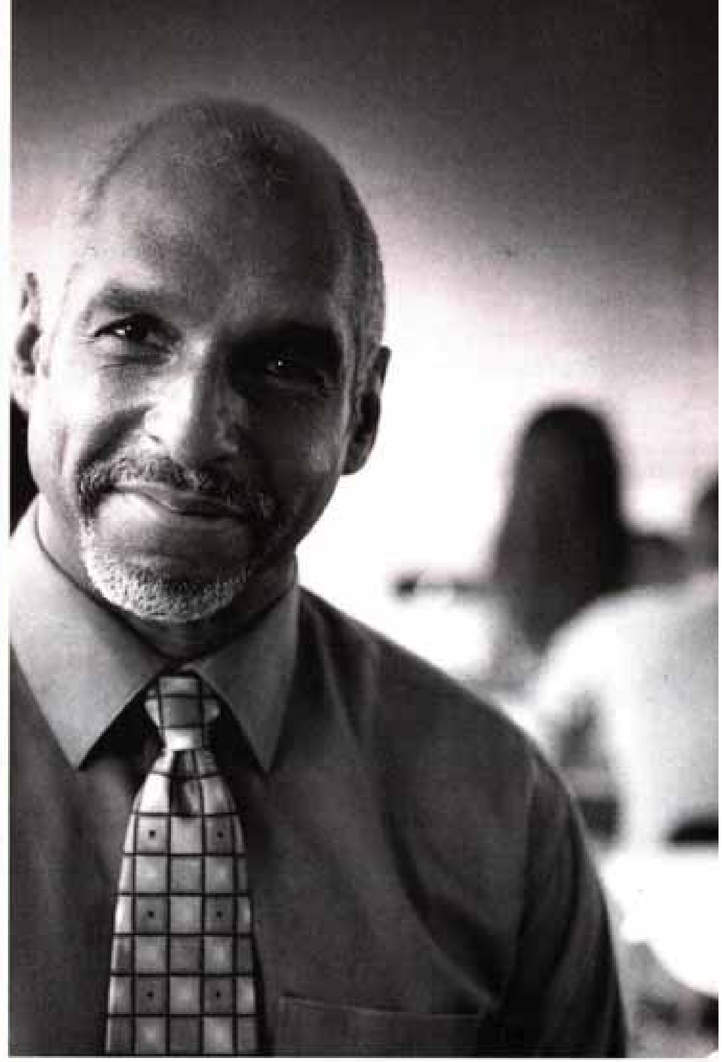


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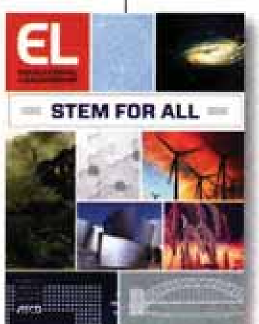
Marge Scherer

Helping STEM Take Flight

After watching a shirt being wafted into the air as it dries over a hearth, the tinkerer Joseph Montgolfier decides to try lighting a fire under a balloon—and creates the first flying machine.

After observing an art object swinging from a cathedral's ceiling, Galileo mulls over the mechanisms of a pendulum-driven clock—and produces one 50 years later.

Adapting a wine press, Johannes Gutenberg invents the first printing press, which leads not only to the rise of a newly literate class, but later to their increased need for spectacles.



A group of Murano glass blowers expelled from Venice because of the fire hazards from their furnaces collectively learns so much about the properties of glass that, eventually, future scientists, mathematicians, technologists, and engineers acquire the know-how to build spectacles, microscopes, telescopes, and cameras that can even take pictures of the moon.

These scenarios depicted on recent PBS science documentaries[1] dramatically illustrate both the light-bulb moments of discovery and the years of systematic exploration that have led to the innovations we now take for granted. An interesting takeaway is how discoveries morph into other discoveries; geniuses and countless unknown collaborators depend on one another to make unanticipated connections among science, technology, engineering, and math—as well as many other areas of study, including the arts and literature. With all the complex problems in need of solutions today, one cannot help but hope that today's students will follow in these innovators' footsteps.

This issue of *Educational Leadership* addresses the growing STEM education movement (science, technology, engineering, and mathematics). Although some say the need for STEM workers is at a crisis point (p. 10), others assert the workforce "crisis" is exaggerated (p. 79). Most, however, remain convinced that all students could profit from more in-depth science literacy regardless of the career path they take (pp. 79, 84, 86, 91). Here are some of the points our authors make about the education students need:

Real-world learning is central. Jo Anne Vasquez (p. 10) writes that STEM education "removes the traditional barriers separating the four disciplines and integrates them into real-world, rigorous, relevant learning experiences for students." No matter the level of STEM education a school may be able to provide, "Application is at the heart of STEM education. When students ask, 'Why do I have to learn this?' a STEM experience provides an answer."

New standards offer opportunity. Propelling the STEM movement are the Next Generation Science Standards, which require students to engage in *doing* science by modeling, analyzing, and designing, Jeff C. Marshall (p. 16) writes. He urges that teachers start small as they implement the new standards but prepare to run a marathon rather than a sprint.

Let the tinkering begin. Bronwyn Bevan and colleagues from the Exploratorium (p. 28) explain how the maker movement celebrates creativity and entrepreneurship. They describe how to bring tinkering to school with simple tools and materials and without resorting to step-by-step, recipe-like activities. Making objects float in wind tubes and building circuits can encourage students to collaborate, persist at their work, and learn that second drafts are part of learning.

All students need STEM. Computer science knowledge can no longer be reserved for elite students, Jane Margolis and colleagues note (p. 48). Christine M. Cunningham and Melissa Higgins (p. 42) make a similar point about engineering, another field in which women and minorities are disproportionately underrepresented. Because traditional activities may fail to attract many students, we must reframe challenges to demonstrate how engineering can help people and society.

Instill the value of science. There are many wonderful STEM school models and programs that authors describe in this issue (pp. 54, 68). Lee Shumow and Jennifer A. Schmidt (p. 62) remind us that scientists often name a high school teacher as the person who sparked their initial interest in science. Expressing your enthusiasm and interest in learning science may well inspire those who will need to figure out how we got to now and where we are going in the future. EL

[1]See *How We Got to Now* with Steven Johnson at www.pbs.org/how-we-got-to-now and *Ben Franklin's Balloons* at www.pbs.org/wgbh/nova/space/ben-franklins-balloons.html.

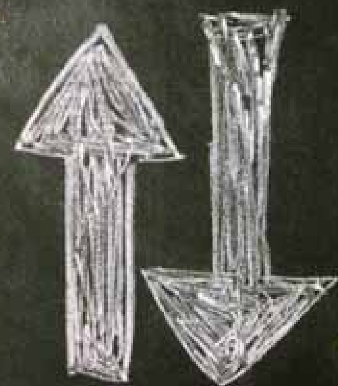
DOUBLETAKE

Research Alert The Ups and Downs of STEM

The Ups

Since 2007, student interest in majoring in science, technology, engineering, and mathematics (STEM) has increased sharply in two fields: engineering and biology, according to research presented at the 2014 annual meeting of the American Educational Research Association. The study looked at data from the freshman survey conducted annually by the University of California at Los Angeles—specifically, at the proportion of freshmen planning to enroll in STEM fields.

Engineering experienced the greatest growth, at 57.1 percent, followed by biology at 28.2 percent, mathematics at 12.6 percent, and the physical sciences at 11.1 percent. The research, conducted by Jerry A. Jacobs and Linda Sax, was highlighted in the April 2014 issue of *The Chronicle of Higher Education* (see http://chronicle.com/blogs/ticker/study-finds-recession-spurred-stem-enrollments/75403).



The Downs

According to the *U.S. News*/Raytheon *STEM Index*, which measures U.S. activity in those fields relative to the year 2000, high school aptitude and interest in pursuing STEM fields have not kept pace with the demand for STEM workers. Although STEM employment in the United States has increased by more than 30 percent, from 12.8 million STEM jobs in 2000 to 16.8 million STEM jobs in 2013, high school student interest levels in STEM are now slightly below where they were in 2000. The report also notes a small drop in the latest U.S. PISA scores in math and science, compared with how students fared on those assessments in 2000. The index is available at www.usnews.com/news/stem-index.

Only Online

Teach the Hour of Code

Show your students that anyone can learn the basics of computer programming—in only 60 minutes—by hosting an Hour of Code in your classroom. Hour of Code events are one-hour tutorial sessions that give students the opportunity to write their first few lines of code. The tutorials are game-like and self-directed, enabling students to work at their own pace and skill level.

Although anybody can host an Hour of Code anytime, the goal is for tens of millions of students to try an Hour of Code during December 8–14, 2014, in celebration of Computer Science Education Week. To sign up or learn more about the tutorials, go to http://code.org.

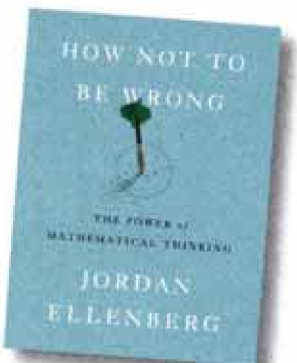
OLLYY/SHUTTERSTOCK

Relevant Reads

How Not to Be Wrong: The Power of Mathematical Thinking **by Jordan Ellenberg**
(Penguin Press, 2014)

"When am I going to use this?" Every mathematics teacher has heard this question, and often the answer is an unsatisfactory, vague suggestion that the student may eventually embark on a career in STEM. Jordan Ellenberg offers a better answer:

> Knowing mathematics is like wearing a pair of X-ray specs that reveal hidden structures underneath the messy and chaotic surface of the world. Math is the science of not being wrong about things, its tools and habits hammered out by centuries of hard work and argument. With the tools of mathematics at hand, you can understand the world in a deeper, sounder, and more meaningful way.



To support this grand claim, Ellenberg presents illustrations from politics, medicine, economics, and theology. Is the United States facing an "obesity apocalypse"? Do colleges whose students have higher average SAT scores charge higher tuition? Even readers who normally avoid mathematics will come away from this book feeling more in the know.

ScreenGrabs

Check out the following TED Talks on STEM:

- **In "The Magic of Fibonacci Numbers," the "mathemagician" Arthur Benjamin explores hidden properties of the Fibonacci series and reminds us how inspiring mathematics can be: www.ted.com/talks/arthur_benjamin_the_magic_of_fibonacci_numbers**

- **In "Hands-On Science with Squishy Circuits," educator AnnMarie Thomas shows how homemade play dough can be used to demonstrate electrical properties—and turn little kids into circuit designers: www.ted.com/talks/annmarie_thomas_squishy_circuits**

Numbers of Note

The Gender Gap

In the Workplace

24 The percentage of U.S. STEM jobs held by women in 2009.

48 The percentage of *overall* U.S. jobs held by women in 2009.

In STEM Degrees

39 The percentage of 4-year STEM undergraduate degrees earned by women in 2009.

61 The percentage of 4-year STEM undergraduate degrees earned by men in 2009.

In High School

13 The percentage of U.S. girls in the high school graduating class of 2016 who want to major in a STEM subject in college.

45 The percentage of U.S. boys in the high school graduating class of 2016 who want to major in a STEM subject in college.

Sources

In STEM Degrees: American Institutes for Research. (2012). *Broadening participation in STEM: A call to action.* Washington, DC: Author.

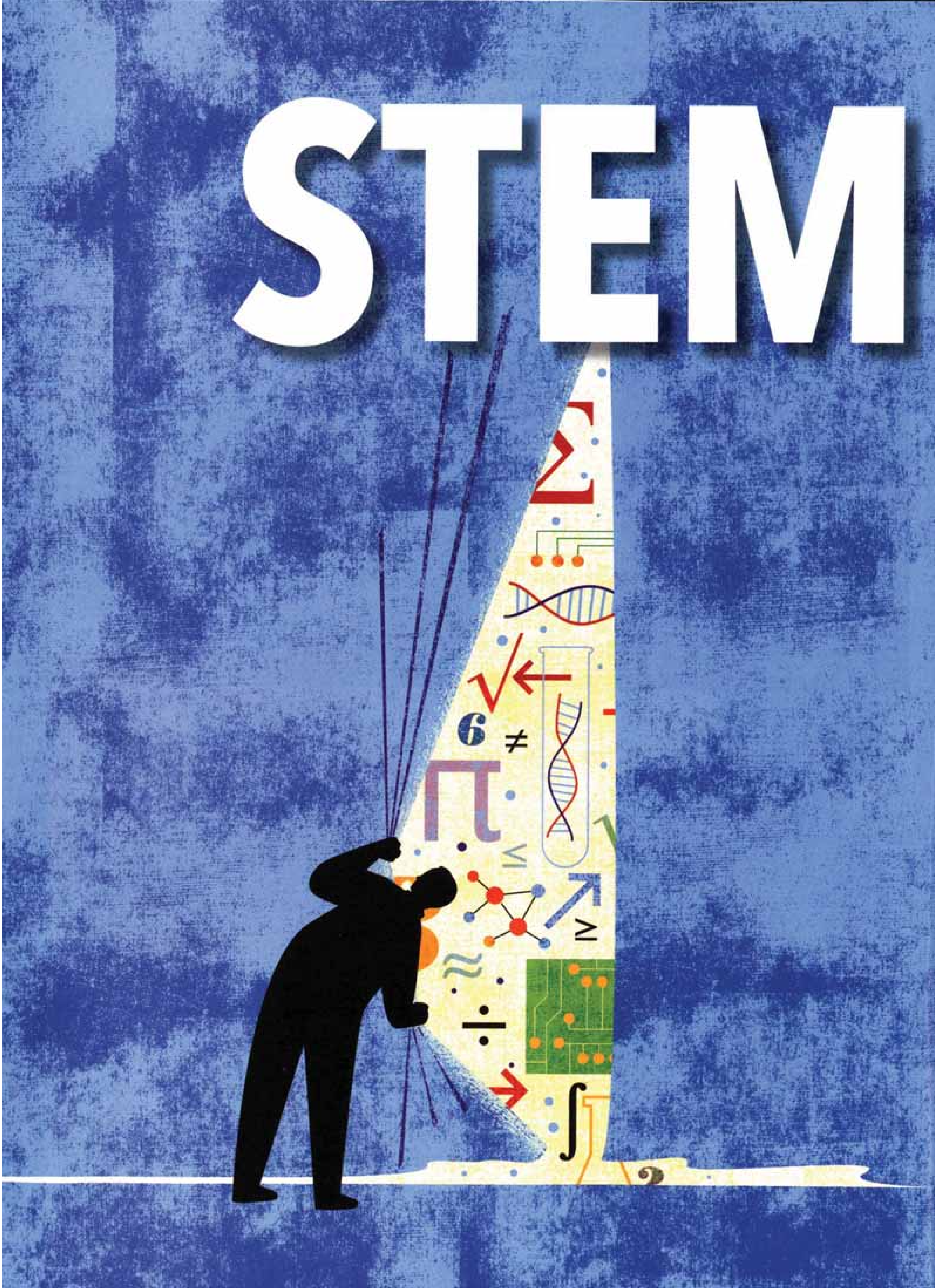
In the Workplace: Commerce.gov. (2012, February 6). The state of our union's 21st century workforce [blog post]. Retrieved from the *Commerce Blog* at www.commerce.gov/blog/2012/02/06/state-our-union's-21st-century-workforce

In High School: My College Options & STEMconnector. (2012). *Where are the STEM students?* Washington, DC: Authors. Based on a survey of 5.5 million U.S. high school students.

PageTurner

"Failure is a necessary attribute of engineering. That's quite a contrast from traditional schoolwork."

—*Christine M. Cunningham and Melissa Higgins, p. 42*


STEM

Beyond the Acronym

STEM education isn't just one thing—it's a range of strategies that help students apply concepts and skills from different disciplines to solve meaningful problems.

Jo Anne Vasquez

Everywhere you turn, STEM-mania has set in. Most educators are familiar with the acronym, but many have questions: Why is STEM education important? Is it for all students, or just for math- and science-oriented students? Can it improve my teaching? Is this just one more add-on to my already packed curriculum?

Everything Has a Beginning

The concept of STEM—for science, technology, engineering, and mathematics—was introduced in the 1990s by the National Science Foundation. Not long after its introduction, we Americans learned that *The World Is Flat* (Friedman, 2005) and that our students were going to be left behind in the globally competitive marketplace because many other countries were out-STEMming us. Government and private funding began to flow toward all different types of STEM education programs, and today STEM has come to be recognized as a meta-discipline—an integration of formerly separate subjects into a new and coherent field of study.

STEM is not a curriculum (although there are STEM-focused curriculums, such as Engineering Is Elementary and Project Lead the Way). It does not replace state standards, nor is it meant to be a quick fix for our education problems. Rather, STEM education is an approach to learning that removes the traditional barriers separating the four disciplines and integrates them into real-world, rigorous, relevant learning experiences for students (Vasquez, Sneider, & Comer, 2013).

BEATRIZ GASCON J/SHUTTERSTOCK

> Space, you see, is just enormous–just enormous.
> Let's imagine, for purposes of edification and entertainment, that we are about to go on a journey by rocket ship. We won't go terribly far–just to the edge of our own solar system–but we need to get a fix on how big a place space is and what a small part of it we occupy.
> Now the bad news, I'm afraid, is that we won't be home for supper.
>
> –Bill Bryson from *A Short History of Nearly Everything*

From Definition to Practice

Defining STEM is the easy part; implementing STEM education on a large scale is more challenging. Part of the problem is the widespread confusion about what STEM actually looks like in the classroom. (Bybee, 2013).

STEM teaching can take various forms. It doesn't necessarily have to incorporate all four of the STEM disciplines every time, and it's not always problem- or project-based. But all STEM learning does have one thing in common—it gives students opportunities to apply the skills and knowledge they have learned or are in the process of learning. Application is at the heart of STEM education. When students ask, "Why do I have to learn this?" a STEM experience provides them with an answer.

> All **STEM learning** has one thing in common–it **gives students opportunities to apply the skills and knowledge** they have learned.

Here's one example of a STEM unit (Vasquez, Sneider, & Comer, 2013). A group of 5th grade students are learning about force and motion in science and about data analysis in math. They work in teams to design roller coaster tracks out of cardboard boxes and tubes. As a first step, they use a measuring tape, marbles, masking tape, and several sections of plastic track to learn how a marble moves along the track. They are instructed to measure, in one-second intervals, how the marble accelerates as it rolls down the inclined track. The students plan and conduct the experiment without detailed instructions. Each group compiles its data into a graph, applying the data analysis methods they have studied to choose the appropriate type of graph (for example, bar or line) and what data to use (mean, median, or mode).

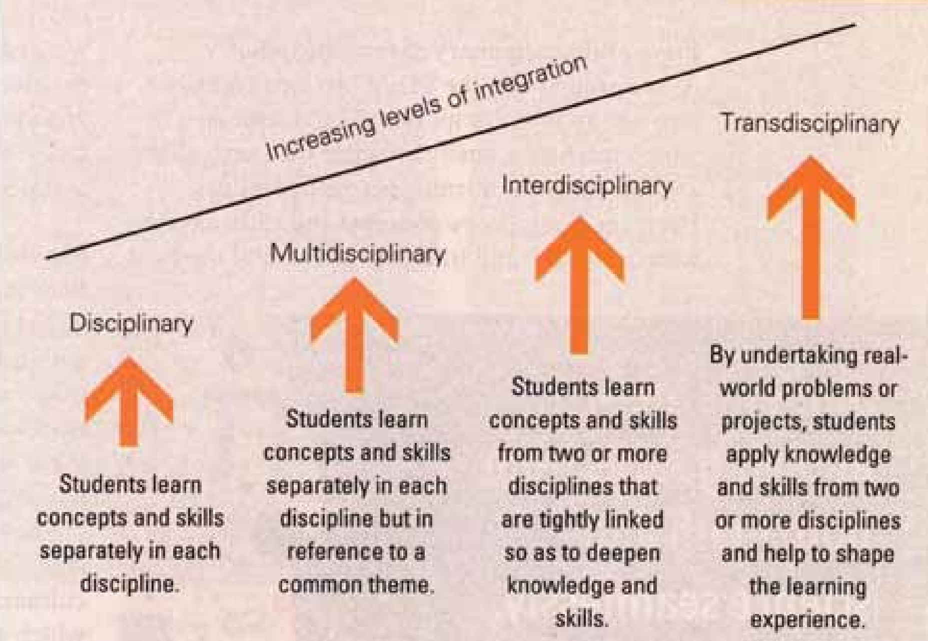
Then the class compiles all the data into one graph that represents the data from all the groups. To do so, they have to debate and decide issues related to the science and math concepts they are learning. For instance, the students see that one group's set of data differs greatly from the others, and on further investigation they learn that the reason is because that group chose a different level of incline for its design. Thus, instead of just being taught the statistical concept of *outliers*, the students gained an authentic understanding of this concept.

During the roller coaster activities, these students are experiencing *transdisciplinary* integration—more commonly referred to as problem-based or project-based learning—which is the most advanced level of STEM teaching and learning. Transdisciplinary integration, grounded in constructivist theory (Fortus, Krajcik, Dershimerb, Marx, & Mamlok-Naamand, 2005), has been shown to improve students' achievement in higher-level cognitive tasks through the application of scientific processes and mathematical problem solving (Satchwell & Loepp, 2002).

Throughout this transdisciplinary experience, the students were applying the new content they had learned in their mathematics (data analysis) and science (force and motion) classes to solve an authentic problem that was of interest to them. They were increasing their communication and collaboration skills as they worked in small groups and then compiled their group results. They were also practicing the engineering design process as they

- defined the problem they needed to solve (to build the roller coaster);
- developed a solution as a group, agreeing on a plan or blueprint; and
- optimized their design (tested whether the roller coaster ramp worked correctly and whether they could collect the data they needed).

FIGURE 1. The Inclined Plane of STEM Integration



Source: From *STEM Lesson Essentials, Grades 3–8: Integrating Science, Technology, Engineering, and Mathematics* (p. 73), by Jo Anne Vasquez, Cary Sneider, and Michael Comer, 2013. New York: Heinemann. Copyright 2013 by authors. Reprinted with permission.

STEM Integration as an Inclined Plane

Transdisciplinary STEM education is the form of integration most often described in the literature because of its relationship to project-based or problem-based learning. It is also the hardest to achieve; it takes careful planning, collaboration, and time to execute within the classroom. But if full transdisciplinary STEM instruction isn't practical (for example, in some middle schools or high schools where subject-area teachers don't have enough common planning opportunities), there are other levels of integration through which teachers can provide STEM experiences for their students.

When students ask, "Why do I have to learn this?" a **STEM experience provides** them with **an answer.**

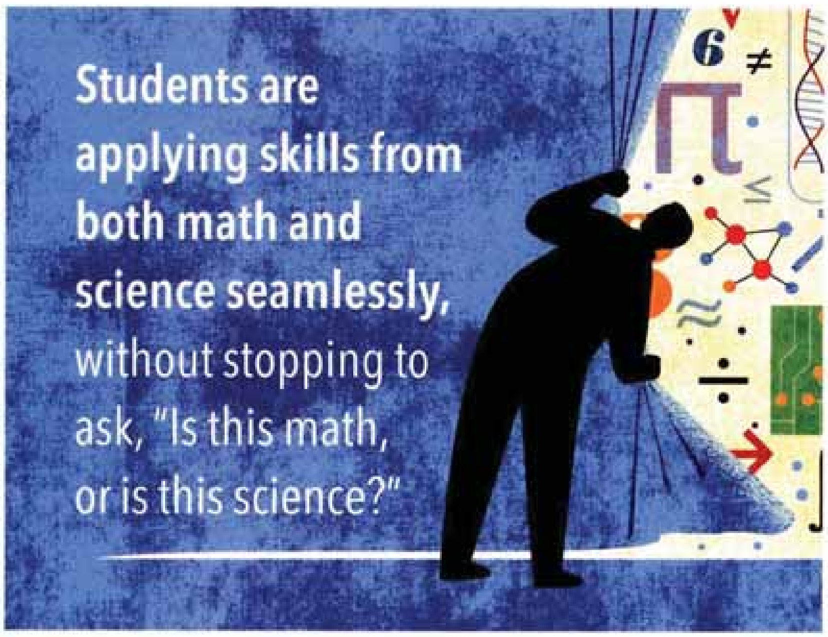
Think of STEM teaching and learning as an inclined plane that has increasing levels of integration (see fig. 1). At the bottom of this plane sits disciplinary teaching, where students learn the content and skills of the different subjects in separate classes. At the highest point of the inclined plane is transdisciplinary integration. As we move up the plane from disciplinary to transdisciplinary, there are two other approaches to organizing the STEM curriculum—*multidisciplinary* and *interdisciplinary*.

Multidisciplinary Integration

Multidisciplinary, or thematic, integration means teaching concepts and skills in separate courses, but linking the content through a common theme. For example, suppose a group of teachers decide to integrate the theme of "structures" into their classes. The science teacher has students study the properties of rocks and compare building materials, such as limestone or marble. In English class, the students write a paper after interviewing construction companies in their community to learn about the process of building a new structure. In history or social studies, they explore the importance of historical structures like the Parthenon and the U.S. Capitol. And in mathematics, they conduct a cost analysis for the construction of some of these historic buildings, researching what the labor, materials, and so on might have cost when they were built and comparing those total costs to what the construction would cost today.

From Multidisciplinary to Interdisciplinary

As we progress on the STEM inclined plane, we move to an interdisciplinary STEM approach in which teachers actually organize the curriculum around common learning across disciplines. Here, the disciplinary concepts and skills become interconnected and interdependent, and the lines between the disciplines become more blurred.



For example, a group of high school students decide they want to revegetate an area of their community that was destroyed by a wildfire. The students make this suggestion to their science teacher, who meets with the mathematics teachers to plan how both of these disciplines can contribute to the content and skills the students will need. Together, the teachers decide that in science class, students will run transect lines to gather data on the types, amount, and geographical distribution of plants in a surrounding area that was not burned in the fire. In math class, they will analyze the data and provide the plot points for the type and number of new plants that should be introduced into the burned-out area.

By gathering and analyzing the mathematical patterns of plant distribution, the students are able to create a viable plan to restore the ecosystem that was lost. In other words, they worked together to create a mathematical model to solve a scientific problem. The students are applying skills from both math and science seamlessly, without stopping to ask, "Is this math, or is this science?"

Moving Up the Plane

Both multidisciplinary and interdisciplinary STEM instruction are worth doing; compared with traditional instruction, these approaches offer increased relevance and rigor. But we don't need to stop there—it's often a small step from these approaches to transdisciplinary STEM learning.

The middle school students' multidisciplinary study of water conservation, for example, could culminate with a transdisciplinary experience in which students see how much water the school can conserve in one week. They might use mathematics skills to calculate the baseline amount of water per student that the school uses for landscaping and in the cafeteria, science skills to design water catchment areas on their school grounds, and language arts skills to write up their findings. In social studies, they might research what groups would be receptive audiences for their findings, such as the local water agency, school administrators, groundskeepers, and other students. This transdisciplinary STEM experience would be both relevant to the students and beneficial to the community (Curtis, 2002).

To move the high school students' revegetation learning experience from interdisciplinary to transdisciplinary, the students would use the data and information they gathered to actually carry out the revegetation project. In addition to applying their science and mathematics learning, they would develop many other content and skill areas as they planned the steps needed to accomplish the task, wrote to local nurseries to ask them to donate plants, got community members involved, raised the funds needed, and so on.

Creating STEM Experiences

Planning authentic STEM experiences, at whatever level, must start with the outcomes we desire for students. At the heart of STEM teaching are the following questions:

- What should the students know and be able to do? What are the enduring understandings they will gain through these STEM experiences?
- How will I know whether my students have achieved the desired results? What evidence of student understanding will I need?
- What prior knowledge and skills will the students need to perform effectively if they are to achieve the desired results?
- What level of integration will be the most effective to accomplish the learning goals?
- How will lessons be sequenced? What resources and materials will students need to accomplish the learning goals?

Developing integrated STEM experiences is not a linear process. It takes collaboration and preparation. If you haven't taught this way before, it will stretch you as a professional. If you are a middle school or high school teacher, you'll need to think of your content area in the context of other content areas. If you are an elementary school teacher, you'll need to break down those content silos—for instance, showing students the relevance of the persuasive writing they're learning in English lessons by applying it to a science topic they have researched, such as, "Should the buffalo at the bottom of the Grand Canyon be relocated?"

The benefits are worth it, though. Most teachers have experienced the feeling of, "I thought I taught it. I know I taught it. But then I figured out they really didn't get it!" In STEM education, students show you whether they really "got it" as they apply and connect their learning to new situations. This application of the disciplinary concepts and skills is the real power of an integrated approach.

It's OK to go slowly at first. Don't feel that you need to embrace STEMmania too quickly. But when you do, you may wonder, "Why haven't I been teaching this way all along?" EL

STEM Is Everywhere

Pick up a pen and take a close look at it. Do you think this is a piece of technology? If you're like most people, you probably answered no. We tend to think of technology as just things we plug in; in fact, however, technology is anything that is made by humans and used to solve a problem.

The pen certainly solves a lot of problems, and it's very convenient. Let's look at this pen a bit closer. Are there different parts that make up the pen? How many would you get if you took it apart? What happens if you touch the point of the pen to your tongue? Do you think that ink would harm you? (It would not, because this ink was developed and tested by biochemists who made certain the ink was not toxic.)

The physical properties of your pen (hardness, durability, and mass) and the way the parts function together result from the calculations of mathematicians and the design choices of engineers who worked in interdisciplinary teams to develop it. The humble pen in your hand is an excellent example of technology based on science, engineering, and mathematics.

Author's note: Examples used are from Science Foundation Arizona's Helios STEM Pilot Schools funded by Helios Education Foundation.

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In Step with the New Science Standards

Jeff C. Marshall

Whether your state has adopted the Next Generation Science Standards or will soon revise its own science standards, one thing is clear: Change is underway—in what is learned, in how we teach, and in how we assess. This is more of a revolution than just another iteration of the same old stuff. It's a dramatic shift in the expectations that we have for all students. Let's look at five ways that the new science standards will influence teaching and learning and five recommendations that can help ensure success as you begin your journey.

The Next Generation Science Standards can transform how teaching and learning unfold in the classroom. Here's what they look like—and how you can get started.

What to Expect from the New Standards

① ***The standards provide opportunity.*** Teachers typically vary in their acceptance of standards, with some teachers seeing them as an obstacle that gets in the way of success and others viewing them as a foundation that guides instruction and learning. I suggest that we look at the new standards in a positive light—as an opportunity to challenge learners through authentic, meaningful learning contexts. We can debate whether there are too many standards or take issue with specific ones, but all in all, the new standards afford an opportunity to make learning relevant, challenging, and meaningful for all students. This shift from lesser to greater meaning is inherent in the basic architecture of the standards, which are referred to as *performance expectations*.

To succeed with the standards, schools and districts must shift from a predominant focus on lower-order thinking to one that makes higher-order thinking the norm. Many of the former state standards that were awarded high marks from the Fordham Institute's evaluation of science standards (Gross et al., 2005) placed great value on such skills as *listing*, *recalling*, and *defining*; relevance and meaning were secondary to the learning, if they were present at all.

The Next Generation Science Standards require students to engage in *doing* science by modeling, analyzing, and designing. These actions, by their very nature, encourage relevance, creativity, critical thinking, and meaning. (See fig. 1 on p. 18 for a comparison between the new middle school performance expectations and one state's previous science standards.) This new framework necessitates that we think differently about how teaching and learning transpire.

FIGURE 1. Comparison of NGSS Performance Expectations and Previous State Science Standards for Middle Grades

Discipline	NGSS Performance Expectation	2005 South Carolina Science Standards
Life Science	MS-LS1-5. Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.	7-2.7. Distinguish between inherited traits and those acquired from environmental factors.
Physical Science	MS-PS3-5. Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.	6-5.1. Explain how energy can be transformed from one form to another in accordance with the Law of Conservation of Energy.
Earth/Space Science	MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.	6-4.8. Explain how solar energy affects Earth's atmosphere and surface (land and water).

② *Instruction builds toward mastery of performance expectations.*

Former state and national science standards typically were crafted with a one-to-one ratio between the standard and the objective, almost as though learning were a checklist to complete. For instance, a previous 3rd grade standard began, "Illustrate the life cycles of seed plants and various animals. . . ." This standard could have been achieved in one class period through direct instruction, with time given for the students to draw their illustrations. This only served to perpetuate the feeling that the standards were prescriptive, limiting, and just something to "cover."

Not so with the new performance expectations, which provide objectives that often will take days to master. Students will need to explore, study, and investigate before they can provide evidence-based claims or model complex concepts and phenomena observed in the natural and designed world.

For example, in 4th grade, before students can "use evidence to construct an explanation relating the speed of an object to the energy of that object" (4-PS3-1), they must first explore, investigate, and collect data regarding an object moving at different speeds. They might begin by exploring the energy associated with a car rolling down an inclined surface; as the incline increases, so will the distance traveled because the potential energy increases.

Likewise, high school students must explore and investigate meiosis and mutations before they can "make and defend a claim based on evidence that inheritable genetic variations may result from (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors" (HS-LS3-2). Students might brainstorm various ways that information can be passed from one generation to the next. (These could include diaries, newspapers, movies, and e-mails, as well as DNA.) Once students begin to understand the basic process of how genetic information is passed from one generation to the next, they might discuss how possible variations occur. As they identify one of the mechanisms—for example, random, viable error in the passing of the code—the teacher might introduce supporting examples, such as how antibiotic-resistant bacteria evolve. Thus, instruction builds toward mastery of the performance expectations instead of conforming to a checklist of material to cover.

③ *Practices are integrated with concepts.*

In the National Science Education Standards, the former guiding document for most state science standards, inquiry was separated from the content standards (National Research Council, 1996). Instruction often separated the "doing of science" from the content of science. For example, many teachers taught the scientific method as a unit separate from the concepts under study.

This was problematic on two levels: First, it taught that science is always conducted in a single linear sequence, which is not true; second, contextual, relevant learning experiences were largely absent in this approach.

The Next Generation Science Standards help remedy this with performance expectations that integrate specific practices with core concepts. For example, the high school expectation, "Plan and conduct an investigation to promote evidence that feedback mechanisms maintain homeostasis" (HS-LS1-3) unites practices (plan and conduct an investigation) with core concepts (mechanisms that maintain homeostasis).

④ *Strategies are aligned to performance expectations.*

Although the new science standards provide the foundation on which teaching and learning will transpire, the curriculum is left up to the state, district, or school. With the change in expectations and the significant increase in rigor and in the need for higher-order thinking skills, it makes sense to rethink which strategies will promote success for all students.

Inquiry-based instruction provides an equitable strategy for achieving mastery. It's been shown to facilitate greater student achievement relative to the learning of both core concepts and scientific practices (Roth, Marshall, Taylor, Wilson, & Hvidsten, 2014). A five-year study that included more than 10,000 students has shown that students of teachers who focus heavily on inquiry-based instruction significantly outperform similar students in classrooms where the teacher uses more traditional forms of instruction (Marshall & Alston, in press). The exciting part is that these findings hold true for male, female, white, Hispanic, and black students at all ability levels.

Inquiry-based instruction has additional strengths. First, it provides opportunities to more easily differentiate instruction. When students are engaged in the design of an investigation or are asked to model their understanding, creativity flourishes. Because learning is not prescriptive, individual students or small groups of students can take more or less challenging approaches in their investigations.

Second, inquiry-based instruction fosters mastery of more advanced, higher-order thinking skills. With that greater emphasis, the need for group interaction becomes paramount to success. As learning becomes more complex, there's a greater need to gather input from multiple perspectives. Moreover, if the questions are challenging enough, students need ideas and assistance from others to complete the task at hand, which could involve carrying out an investigation, analyzing and interpreting data, and communicating findings.

Finally, inquiry-based instruction addresses student (and teacher) apathy. Around 3rd grade, students frequently begin to disengage from

By sandwiching change between slices of the familiar, **teachers can enact incremental changes that can dissipate the anxiety** typically associated with change.

learning (Fried, 2001). They often realize that school is a game to master—and that mastering the game is more important than learning. Thus, *learning* becomes different from *school*. By seeking answers to real-world problems, inquiry-based instruction provides a strategy to reengage those who previously failed to see purpose and meaning in school.

⑤ *Assessments drive change.*

Undoubtedly, high-stakes tests will drive the change. Just as with the Common Core State Standards, the assessments for the Next Generation Science Standards will lag behind implementation. This is beneficial because it gives us time to assemble appropriate professional development opportunities that seek to transform instructional practice, but it's also limiting because we can only approximate the final metrics.

Nevertheless, the new standards provide *assessment boundaries* in many of the performance expectations to help guide the depth of learning. For instance, for the high school life science performance expectation, "Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms" (HS-LS1-4), the assessment boundary states, "Assessment does not include specific gene control mechanisms or rote memorization of the steps of mitosis." In light of that, an assessment might ask students to create a five- to eight-panel cartoon strip, using 30 words or fewer, to progressively show how a zygote differentiates into a complex organism.

Five Recommendations for Success

① *Move rocks, not boulders.*

It's best to start small, seeing intended changes through to fruition before tackling more. The Electronic Quality of Inquiry Protocol (EQUIP) rubric provides one example of an instrument that teachers can use to target intentional change (Marshall, Smart, & Horton, 2010). The rubric provides 19 indicators of practices linked to student achievement that teachers can change in the areas of instruction, curriculum, assessment, and discourse in the classroom. Indicators include such items as teacher and student roles, question complexity, communication patterns, the role of assessment, the degree of student reflection, and integration of content and investigation.

The instrument doesn't seek to measure all forms of quality instruction—only those that are inquiry-based. There are four levels of proficiency: *pre-inquiry*, *developing inquiry*, *proficient inquiry*, and *exemplary inquiry*. (The Electronic Quality of Inquiry Protocol rubric is available for download at www.clemson.edu/hehd/departments/education/iim/documents/equip-2009.pdf.)

What it needs is for the air to be made right. If you want a bee to make honey, you do not issue protocols on solar navigation or carbohydrate chemistry, you put him together with other bees...and you do what you can to arrange the general environment around the hive. If the air is right, the science will come in its own season, like pure honey.

–Lewis Thomas from *Lives of a Cell: Notes of a Biology Watcher*

For instance, the *proficient inquiry* expectation for the instructional indicator Order of Instruction states that teachers should provide opportunities for students to explore major concepts (such as forces and motion, inheritance of traits, and chemical reactions) *before* the formal explanation occurs and that students and teachers will be involved in the explanation. To that end, 2nd graders, armed with a magnifying glass, a ruler, and their notebook, might explore the different forms of living matter (plants, insects, birds, and so on) in a field or outdoor classroom and sketch and describe what they found. On returning to class, they could share their findings, conjecture why certain things were or weren't present, and begin to explore what other habitats might look like, given different conditions. In this case, students are exploring biodiversity on their own, without first being told about the various habitats and the kinds of living things found in each one.

Although seemingly small, this change takes time and effort. However, the effect can be enormously beneficial to students. As Malcolm Gladwell (2000) points out in *The Tipping Point*, small changes can have extraordinary effects—when the change is the right one.

② *Offer a peanut butter and jelly sandwich instead of Brussels sprouts.*

Because people tend to avoid change and because change can produce anxiety, it's important to introduce it gradually. Two approaches will help: scaffolding the change and using the sandwich effect.

Scaffolding change allows for growth while enabling students and teachers to remain within their comfort levels. For instance, breaking an assignment or goal into smaller timed tasks enables students to progress without becoming cognitively overloaded. Instead of giving students 50 minutes to plan, carry out, and communicate findings concerning a scientific question, you could scaffold the experience. Give students eight minutes to develop and present their group's procedure, then three minutes to discuss how they'll collect and organize data, and so forth. Note that the emphasis moves away from telling students what to do. Instead, they engage in the work through a series of guiding scaffolds. Students don't get overwhelmed, and if they do, they only have to wait a minute or two to get teacher support.

By sandwiching change between slices of the familiar, teachers can enact incremental changes while dissipating the anxiety typically associated with change. For example, if students have always completed prescriptive lab experiences in which everything was provided for them, begin with small changes to make the inquiry less prescriptive. If students will be collecting data, give the procedure, but don't include the data table. Instead, let groups wrestle with how to organize the data. Then, as a class, work through how to make sense out of what the students observed or collected.

Students frequently struggle at first and ask what they're supposed to do. This provides a great opportunity to ask them to discuss the kinds of data they'll need to collect and how they'll go about organizing the data. The first time students do this, you can walk through the process with the class as a whole, but over time, groups or individuals should be able to organize data without major teacher support. Thus, you've sandwiched the change (collecting and analyzing data) between the familiar (procedures and questions).

③ ***Muck around, and then make sense.***
In inquiry-based instruction, students need opportunities to explore ideas before the formal explanation occurs. However, this shift in approach takes time, and it should be tackled collaboratively as a school or science department and supported through sustained professional development. We need to acknowledge that most of our preparation as professionals and most of our experiences as students were counter to this new approach. The explain-first paradigm sufficed in a world that sought and valued primarily factual knowledge, but today such knowledge is only a small portion of expected outcomes.

For example, in a life science class in which students are beginning to study the cell, students can view microscope slides or digital images *before* you've told them the names and functions of the organelles. As they draw what they see, formulate questions, and model things that are going on in the cell, they create need-to-know information. Compare this with the more traditional situation in which the teacher tells the students all the parts and functions of the organelles and leaves them to memorize and identify the parts from pictures or slides.

Likewise, in a unit on weather, you could ask students to explore an essential question, such as, How can you predict tomorrow's weather? This sets them on a quest for learning. In contrast, just telling them what's required in terms of instruments and data doesn't give them the opportunity to muck around with books, resources, and equipment to begin solving the question.

The Next Generation Science Standards require students to **engage in doing science by modeling, analyzing, and designing.**

Because this shift in instructional approach takes time to master, teachers and administrative leaders need to carefully prioritize professional development. We already know many essential components of effective professional learning:

- It needs to be sustained over a significant period of time (1–2 years is the target for major instructional transformations).
- It needs to provide modeling and time for practice.
- The administration needs to value it as a priority. This work is not an add-on to everything else; instead, learning is offered *in place of* something else.
- Administrative support needs to be present throughout the professional development.

Sometimes an internal person in the district can facilitate this process without assistance; in other cases, uniting with an external consultant can add credibility and provide guidance in key areas. The time and effort that teachers spend in targeted professional development must become a central focal point because they're essential to achieve this shift.

④ *Run the marathon instead of the sprint.*

The tendency in our quick-fix society is to seek super-fast solutions—even to problems as complex as learning. But just telling students more facts, having them memorize more information, or assigning more of the same type of problems won't help them excel with the new science standards.

Instead, the goal should be sustained growth over an extended period of time. Teachers should give students data sets to interpret, provide multiple experiences with science content rather than just one, and offer time for students to practice after they have understood the concept—not before. Although our inclination is to make lots of changes all at once, both teachers and students need time to adjust, so it's preferable to scaffold changes, adding one new piece at a time and developing competence before tackling more.

⑤ *Put the challenges in perspective.*

Challenges often accompany change. However, we can address them by being proactive and intentional.

The first challenge is this: Inquiry-based instruction, which aligns so beautifully with the Next Generation Science Standards performance expectations, isn't the easiest way to instruct. But considering the academic success and personal growth that students experience when they engage in inquiry learning, our goal should be *effectiveness* as opposed to just ease and efficiency.

A second challenge is that classroom management looks different when students are active and engaged (Marshall, 2013). Compliant learners who sit passively in rows will behave differently from active, engaged learners who are exploring and creating. This can be exciting, but it requires forethought in your role as a facilitator of learning.

An excellent way to begin shifting from teacher-as-teller to teacher-as-facilitator entails improving your questioning. Try to move away from fact-based, fill-in-the-blank questioning toward asking more *how* and *why* questions. Consider the way you respond to student comments. Instead of simply affirming the accuracy or inaccuracy of a response, move toward a more conversational style that seeks and values input from everyone in the classroom.

It's a Victory for the Team

The Next Generation Science Standards provide a framework to help teachers and students thrive. And because of their natural alignment with inquiry-based instruction, they offer an equitable approach for achieving mastery.

Effective professional development will be essential to help teachers transition from previous approaches to newer and more relevant forms of instruction and curriculum. However, the success that teachers can experience with all groups of students at all ability levels makes this effort toward transformation worthwhile. EL

Author's Note: The standards quoted in this article are from NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

Editor's Note: Coincidentally, two rubrics mentioned in this issue share the same acronym, EQUIP. In Jeff Marshall's article, "In Step with the New Science Standards," the Electronic Quality of Inquiry Protocol (EQUIP) rubric focuses on assessing the level of inquiry learning in the classroom. In Jo Ellen Roseman and Mary Koppal's article, "Aligned—Or Not?" the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric provides criteria by which to measure the alignment and overall quality of materials with respect to the Next Generation Science Standards.

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ALIGNED

With the advent of the Next Generation Science Standards, educators and curriculum developers need to know which materials are really aligned to the new standards.

Jo Ellen Roseman and Mary Koppal

In February 2014, a year after the release of the Next Generation Science Standards (NGSS), state leaders and national partners in the development of the standards met to consider strategies for implementing this ambitious new vision for science education. Among other key aspects of implementation—from professional development to assessment to advocacy—the role of curriculum and instructional materials was a major focus. States and school districts seeking to implement the new standards wanted to know which materials are aligned to the standards and support the standards' three-dimensional learning approach.

The answer from the standards' developers was short but not sweet: You won't find much now, and it's going to take time. Our work here at Project 2061, a long-term science literacy initiative of the American Association for the Advancement of Science (AAAS), suggests that we shouldn't be too surprised at this cautious response.

Because AAAS is a partner in the development of the new standards, we're committed to their success, but we're realistic about the challenges that lie ahead. These standards are different in some important ways from previous standards, and those differences are likely to have major implications.

What's New?

Two major differences between the new standards and previous ones are likely to affect the design and use of textbooks and other curriculum materials.

Three-Dimensional Learning

The Next Generation Science Standards differ from earlier standards in their focus on having students understand and demonstrate their science knowledge by using it, just as professional scientists and engineers apply their knowledge to investigate and innovate. Students will engage in *science and engineering practices* and use *disciplinary core ideas* and *crosscutting concepts* to make sense of new information, explain phenomena in the world around them, solve problems, and make informed decisions. The working together of these three elements is called *three-dimensional learning*. Each of the three dimensions is important in its own right and contributes to learning in the other two dimensions.

WONDERFULPIXEL/SHUTTERSTOCK

OR NOT?

The *disciplinary core ideas* are central to earth, life, and physical science and explain a host of phenomena in the natural and designed world.

The *crosscutting concepts* (such as patterns and cause and effect) serve as intellectual tools for connecting important ideas across all science disciplines. For example, finding patterns in data enables us to make predictions about new phenomena.

The *science and engineering practices* build on what earlier science standards called inquiry or science process skills to engage students in asking questions or refining problems; investigating and analyzing data; developing and using models; constructing evidence-based explanations and arguments; and obtaining, evaluating, and communicating information.

Research shows that learning improves when science content learning and science inquiry work together, rather than being separated, as is common in classrooms and curriculums today (National Research Council [NRC], 2007, 2012).

> Curriculum materials will have to **do much more than simply cover a set of specified ideas and skills.**

Engaging in science and engineering practices helps students learn science content, and learning the content helps students engage in the practices. Leave one out, and students may not develop proficiency in the other.

The new standards also challenge educators to integrate these three dimensions of learning coherently. Core ideas, crosscutting concepts, and science and engineering practices must build on one another within and across lessons and units and across grade bands. Coherence requires that materials take into account essential science ideas, common student misconceptions, and basic ideas to build on (Roseman, Linn, & Koppal, 2008).

As a starting point for thinking about coherence, educators and publishers can look to the standards themselves, which provide sample learning progressions at each grade band, as well as a matrix illustrating the practices students are expected to master. Another important resource is the AAAS *Atlas of Science Literacy* (www.project2061.org/publications/atlas), which maps the development of nearly 100 big ideas and skills in science, mathematics, and technology from kindergarten through high school and summarizes the research on students' conceptual difficulties for each.

These can be useful tools, but curriculum developers will need classroom data to select phenomena-based activities for students, refine the sequencing of student experiences into a coherent content storyline, and provide the instructional scaffolding necessary for ensuring student learning.

Performance Expectations

To support three-dimensional learning, the standards are structured as performance expectations that require students to demonstrate their knowledge of the three dimensions (NRC, 2012). This is a departure from earlier standards, which typically presented learning goals as knowledge or skill statements (for example, "students should know that . . ." or "students should be able to . . ."). The standards make it clear that performance expectations should not be construed as curriculum. Rather, they're intended to specify what students should know and be able to do for assessment purposes.

For example, an 8th grade performance expectation for life sciences states, "Students who demonstrate understanding can: Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism" (NGSS Lead States, 2013).

Curriculum developers are challenged to provide opportunities for all students to learn all the dimensions of each performance expectation—science practices, crosscutting concepts, and disciplinary core ideas. How this will be accomplished in yearlong or multiyear curriculum materials that target a larger set of performance expectations over time is yet another challenge for developers and publishers.

In the Grip of the Old

Although this increased emphasis on the interplay of science content and science practices is a move in the right direction, changing what actually happens in the classroom won't be easy. A national survey (Banilower et al., 2013) found that a teacher explaining an idea to the whole class was still the most frequent activity in science classrooms, with about 90 percent of the classes including it as part of their most recent lesson. Hands-on activities (which are more likely to be aligned to the science practices) were reported for only 39 percent of the high school classes and for 50 percent and 52 percent of the middle and elementary school classes, respectively.

The same survey showed that more than three-fourths of middle and high school science classes and about two-thirds of elementary science classes use commercially published textbooks or modules. Across all grade levels, nearly 70 percent of the teachers participating in the survey reported using textbooks to guide the overall structure and content emphasis of their instruction. Research has shown that too many materials emphasize technical terminology rather than making connections among important ideas to provide students and teachers with a coherent science narrative (Roseman, Stern, & Koppal, 2010).

Clearly, the quality of the curriculum materials that are developed to support the new standards will be crucial to the standards' success.

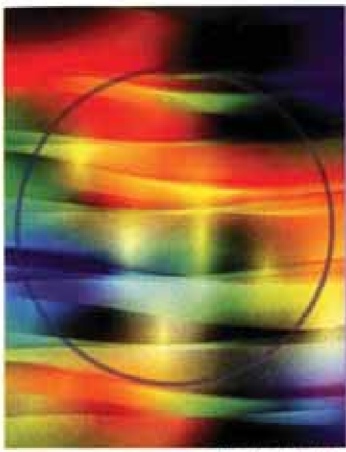
The Next Generation Science Standards differ from earlier standards in their **focus on having students understand and demonstrate their science knowledge by using it.**

Help Is on the Way

Given these two major differences between the old and new standards, and given the importance of the textbook to classroom instruction, what does alignment to the new standards look like? Curriculum materials will have to do much more than simply cover a set of specified ideas and skills. Some developers and publishers are attempting to modify their materials, whereas others are merely making claims of alignment. To date, however, there has been little guidance on what it means to align to the new standards or to support students in achieving the performance expectations.

However, with the release of the Educators Evaluating the Quality of Instructional Products (EQuIP) rubric (NGSS Lead States, 2014), science educators and curriculum developers and publishers now have a set of criteria they can use to assess materials, lessons, and units. (To download the rubric, go to www.nextgenscience.org/resources.) Drawing on criteria developed by Project 2061, the rubric can be used to examine the alignment of material to the Next Generation Science Standards, the quality of the instructional support provided, and the extent to which the material provides support for monitoring students' progress.

It should be noted that the rubric's criteria have not yet been calibrated to indicate the level at which materials do or don't meet each individual criterion. According to the NGSS website, additional resources are being developed for use with the rubric, including scoring guides, a professional



LANTICA/SHUTTERSTOCK

> It is sometimes said that scientists are unromantic, that their passion to figure out robs the world of beauty and mystery. But is it not stirring to understand how the world actually works–that white light is made of colors, that color is the way we perceive the wavelengths of light, that transparent air reflects light, that in so doing it discriminates among the waves, and that the sky is blue for the same reason that the sunset is red? It does no harm to the romance of the sunset to know a little bit about it.
>
> –Carl Sagan from *Pale Blue Dot: A Vision of the Human Future in Space*

development guide, and criteria for textbook and curriculum developers.

Curriculum research and development groups, including our own here at AAAS, have begun to apply the criteria to different curriculum materials. We're currently using the EQuIP rubric to analyze a six-week unit designed to give 8th grade students a strong foundation in chemistry and biochemistry as preparation for high school biology (AAAS/BSCS, 2014). So far, our analysis indicates that the unit is well aligned to several core disciplinary ideas in physical and life science and to the crosscutting concepts of matter conservation and patterns. Moreover, it coherently builds toward a set of performance expectations at the middle school level.

As others apply this tool and report on their results, the rubric should evolve to better meet the needs of educators who are evaluating materials and of curriculum developers who are designing or modifying materials.

Supply and Demand

With 11 states and the District of Columbia—about 26 percent of the U.S. student population—already committed to the new science standards and more states likely to come on board, the Next Generation Science Standards are in a position to exert significant influence on the design and use of science curriculum materials. By providing a common set of criteria for judging curriculum materials in the context of the new standards, the EQuIP rubric can help the science education community build consensus on what well-aligned materials should look like and what evidence developers and publishers should provide to support their claims of alignment.

On the supply side, developers and publishers need to take responsibility for understanding and taking seriously the changes called for in the standards and for providing educators with valid evidence for their claims of alignment. On the demand side, teachers need to take responsibility for understanding the standards and for becoming more critical consumers of publishers' claims. EL

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TINKERING Is Serious PLAY

The maker movement shows that creativity, playfulness and ingenuity can fuel STEM learning.

Bronwyn Bevan, Mike Petrich, and Karen Wilkinson

Gas-powered Roman chariots, singing greeting cards, play dough circuit boards, and homemade voltage detectors are just a few of the science projects you might see when you apply a maker approach to STEM education.

The maker movement celebrates creativity, innovation, and entrepreneurship through the design and construction of physical objects. Maker activities may come across as playful, even slightly wacky, explosions of inventiveness. But in education contexts like schools, museums, libraries, and after-school programs, research shows that if the invitation to creativity is accompanied by intentional structure and guidance, maker activities can be channeled to support deep student learning (Blikstein, 2013; Vossoughi, Escudé, Kong, & Hooper, 2013).

At the Tinkering Studio in the Exploratorium, a museum of science, art, and human perception in San Francisco, we've been developing maker activities for almost two decades. During this time, we've observed how tinkering can support children's development of productive science learning identities. By this we mean that young people become interested in science, feel capable of doing science, and want to do science (Krishnamurthi, Bevan, Rinehart, & Coulon, 2013).

Productive science learning identities are crucial for students choosing to pursue science academically, professionally, and through lifelong engagement. STEM-rich maker activities are powerful places for this identity work because they can accommodate a wide variety of interests and experiences, they blend intellectual and socioemotional engagement, and they provide

Through tinkering activities, **young people become interested in science,** feel capable of doing science, and want to do science.

opportunities for young people to develop, pursue, persist with, and accomplish original ideas and solutions in which they can take pride and ownership.

From Wind Tubes to Circuits

Wind tubes are an example of a maker activity that can serve as a motivating, engrossing introduction to scientific understandings.[1] The wind tubes activity consists of two to three fans facing upward, each set to a different speed (low, medium, or high). A clear acrylic tube is placed over each fan, with an 8-inch gap at the bottom so that objects can be inserted into the tube and lifted up by the breeze. Children work with an array of low-cost materials—berry baskets, cardboard toilet paper rolls, pipe cleaners, straws, masking tape, pieces of cardboard, feathers, tissue paper, string, Wiffle balls, and so on—to construct objects that will float or fly.

The first object children make typically shoots up and out of the wind tube too quickly, or perhaps sinks down and doesn't fly, or bobbles erratically in the tube. They return to the worktable to refine the design, perhaps to add more stability, to streamline, to add weight or remove weight. They test and retest their designs.

Through this process, learners engage in making predictions, designing, testing, revising, and retesting. They grapple with the scientific phenomena of symmetry, balance, weight, and turbulence. When teachers use wind tubes in the classroom, they might provide a period of initial experimentation and then ask students to record their predictions, data, and evidence-based assessments of the relationship of design to flight. As students share their data, they are likely to observe that more than one design element produces similar results. Can they further explore these similarities to elucidate key scientific principles from their firsthand experiences? With students now personally invested in the phenomena, the activity opens the door for further studies of motion and stability, forces and interactions.

Making might look like fun and play, but as Edith Ackermann from MIT says, play is a child's most serious work (Duffalo, 2010). Indeed, both Lev Vygotsky and Jean Piaget have argued that play is a central developmental process for learning.

An example of channeling playfulness into curricular learning comes from the Lighthouse Community Charter School in Oakland, California, where high school students have access to a making space, located inside their science classroom, to build and test their developing scientific ideas and understandings. As a part of the 9th grade physics class, led by Ed Crandall, students are asked to develop investigations that may often require designing and engineering various apparatus that they can use to test their hypotheses or assumptions. One student, a swimmer, explored whether it was possible to build a gill that swimmers could use to extract oxygen from water. Another student, a passionate graffiti artist, designed and experimented with different spray paint can nozzles.

A third group of students wondered why raindrops, falling from such dizzying heights, don't kill people when they fall on their heads. They decided to build an apparatus that would enable them to simulate and measure rainfall. Their goal was to use a counteracting flow of air to suspend a drop of water; when the water drop stopped falling, they could measure the air velocity to determine the rate at which the "rain" was falling. The process of developing the questions; identifying the parameters and variables; and designing, constructing, and fine-tuning a wind tunnel to accomplish their goal ultimately deepened the students' commitment to the process of understanding how friction, gravity, and velocity interact to save us from the force of falling raindrops.

As these examples show, maker activities not only help students develop deep, firsthand learning about scientific concepts, but also engage them in the practices of science and engineering (National Research Council, 2012)—developing questions, defining problems, testing solutions, responding to feedback, and generating explanations or solutions.

A Growing Movement

Making as an instructional practice has deep roots. John Dewey, Jean Piaget, John Friedrich Froebel, and Maria Montessori all promoted making as central to the process of learning. Seymour Papert (1993) argued that the process of physically constructing an object is an effective way for students to both develop and demonstrate understanding. The current maker movement extends and updates this history by integrating digital tools and technologies (such as small, low-cost microprocessors or 3-D design software) into activities that support young people's design and construction goals.

Across the United States, schools, science museums, children's museums, and libraries are designing and building maker programs. School districts in Abemarle County, Virginia; Scarsdale, New York; Lakewood City, Ohio; and Monticello, New Jersey, have created dedicated makerspaces. Brightworks, a school in San Francisco, has organized its entire curriculum around making and invention. Poughkeepsie Day School in New York's Hudson Valley has two different dedicated makerspaces for its preK–12 student body, including a media-rich makerspace attached to the library and a blended physical-digital makerspace that can accommodate paint, sawdust, glue, and other more messy processes and materials.

Although the research on making as an educational practice is relatively new, it has begun to document the ways in which maker activities support the development of students'

Children learn about circuits as they build electronic sculptures that light up, move, and make sounds.

productive science learning identities, collaboration, and innovation (Blikstein, 2013; Kafai, Peppler, & Chapman, 2009). Some scholars argue that making—if it's implemented with an equity lens that pays attention to the intellectual, emotional, and cultural resources children bring to the activity—has an especially powerful potential for engaging young people who have been historically underrepresented in STEM fields (Vossoughi, Escudé, Kong, & Hooper, 2013).

At the Exploratorium, we've developed a framework (see "What Learning in Tinkering Looks Like," p. 32) to evaluate the effectiveness of our maker activities; this framework can apply to the classroom as well (Bevan, Gutwill, Petrich, & Wilkinson, in press). Its dimensions of learning, which include student engagement, initiative and intentionality, social scaffolding, and developing understanding, are features of student activity and behaviors that we can look for, observe, and support to sustain student engagement in the scientific practices inherent in the tinkering processes (Petrich, Wilkinson, & Bevan, 2013).

From Fabrication to Invention

Some researchers caution that there's a risk of presenting maker lessons as step-by-step, recipe-like fabrication activities (Resnick & Rosenbaum, 2013). For example, Blikstein (2013) recounts how his students' introduction to using laser cutters and vector drawing software, which he envisioned as a starting point for creative invention, was such a hit that students became obsessed with repeating the same laser cutting activity each week. They had learned how to produce professional-looking acrylic key chains, and they were content to stop at that point and move into mass production. This phenomenon threatened to shift the classroom from a locus of invention to a facility for fabrication.

To counter such "temptations of trivialization" (Blikstein, 2013, p. 8), it may be important to keep in mind that a powerful aspect of maker activities is what some call "tinkering" (Resnick & Rosenbaum, 2013; Wilkinson & Petrich, 2014). Tinkering, we believe, differs from mere fabrication because it centers on creative, improvisational problem-solving. In tinkering, the purpose of the project may shift as the learner gains new insights and improvises new solutions. Because the end point is unknown and emergent, tinkering closely parallels the exploratory and creative practices of science and engineering.

Schools can partner with local museums, libraries, and community makerspaces to develop maker programs.

Classrooms may need to alternate between fabrication and tinkering; fabrication activities can be useful to familiarize learners with tools or properties of materials and help them develop skills that can later serve more complex and creative tinkering endeavors. Fabrication can provide quick and early moments of success that can be important foundations for deeper learning. It's important to move beyond this phase, but the road from fabrication to invention is not a one-way street: As activities become more complex and students encounter new tools and tasks, they may need to return to more fabrication-oriented projects to become fluent with new techniques. An initial grounding in recipe-based activities can serve as the gateway to creative experimentation later.

For example in a tinkering class on circuitry, students begin exploring the basic concepts of circuits by connecting batteries, bulbs, motors, and buzzers using wires and clips. These "circuit blocks" become the foundations for finding out what works and what doesn't. Adding switches and other inputs or outputs both allows students to develop a general understanding about how to wire a circuit and helps them understand that there are relationships between the types of circuits they build and the brightness of bulbs, speed of motors, or volume of buzzer tones.

With these foundational experiences behind them, students are ready to move on to a series of circuit-related activities that each draw on the initial experience, but add new complexities and often aesthetic opportunities for play, exploration, and personal expression.[2] For example, students may build "scribbling machines"—small objects that use markers as legs to move, leaving colorful trails that map their movements. Students pursue their own ideas for designing and customizing their machines, relying on the basic circuitry skills they developed earlier to power the offset motor that makes the scribbling machine move. Because their basic understanding of circuits has been established, when students' first designs don't behave as they planned, they are able to explore other variables, such as the construction of the body, the length of the legs, or the type of offset weight attached to the motors.

tables with cardboard and glue. A room filled with tools but missing makers and their work is like an empty computer lab. Ensure that students will have the guidance and inspiration of an attentive maker by assigning a staff person to lead activities. Provide opportunities for students to share their knowledge of tools or processes they are passionate about.

Making Future Scientists

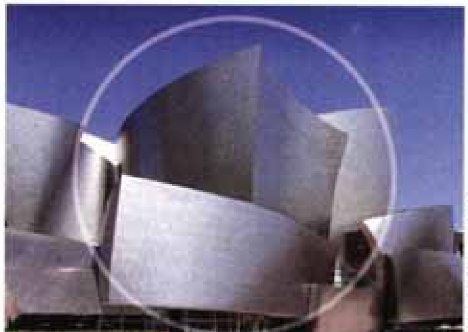
As we mentioned, tinkering activities can help produce students who are interested in science, feel capable of doing science, and want to do science. Some young people will channel these positive science learning identities into future studies and professions. Others will channel them into lifelong engagement with different aspects of nature (environmental stewardship, kitchen chemistry, and so on). Still others will stay tuned in to scientific developments in the news or in their local communities, or perhaps encourage their own children to pursue science careers.

Makerspaces, maker activities, and makers themselves already exist in many communities across the United States. Schools can partner with local museums, libraries, and community makerspaces to develop maker programs. You might want to test out a maker program in an after-school or family night context first. Once you and your colleagues see the active, joyful engagement that young people express in such programs, we can almost guarantee that you will want to seek out ways to integrate making and tinkering into regular school practices and classrooms. EL

[1]For details on how to build wind tubes, see http://tinkering.exploratorium.edu/sites/default/files/projectpdfs/Wind_Tubes.pdf.

[2]For a guide for circuit boards, see http://tinkering.exploratorium.edu/sites/default/files/Instructions/circuit_boards.pdf.

[3]For a collection of open-ended maker activities, see http://tinkering.exploratorium.edu/projects.



TUPUNGATO/SHUTTERSTOCK

Can one think that because we are engineers, beauty does not preoccupy us or that we do not try to build beautiful, as well as solid and long-lasting structures? Aren't the genuine functions of strength always in keeping with unwritten conditions of harmony?

–Gustave Eiffel
Quoted in *Remaking the World: Adventures in Engineering* by Henry Petroski

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How to Bring Tinkering to School

Research and experience suggest a number of guidelines for bringing maker activities to schools. In a literature review prepared for the National Research Council, we identified the following elements that research suggests are important to developing tinkering as a context for learning (Vossoughi & Bevan, 2014):

Create environments for making. Dedicated makerspaces can promote a new level of commitment to making; projects can be left out overnight, and specialized tools can be sectioned off. But dedicated spaces aren't always possible: Many programs have instead transformed classrooms and other settings to support the development of a maker community. Ways to transform a classroom or lunchroom into a temporary makerspace can include placing examples of prior maker work around the room for inspiration, developing a maker language that stresses such ideas as *iterations* or *drafts*, designing and replicating experiments, and organizing work spaces so that students can organically begin to collaborate if and when it makes sense (Sheridan et al., in press).

Interleave fabrication and tinkering. Maker activities support student engagement in scientific and engineering practices through open-ended, creative making. When students are introduced to new ideas or processes, however, they may need simple and easily achievable opportunities to master key ideas, relationships, or tools (Blikstein, 2013). For example, in introducing the wind tubes activity, you might have students start with just one material, such as cardboard cut or folded into different shapes, to observe how key dimensions like size, weight, or shape affect flight.

Provide multiple pathways. Select maker activities that are open-ended and don't have one right answer.[3] Invite students to write about or discuss the most challenging parts of their process and how these challenges led to the students' creations. The breakthroughs associated with the bigger challenges—for example, when a student persists through repeated frustrations to finally figure out the right gear ratio to propel a small motorized solar vehicle—are usually the parts of the process that students are most proud of (Petrich, Wilkinson, & Bevan, 2013).

What Learning in Tinkering Looks Like

Learning Dimension	Learning Indicator During tinkering activities, learners ...
Engagement	• spend time in activities • display motivation or investment in activities
Initiative and Intentionality	• set their own goals • seek and respond to feedback • persist to achieve goals • take intellectual risks or show intellectual courage
Social Scaffolding	• request or offer help to solve problems • inspire or are inspired by new ideas or approaches • make physical connections to the work of others
Development of Understanding	• express a realization through affect or utterance • offer explanation(s) for a strategy, tool, or outcome • apply knowledge • strive to understand

Maker activities may come across as playful, even slightly wacky, explosions of inventiveness.

Show that making is a common practice. Draw explicit connections between maker activities or tools and students' lives and interests. You can do this through class discussions about students' experiences with similar products, tools, or processes. Ask questions like, What kinds of objects in your house depend on electricity? What kinds of building activities have you seen or done at home? Who do you know whose job involves building or designing things? This process of relating the new to the familiar positions students as knowledgeable and experienced makers and opens the process to students who may not already think of themselves as makers or scientists (Vossoughi et al., 2013)

Don't equate making with tools alone. Although high-powered tools can be seductive, remember that making is a creative, person-led process. Making can include students lying on pillows on the floor crocheting, or sitting at

Teachable Moments IN MATH

The new math standards in grades K–2 highlight key concepts that students are expected to understand. Here's why they're important and how teachers can build on them.

Linda Griffin and David Ward

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One morning during the daily calendar routine, Ms. Baxter asks her 1st graders to think of a variety of ways to express the number of the day—12. Her exuberant students come alive with ideas to share. One child suggests 6 + 6, another 10 + 2. Others suggest 2 + 2 + 2 + 2 + 2 + 2 and 5 + 5 + 2. Finally, another one proposes 11 + 1. Ms. Baxter writes each expression on the whiteboard.

The next day, she writes 12 = ___ + ___ on the board and asks the students to recreate their thinking from the day before. Expecting a flurry of hands, Ms. Baxter is surprised when her students' faces show puzzlement. "You wrote it wrong," one child says. "It's backward," says another. More comments follow: "Put the 12 on

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the other side." "You can't write the answer first!"

Ms. Baxter is now the one looking puzzled, and she's faced with a teaching decision. Should she just rewrite the sentence in the more familiar format (___ + ___ = 12) and avoid this confusion? Should she tell the students that writing an equation this way is perfectly acceptable? Should she ask them more questions to find out why this form of the equation is so bothersome to them? Should she ask them what the equal sign means? Which of these instructional responses is most aligned with the concepts that 1st graders are expected to understand in the Common Core State Standards for Mathematics?

As teachers in classrooms across the United States put the new mathematics standards into practice, they'll face countless situations like this one. When teachers encounter an unexpected response or question from students, they must make an instant decision about the significance of the question and choose their response accordingly. The true success of the implementation of the new math standards will be measured here, in the innumerable minute-by-minute decisions that teachers make during instruction. Much attention has been focused on helping teachers use the new standards to plan lessons and units, but teachers also need to understand the intent and trajectory of the standards to capitalize on teachable moments in ways that support students' mathematical understanding and reasoning.

> Many of the early **strategies children will develop** for solving addition and subtraction problems **rely on a meaningful understanding of counting.**

These new standards are not intended to be new names for old ways of doing business. For many teachers, meeting the standards will require a major shift in their approach to mathematics instruction, away from rote memorization and toward understanding and reasoning.

In our work with student teachers, we've found that teachers are better positioned to make instructional decisions that build a foundation for students' mathematical success when they recognize the key concepts in the standards, even when these concepts surface at unexpected times. Let's look at some essential terms in the math standards, as well as at some instructional shifts that will promote understanding.

The Equal Sign

Understand the meaning of the equal sign, and determine if equations involving addition and subtraction are true or false. (1.OA.D.7)

The meaning of the equal sign might seem obvious. After all, it's one of the first symbols that children encounter when learning about operations. However, its ubiquitous presence can lead to misunderstandings about its meaning, as illustrated in the opening vignette. Students often interpret the equal sign to mean "the answer is."

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For example, when students are asked to answer $5 + 6 = \_\_\_$, they may interpret the equal sign as the signal to write the solution in the blank. However, its meaning is much more robust. It means "is the same as" and expresses a numerical relationship. When students recognize the equal sign as a relational sign, it lays the foundation for future mathematical learning. With this understanding, statements like $8 = 3 + \_\_$ and $4 + 2 = 5 + \_\_$, and later, $x + 5 = 11 - x$ make sense and open the door to new strategies for solving complex problems.

Why this concept is important. Understanding that the equal sign signals a relationship between quantities, that it isn't just a prompt to "give the answer," has been shown to offer lasting benefits as students move into the more abstract areas of mathematics in algebra and beyond (Knuth, Stephens, McNeil, & Alibali, 2006). Teachers can use discussions like the one described in the opening vignette to uncover misconceptions about this symbol and address them before they become an impediment to future learning. Engaging in frequent discussions about the symbol and its meaning in the early grades is crucial because developing a comprehensive understanding of the equal sign is a complex process that happens over time, not in a single lesson (Carpenter, Franke, & Levi, 2003).

How you can enhance it. Primary grade teachers can help pave the way for a smooth transition into algebra by making two shifts in their day-to-day practice.

First, from the time you introduce the equal sign, use language to expand students' understanding of it. Replace *equals* with synonyms such as *is the same as, has the same value as, balances*, or *is worth the same as.* Make a poster with the equal sign in the center and a web of synonyms around it, and include a drawing of a balance scale or teeter-totter as a visual reminder. Keep this poster in a prominent place as a reminder for students to use a wide range of terms as they build a deep understanding of the symbol.

Second, make sure that students are regularly exposed to number sentences that vary the position of the equal sign. Review your instructional materials. If the equal sign is always shown in the same position, rewrite some of the number sentences to ensure that students build a flexible and robust understanding of the symbol.

Cardinality

Understand the relationship between numbers and quantities; connect counting to cardinality. (K.CC.B.4)

Young children can "count" objects by mimicking the counting actions they've seen others do long before they understand that counting tells us important information—how many we have. Picture this: The teacher hands a kindergartner seven cubes and says, "Count these for me." The child touches each cube once, saying the next number in the count sequence, ending with seven.

Can the teacher conclude that this child understands counting? In fact, it's impossible to know without asking the child one final question: "How many cubes are there?" The child who responds "seven" understands that the last number in the sequence has special meaning—it tells the cardinality of the collection, how many are in it. A child who hasn't yet developed the concept of cardinality won't be able to answer the question and will often assume it's a cue to replicate the same counting actions that he or she just completed.

Why this concept is important. Cardinality is the ability to bring meaning to the counting process. It opens the door to using numbers for describing and comparing and lays the foundation for combining (adding) and separating (subtracting). Many of the early strategies children will develop for solving addition and subtraction problems rely on a meaningful understanding of counting (Clements & Sarama, 2009; Cross, Woods, & Schweingruber, 2009).

How you can enhance it. Two instructional shifts are helpful here. First, don't assume that a child's ability to recite numbers in order means that he or she comprehends counting and quantity. To find out, ask, "How many?" after each counting task, even when modeling those tasks. When taking the lunch count in the morning, count the raised hands—and then be sure to ask, "How many children ordered hot lunch today?"

A second shift is to approach early counting tasks with an eye toward addition and subtraction. Offer many opportunities for students to count a variety of objects in different-size sets and ask, "How many would we have if we combined these two piles of cubes?" and "How many would you have if I took two pencils out of your basket?" Such tasks encourage students to bring meaning to the counting process and use it as a strategy to solve more complex problems.

Properties

Apply properties of operations as strategies to add and subtract. (This skill appears in several 1st and 2nd grade standards.)

Encourage the exploration of a variety of student observations, even those that may prove to be false.

Working and thinking strategically are hallmarks of the new standards in math. This applies even to basic skills, such as computation with addition and subtraction. Using the commutative and associative properties, young children can make insightful calculation decisions that will simplify computation and reduce errors.

For example, when a student is faced with a problem like $6 + 7 + 4$, a clever calculation move would be to rearrange the numbers by applying the commutative property $(7 + 6 + 4)$ and regroup by applying the associative property $(7 + [6 + 4])$ to create a new problem that's much easier to solve. Teachers need to emphasize the concepts, not the terminology. In fact, the goal isn't to "teach" these properties at all, but rather to give students opportunities to observe patterns, identify relationships, and make their own generalizations about how numbers can and can't be manipulated for each operation (Carpenter et al., 2003).

Why this concept is important. Simplifying calculations isn't the only benefit of knowing and using properties. Mathematical Practice 7 states that "mathematically proficient students look closely to discern a pattern or structure." Students who develop a habit of mind for problem solving that includes reflection and planning ahead will be able to use this skill to great advantage throughout their mathematical careers. Students without this capacity have a tendency to plunge headlong into every problem without first taking a step back to identify the goal and consider multiple solution paths. Whether the context is single-digit addition or more advanced topics, making and using generalizations in clever ways to simplify seemingly complicated problems are essential problem-solving skills.

How you can enhance it. The primary instructional shift here is to create regular opportunities for students to make and test generalizations about numbers and operations. For example, pose a set of problems containing number pairs like $5 + 2 = ?$ and $2 + 5 = ?$ Observe students as they solve them, and watch for a student who immediately knows the answer to the second problem after solving the first. Ask this student to share his or her strategy with the class, and see who agrees or disagrees. Follow up with questions like, "Will this always be true, even for large numbers? How could we know for sure? Is this true for subtraction, too?"

Given the chance to observe and discuss pairs of numbers combined in "forward" and "backward" order, students will invariably come up

EL Online

For more on how teachers can encourage students to think about the meaning of the mathematical operations, read the online-only article "Beyond Computation" by Deborah Schifter and Susan Jo Russell, available at www.ascd.org/el1214schifter.

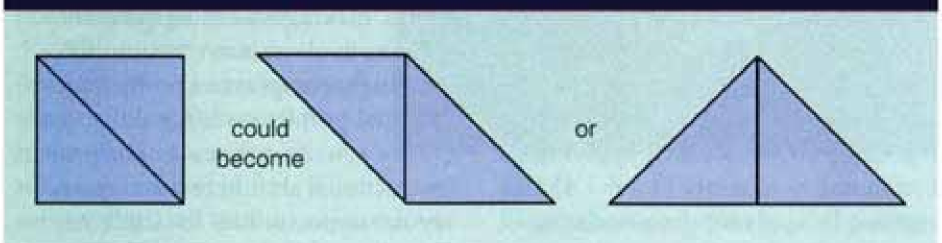
with some version of a "turnaround" rule for addition—the commutative property—and will then use it to solve more complex problems. Remember that the practice of observing and generalizing is as important as knowing and using the properties. Encourage the exploration of a variety of student observations, even those that may prove to be false.

Composing and Decomposing

To compose means "to create or to build." To decompose means "to break down." The fact that these two verbs occur in *six* Common Core standards and across *three* mathematical domains in the K–2 standards is a strong indication of their importance.

Let's look at geometry to illustrate the concept. Students who can compose and decompose shapes have the ability to put geometric pieces together, take them apart, and—most important—put them back together in different ways (see fig. 1).

FIGURE 1. Decomposing and Recomposing Geometric Shapes



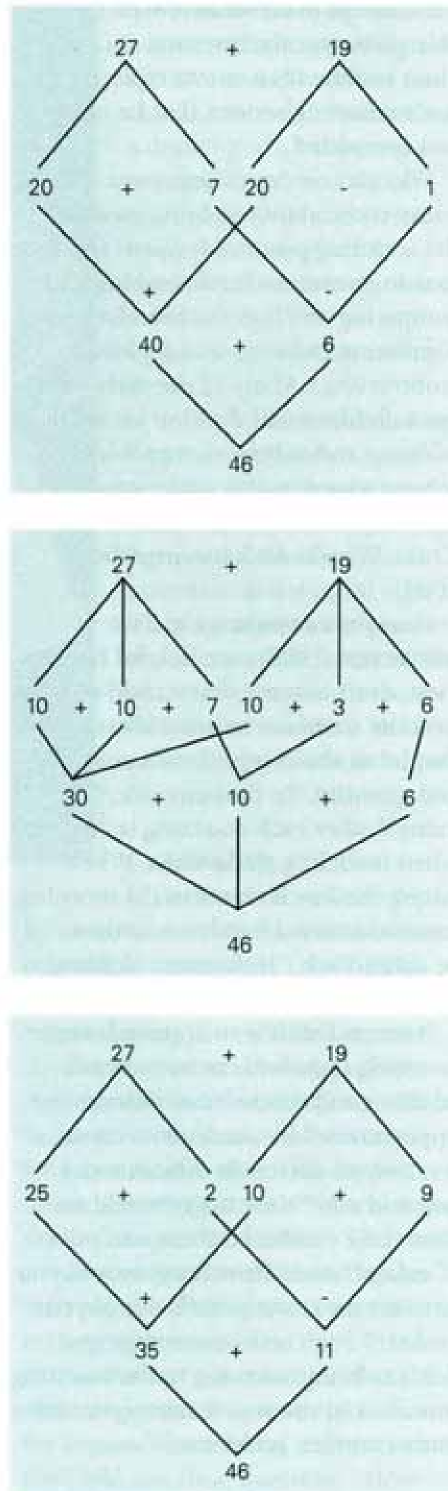
Several standards in the number domains use the terms *compose* and *decompose* to describe similar thinking applied to quantities. Consider the problem 27 + 19 = ___. A student who can compose and decompose numbers could solve this problem by breaking the numbers apart and putting them back together in convenient and clever ways (see fig. 2).

Why this concept is important. Students who develop flexible thinking about numbers early in their schooling are poised to develop complex mathematical thinking as they progress through the grades. Students who can decompose and recompose numbers see many options when presented with a challenging computational problem. Students without this ability typically have only one way to approach it: They line up the numbers vertically and follow a memorized procedure. The ability to compose and decompose numbers also enhances students' knowledge of place value and landmark numbers, such as 25 and 75, and potentially even their reasoning with negative numbers.

How you can enhance it. Use every opportunity to encourage flexible thinking about numbers. Ask, "What's another way to think of that number? How could we break that number into simpler pieces?" Pose number riddles with clues like, "I'm thinking of a number that's made of 4 tens and 7 ones. What's my number?" Or, "If you take my number apart one way, you can see 25 and 25 and 5. If you take it apart another way, you can see 40 and 15. What's my number?" Emphasize finding combinations that use "friendly numbers," like decade numbers (multiples of 10), and easy referents, like 25 or 75.

To promote the geometric aspect of this concept, include shape puzzles as free-choice activities. You can even have students create and share their

FIGURE 2. Decomposing and Recomposing Numbers



own puzzles. Research shows that the ability to compose and decompose geometric pieces transfers to flexibility with number combinations (Clements & Sarama, 2009), so be sure to provide experiences with shapes and numbers.

Unknowns

Use addition and subtraction within 20 to solve word problems involving situations of adding to, taking from, putting together, taking apart, and comparing, with unknowns in all positions. . . . (1.OA.A1)

Traditionally, the term *unknown* is associated with variables in algebra, but that's not the intent in this standard. The point here is to ensure that students go beyond solving the traditional, straightforward word problem formats so often found in textbooks.

For example, a problem like this is commonplace in 1st grade: "Dina had 12 marbles. She gave her cousin 7 marbles. How many marbles does Dina have left?" In this example, we can identify a starting amount (12 marbles); an amount of change (7 marbles); and a resulting amount (the unknown). By shifting the unknown to a different position, this problem could provide much more challenge. Consider these versions:

- *Result unknown*: "Dina had 12 marbles. She gave her cousin 7 marbles. How many marbles does Dina have left?"
- *Change unknown*: "Dina had 12 marbles. She gave her cousin some marbles. Now Dina has 5 marbles. How many marbles did Dina give her cousin?"
- *Start unknown*: "Dina had some marbles. She gave her cousin 7 marbles. Now Dina has 5 marbles left in her bag. How many marbles did Dina have at the start?"

The second and third versions of the problem are more complex both linguistically and mathematically. By varying the position of the unknown, students are now required to generate and apply sophisticated problem-solving strategies.

PIOTR KRZESLAK/SHUTTERSTOCK

Mathematics is to nature as Sherlock Holmes is to evidence. When presented with a cigar butt, the great fictional detective could deduce the age, profession, and financial state of its owner. His partner, Dr. Watson, who was not as sensitive to such matters, could only look on in baffled admiration, until the master revealed his chain of impeccable logic. When presented with the evidence of hexagonal snowflakes, mathematicians can deduce the atomic geometry of ice crystals. If you are a Watson, it is just as baffling a trick, but I want to show you what it is like if you are a Sherlock Holmes.

—Ian Stewart
From *Nature's Numbers: The Unreal Reality of Mathematics*

Why this concept is important. Problems with unknowns in different positions promote multifaceted understandings of relationships among quantities and encourage the development of robust problem-solving skills. When children begin solving word problems, they typically use cubes, drawings, or fingers to represent and act out the situation. A "result unknown" problem (like the original marbles problem) lends itself to this strategy.

However, when the change or the start is unknown, the problem cannot readily be represented using materials or drawings. Students will have to try alternative strategies that involve advanced planning. Problems in which the change or start is unknown require students to combine their knowledge of number relationships and mathematical reasoning to generate more advanced strategies.

How you can enhance it. Shift the emphasis for solving word problems from a routine approach in which most of the problems follow a formula or pattern to one in which there's plenty of variation in the types of problems posed. Students will develop new solution strategies when they can't solve the problems using their original methods (Carpenter, Fennema, Franke, Levi, & Empson, 1999).

Review your curricular materials to see whether they include opportunities to solve problems that represent a wide range of types and structures. Keep in mind that it isn't necessary to rely solely on your instructional materials as the source for interesting and varied word problems. Teachers can create their own word problems by varying the number values and the position of the unknown and starring their favorite characters—themselves! There is great power in personalized problems, ones that are based in familiar contexts, such as our school, our class, and our families. If students feel a connection to the problem, they'll eagerly persevere with more challenging problems.

First, Understand

In a 2012 ASCD publication, the first on a list of recommendations for moving the implementation of the new standards forward is to "make sure educators deeply understand the standards and the key instructional shifts they require" (p. 31). Having a thorough understanding of the vocabulary and concepts in the standards provides a strong foundation for making sound instructional choices and will help teachers foster the critical-thinking, problem-solving, and analytical skills that students will need for future success. EL

Authors' note: The standards quoted in this article are from National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common Core Standard Standards for Mathematics*. Washington, DC: Authors. Retrieved from www.corestandards.org/Math

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Engineering FOR Everyone

As schools introduce more engineering activities, six principles will help girls and minority students embrace the E in STEM.

Christine M. Cunningham and Melissa Higgins

The National Science Foundation coined the term *STEM* in the 1990s as a shorthand way to express the importance of science, technology, engineering, and math to future prosperity. But until recently, K–12 educators gave relatively little attention to the *E* in STEM.

Engineering may soon be receiving its due. The new Next Generation Science Standards (NGSS Lead States, 2013) make it a national priority to help U.S. students understand the human-made (that is to say, engineered) world in which we live. Many states have also modified their standards to integrate engineering with science.

But as educators introduce engineering into elementary, middle, and high school classrooms, they face a challenge: how to design educational experiences that are engaging and effective for *all* students. Making engineering instruction more inclusive is important because women and minorities are disproportionately underrepresented in engineering fields in the United States. Most schools have a way to go in terms of inviting everyone into the field.

For example, school-based engineering activities traditionally highlight competitive, decontextualized projects—which fail to attract students who value cooperative work and real-world tasks. Engineering challenges that demonstrate how engineering can help people or society would engage a wider group.

So how do we get to inclusivity?

Six Principles for Inviting Everyone

Curriculum developers associated with the Museum of Science, Boston have identified six design principles that educators can use to ensure that classroom instruction, activities, and materials in engineering engage all students—including students from underrepresented and underperforming populations. We

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Choose activities that highlight **how engineering benefits people, animals, the environment, and society.**

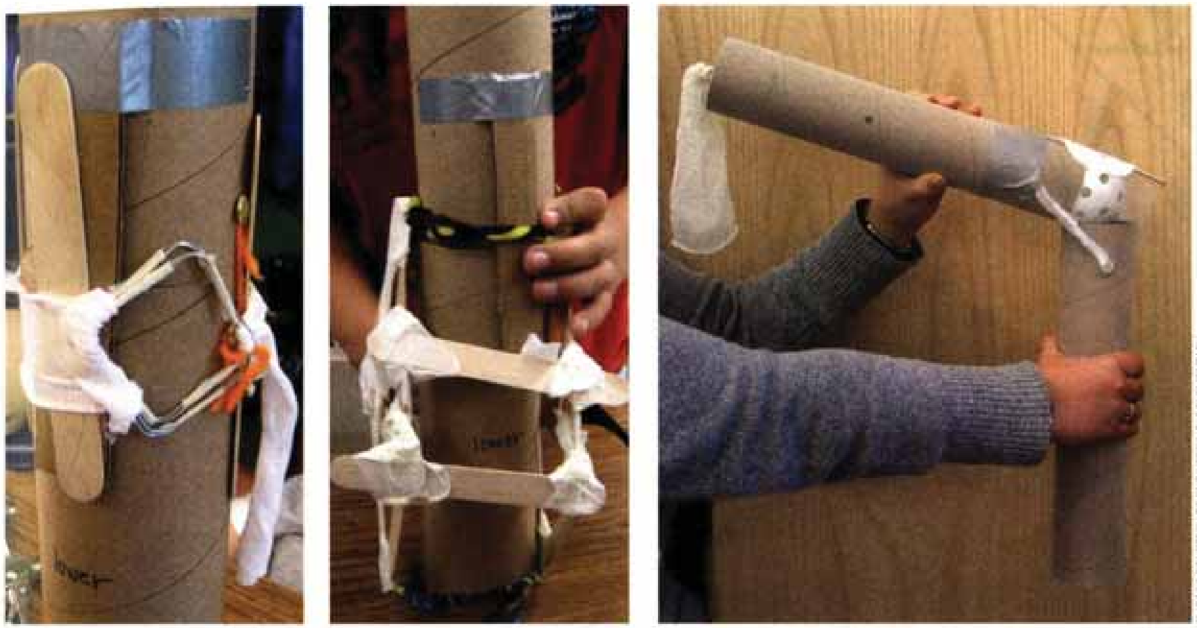
identified these principles while developing the Engineering is Elementary (EiE) curriculum, which guides students through engineering activities based on authentic problems (www.eie.org), but the principles can be applied to engineering activities or units in any classroom.

Set Engineering in a Real-World Context

Many students view the knowledge they learn in school as irrelevant for their careers and future lives (Carlone, Haun-Frank, & Webb, 2011). One way to set a real-world context is through a story—a fictional story, a news item, or even a problem statement.

EiE curriculum units, which are designed for students in grades 1–5, begin with a story. The main character always encounters a problem and solves it using engineering. After reading the story, students tackle the same challenge. This approach immediately places classroom engineering activities in a larger context. The stories are set in different locations around the world; the protagonists represent diverse races, ethnicities, and abilities (giving students role models); and the plots relate to students' own experiences.

For example, most kids have had the experience of being assigned chores they dislike. Unpleasant chores are a plot point in *Lerato Cooks Up a Plan*, a story about a girl in Botswana who is responsible for gathering firewood to cook her family's meals. It's a tiresome chore, especially because Lerato has younger siblings to watch. One of Lerato's friends, a university student studying green engineering, shows Lerato a solar oven. At



PHOTOS COURTESY OF ENGINEERING IS ELEMENTARY

Knee braces students engineered with simple materials show a range of possible solutions.

understand the work of environmental engineers, but also how this work may protect wildlife and ecosystems. Students who recommend where to locate a new bridge see the "helping" nature of geotechnical engineering because they must place the bridge not only where it will be safe, but also where it will allow villagers to easily access the school and clinic on the far side of the river.

Construct Activities with Multiple Solutions

Traditional lessons often require students to arrive at one correct answer. This approach can lead to disengagement, especially if students experience failure repeatedly. Open-ended activities that enable problem solvers to generate a variety of solutions foster creativity, encourage risk taking, and invite exploration of original ideas.

Open-ended activities should be designed so that students evaluate the performance of their designs against a set of criteria and constraints and have a chance to improve these designs. Sharing design solutions with the class as a whole should also be on the bill. Contemplating the common features of successful designs can spark new ideas.

> **"The variety of solutions that the kids came up with was the most exciting thing.** None of the designs looked the same."

Here's an open-ended biomedical engineering challenge from an EiE unit on designing knee braces. Students start by measuring the range of motion of an undamaged human knee joint. Then they're introduced to a model of an injured knee made from a Wiffle ball (the knee joint) set inside two circular cardboard tubes (the thigh and calf) held together by rubber bands. Students will see that this model moves differently from a healthy human knee.

The students' challenge is to engineer a rigid but flexible brace for the model knee that allows a normal range of motion, using only jumbo craft sticks, rubber bands, string, felt, craft foam, fabric, and cardboard. As they engineer, students need to apply knowledge about the range of motion of a knee, knowledge of material properties, and problem-solving skills. After they design a brace, students assess the range of motion it affords and its durability. Students always create different kinds of successful braces—clearly there's more than one solution!

Many teachers we work with say watching students develop a variety of solutions is a highlight of teaching engineering. One 1st grade teacher explains:

> The variety of solutions the kids came up with was the most exciting thing. None of the [designs] looked the same. Not even similar, although they used the same materials. . . . The exciting part was to watch them try it. And then to see the wheels turning and see them talk among themselves about how to improve [their brace]. It was priceless.

first, the oven doesn't work well, but with some careful engineering, Lerato improves the design so it can cook food. Now she can spend less time collecting wood.

After reading the story, students engineer the insulation for their own solar oven, made from a shoebox. First, they conduct controlled experiments to investigate the insulating properties of foil, craft foam, paper, and cotton balls. They use the results from these experiments to decide which materials they'll use as insulation inside their own solar oven.

In addition to our elementary curriculum, EiE has developed an out-of-school-time curriculum for middle school students called Engineering Everywhere, which can be downloaded free from the project website (www.eie.org/engineering-everywhere). Each unit kicks off with a short, lively, documentary-style video that explores a real-world engineering challenge.[1] This storytelling approach piques older students' interest. For example, one challenge invites students to engineer an urban landscape to control storm water runoff—a problem many U.S. communities face. The video introduces students to the problem by taking them on a tour of a city, with an environmental engineer as their guide.

For their engineering design challenge, students work in groups. Each group creates a model city on the bank of a model river. Students place pollutants—small pieces of plastic and drops of food dye and dish detergent—in different locations throughout the city, then use a squirt bottle to model a rainstorm. As the rain falls, students make systematic observations of how pollution is washed off hard surfaces and deposited into the river. They research existing technologies for preventing runoff in cities and test different absorbent materials, then apply what they've learned to their own city models. After-school educators introduce students to an eight-step engineering design process—Identify, Investigate, Imagine, Plan, Create, Test, Improve, Communicate—which students use to guide their work.

Failure is a necessary attribute of engineering. That's quite a contrast with traditional schoolwork.

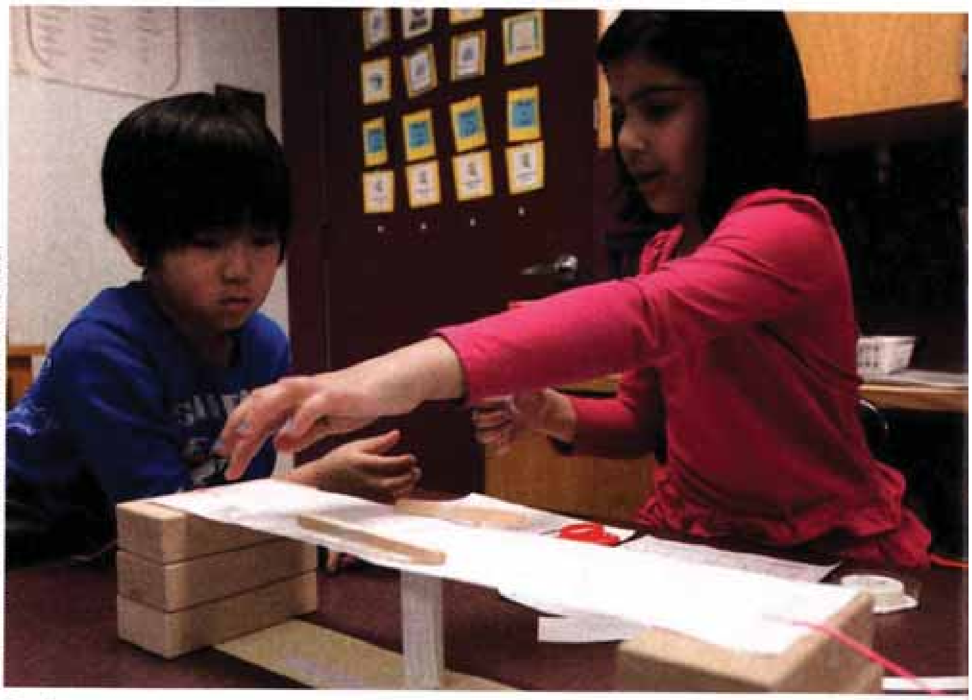


PHOTO COURTESY OF CHRIS SAN ANTONIO TUNIS, MUSEUM OF SCIENCE, BOSTON

Students engineering a bridge discuss how to make it stable and strong.

Highlight How Engineers Help Others

Many students are interested in people-oriented "helping" careers; this is particularly true for girls and underrepresented minorities. Because girls often want to understand the social value of what they're studying, it's a good idea to choose activities that highlight how engineering benefits people, animals, the environment, and society (National Academy of Engineering, 2008).

Sometimes simply reframing an activity you already use so that it emphasizes the altruistic aspect sparks student interest. For example, one common classroom activity is designing an electrical circuit—but often the assignment is made with no particular context. Instead, why not challenge kids to help design an electrical circuit that triggers a buzzer or light when a barnyard water trough is empty? The alarm would alert animal caregivers to refill the trough, ensuring that the animals have drinking water.

Environmental engineers often work to protect the environment. Students who are challenged to design a process for cleaning a model oil spill come to

HEIN NOUWENS/SHUTTERSTOCK

> Alma was a girl possessed by a soaring enthusiasm for systems, sequence, pigeonholing, and indexes; botany provided ample opportunity to indulge in all these pleasures. She appreciated how, once you had put a plant into the correct taxonomical order, it stayed in order. There were serious mathematical rules inherent in the symmetry of plants, too, and Alma found serenity and reverence in these rules. In every species, for instance, there is a fixed ratio between the teeth of the calyx and the divisions of the corolla, and that ratio never changes. One could set one's clock to it. It was an abiding, comforting, unfaltering law.
>
> –Elizabeth Gilbert from *The Signature of All Things*

Value Failure

Failure is a necessary attribute of engineering. Whether you're a student, a teacher, or an engineer, whenever you try innovative ideas, some of your designs will inevitably fail to meet the criteria or constraints of the problem. Because engineering is an iterative process, those designs can always be improved. Failure prompts reflection (What didn't work? Why?) and informs subsequent designs. That's quite a contrast with traditional schoolwork, where failure can carry a stigma.

Engineering activities should embrace failure and cast it as a learning opportunity. We should communicate that students don't fail, the *design* fails. In our experience, students welcome the opportunity to improve their designs. After completing an EiE activity, one student wrote, "I like the plant project. It was fun to mess up and try again." Teachers tell us that students beg to spend more time refining their designs—they come in before and after school and continue their engineering during recess and at home.

The chance to try it again can be a liberating experience, particularly for students who've been categorized as low-achieving. We hear countless stories from teachers of how a student who previously seemed disengaged from schoolwork became highly engaged in an engineering task, persisted through multiple rounds of design, and emerged as a team leader.

Foster Collaboration

Engineers routinely work in teams. Cultivating the skill of teamwork is particularly important because competitive environments can be discouraging to girls and to kids from cultures that value interaction and collaboration (Lee, 2003).

When students work productively in groups, they often identify stronger design solutions and learn more effectively. Collaborating helps students see that when you work with different people, you might generate a more diverse range of ideas, which increases the likelihood that one (or a combination) of these will succeed. Working in teams also gives students a chance to emphasize their areas of strength. Collaboration *across* teams shows kids how they can learn from the successes and failures of others, and when groups pool their data, trends become more apparent.

We see the centrality of teamwork when learners tackle the aerospace engineering challenge of designing a parachute that floats down as slowly as possible. Students experiment with different canopy sizes and suspension line lengths. When they pool their data across groups, the combined information helps them see the relationships among canopy size, length of suspension lines, and drop speed. If students worked individually, it would take each of them a lot more time and trials to reach the same conclusion.

Of course, students, like adults, need to learn *how* to work in teams. Teachers should actively encourage students to share their thoughts, consider other people's perspectives, argue from data and evidence, and compromise to select the best ideas.

Use Readily Available Materials

Using inexpensive materials that are easy to find at grocery, craft, or hardware stores is another way to invite a more diverse group of students to engage with engineering. Because low-tech materials like soda bottles or popsicle sticks are more familiar to students, they're more approachable. Underfunded schools and classrooms can also better afford low-cost equipment. And using easy-to-find materials means kids can continue to engineer at home if they get hooked by a challenge at school.

We find that when engineering challenges employ simple materials (for example, designing a way to make play dough using water, salt, and flour) students often *do* want to continue engineering at home, with positive results. One teacher in a bilingual school shared this story:

> Last year, I worked with a very challenging student population; many of my students had been exposed to trauma and lacked trust in adults and one another. This was often manifested through a lack of motivation on school assignments and outbursts of anger and defiance. That changed when my class began working on the Engineering is Elementary chemical engineering unit, in which students design a process to make play dough. . . . My students became so motivated that almost half the class brought in samples and processes they had developed at home to improve the processes they were working on in class. During class, they discussed the quality of their samples and tried to figure out ways to combine their ideas to come up with the best possible sample. . . . We ended up comparing wheat with corn flour in our samples, as many of my Mexican and Central American students had access to corn flour at home rather than wheat, which brought in a cultural dimension. . . . Several students ended the unit saying they wanted to become engineers as adults.

> One student wrote, "I like the plant project. **It was fun to mess up** and try again."

Every Child an Engineer

As we introduce children to the "new" discipline of engineering, we should do so in ways that will attract and engage all learners and give students opportunities to experience engineering and science education meaningfully. By applying the inclusive design principles outlined here, we'll ensure that every child can engineer. EL

[1] On its website (www.eie.org), Engineering is Elementary provides how-to videos and other free resources to help educators incorporate the kinds of lessons and activities featured in the curriculum into their classrooms.

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Democratizing Computer Science

Why we need to open computer science courses for more students.

Jane Margolis, Joanna Goode, and Jean J. Ryoo

A high school computer science class begins with students divided into groups, writing instructions for making a peanut butter and jelly sandwich. One group of "programmers" goes first, reading instructions to the "computer" (fellow students) for making the sandwich. But a "programming error" occurs: The computer cannot operate because the "algorithm" (instructions) did not specify taking off the lid of the peanut butter as an initial step. Student laughter ensues. Computers are dumb!

The process begins again, with a revised sequence of instructions. But the computer spreads the peanut butter on the table because the algorithm did not specify to spread it on the bread. Whoops and hollers everywhere: Computer science can be fun! All students are engaged.

So begins an early lesson in Exploring Computer Science (ECS), an introductory high school computer science course supported by the National Science Foundation (www.exploringcs.org). ECS's mission is to demystify computer science by introducing students to the fundamental concepts of the field. Students learn about human-computer interaction, problem solving, web design, programming, data analysis and computing, and robotics. Throughout all units, students learn to use computing skills in ways that are meaningful for themselves and their communities.

PHOTO COURTESY OF JEAN J. RYOO

An Equity Imperative

Computer science is generally identified with a narrow stratum of our student population, but all students today need to learn about it because computers are changing how we communicate, innovate, work, play, and think—regardless of career choice. Computer science relies on problem solving and computational practices that are important for everyone. These include using abstractions; automating; creating algorithms; collecting and analyzing data; implementing, testing, and debugging designs; and engaging in creative, critical, and innovative thinking.

Despite its growing importance, computer science is on the sidelines in our schools. The primary

PHOTO COURTESY OF JOHN LANDA

Students develop interest and ability in computer science **when they have opportunities** to engage with it.

college-preparatory course is Advanced Placement (AP) Computer Science, which focuses on programming and fails to attract many students. Computer science is rarely part of the academic core. Further, only a handful of states offer a computer science teacher preparation program that leads to certification.

Computer science is a subject that many students (and adults!) find intimidating. It is stereotypically associated with super-smart, geeky, white or Asian males, many of whom benefited from having resources at home to foster their interest. The statistics of who is (and is not) studying computer science reveal the depth of the problem.

For example, 53 percent of K–12 public school students in California schools are Latino; yet only 8 percent of the nearly 5,000 California students taking the AP Computer Science exam last year were Latino. Six percent of California students are black, but only 1 percent of students taking the exam were black. And only 22 percent of exam takers were female (California Department of Education, 2012; College Board, 2013).

The good news is that a growing number of school districts are working to bring computer science into schools. Exploring Computer Science was first developed in 2008 in partnership with Los Angeles Unified School District as a response to research detailed in *Stuck in the Shallow End: Education, Race, and Computing* (Margolis, Estrella, Goode, Holme, & Nao, 2008). Research conducted in Los Angeles high schools found that schools with high numbers of low-income students of color were offering courses labeled as computer science that included little more than keyboarding and other rudimentary skills. To address this issue and broaden participation in computing, the ECS curriculum was written as an introductory computer science course designed to engage all students in the subject.

Making Computing Relevant

Exploring Computer Science departs substantially from traditional computer science classes focused on programming in which a student predominantly works alone at a computer. Instead, the ECS curriculum is structured around collaborative inquiry practices through which students together explore, design investigations, think critically, test solutions, and solve real problems. ECS classrooms are noisy and active places that encourage exploration, autonomy, persistence, risk taking, and creativity by insisting that there are multiple solutions to a problem and giving students opportunities to seek those solutions for themselves. Sometimes, student work doesn't even require a computer, such as when students learn to think like programmers by writing instructions for making peanut butter and jelly sandwiches.

Science is often misrepresented as "the body of knowledge acquired by performing replicated controlled experiments in the laboratory." Actually, science is something broader: the acquisition of reliable knowledge about the world.

–Jared Diamond
From *Collapse: How Societies Choose to Fail or Succeed*

For traditionally underrepresented students, engagement and learning are deepened when computer science practices are presented in meaningful ways that blend students' social worlds with the world of science (Barton & Tan, 2010). Consider these activities that draw on students' local and cultural knowledge:

- In the first ECS unit on human-computer interaction, students learn about Internet searching by conducting scavenger hunts for data about the demographics, income level, cultural assets, people, and educational opportunities in their communities.
- In the problem-solving unit, students work with Ron Eglash's Culturally Situated Design Tools (http://csdt.rpi.edu), software that helps students see the mathematical and computing principles behind cultural artifacts. In one example, students learn about the history of cornrow braiding and how cornrow designs involve transformational geometry.
- In the web design unit, students learn to use HTML and CSS (cascading style sheets) to create websites on any topic of their choosing, such as an ethical dilemma, their family tree, a possible future career, or worldwide or community problems.
- In the introduction to programming unit, students use the Scratch programming language to create a game or an animated story about an issue of concern.
- In the data analysis and computing unit, students collect and combine data about their snacking behavior and learn to analyze the information and compare it with large data sources.
- In the robotics unit, students program robots to move through mazes or dance to students' favorite songs.

Each unit concludes with a project that connects students' worlds to computer science concepts. For example, in the problem-solving unit, students might connect their knowledge of problem solving, data collection, and minimum spanning trees (subgraphs that connect points on a larger graph) to create the shortest and least expensive route for showing tourists their favorite places in their neighborhood.

Preparing Teachers

In addition to a curriculum, the ECS program includes a professional development program for teachers. It's not easy for teachers to transition from content delivery methods of teaching to inquiry-based instruction. Professional development that builds and supports an ongoing teacher learning community is key. The ECS professional development program spans two years with a combination of two summer weeklong institutes and quarterly Saturday workshops, as well as in-classroom coaching, informal teacher meetings, classroom visits, conferences, and more.

The professional development mirrors how students learn in ECS classrooms. During the summer institute, teachers are immersed in inquiry-based learning as they work in small groups to plan, coteach, and reflect on introductory lessons for fellow teachers who participate as "students." After each lesson, the whole group discusses the implications for teaching these lessons to diverse students: When in the lesson were they the most engaged? The least? Who was never engaged? Why? What strategies contributed to engagement?

The learning continues throughout the school year with monthly professional learning community meetings in which teachers discuss their experiences teaching ECS. The program also includes in-classroom coaching in which coaches who have experience teaching computer science and ECS classes help teachers reflect on how they're implementing the curriculum.

Through teaching ECS, teachers gain an increased appreciation for students' abilities to engage with computer science (Goode, Margolis, & Chapman, 2014). One teacher commented that "I don't need to completely understand each topic in order to teach it—this lets some of my students become the masters and then they can teach the other students." Teachers acquire new understandings of how to facilitate student inquiry, active learning, and student ownership of their learning and of how to draw out their students' investigative abilities and creativity.

PHOTO COURTESY OF JEAN J. RYOO

In a field with strong biases and stereotypes, teachers' new appreciation for students' interest and capacity are essential to broadening participation in computing. Computers don't create cultural change; teachers do. And for this to occur, teachers need the space to think big and be bold about their craft. But it is not just teachers who must change. It is the entire school culture.

Broadening Participation

One of the missions of Exploring Computer Science is to demonstrate that students develop interest and ability in computer science when they have opportunities to engage with it. Keeping the content rigorous yet accessible, engaging, and relevant to diverse students is crucial for broadening participation in computing.

Enrollment patterns of Los Angeles Unified School District (LAUSD) students in ECS reveal high participation rates that closely mirror district demographics. In 2013–14, more than 2,500 LAUSD students enrolled in ECS; 73 percent were Latino, 11 percent black, 7 percent Asian, 8 percent white, and 46 percent female. These ECS demographics are a dramatic contrast to the severe underrepresentation of nonwhite and female students in computer science generally, as indicated by the AP Computer Science statistics (College Board, 2013). ECS has also grown to be a national program with 13 regional programs, including partnerships in the largest three school districts in the United States: Los Angeles, Chicago, and New York City.

Los Angeles student data collected through surveys and interviews show a promising increase in student interest, engagement, confidence, and persistence with learning computer science. There have been statistically significant increases in self-perceived knowledge across all ECS topics, with the largest increases associated with robotics and programming. When reflecting on what she considered a "nerve wracking" process of creating a game in the programming language Scratch, one student said,

> Now I have kind of an idea of how things work, how the cartoonists do stuff and, yeah, it's been awesome. . . . After all of the frustration, it leaves you a satisfying feeling because you're like, "Yes, I did it."

After taking ECS, when students are

asked to describe how computer scientists think, both male and female students are significantly less likely to use words that focus exclusively on intelligence (as they did in the pre-class surveys) and are significantly more likely to use words related to computational practice (such as *analyze*, *program*, or *problem solve*). Female students show a significant increase in growth mind-sets (Dweck, 2007) as they come to view computer science ability more in terms of experience and hard work than innate aptitude. This shift in beliefs is essential to drawing more students into computer science.

ECS classrooms are noisy and active places that encourage exploration, autonomy, persistence, risk taking, and creativity.

Expanding the Effort

Bringing this kind of computer science instruction into the schools is an ambitious reform that must operate on many fronts simultaneously. Courses must exist in the schools; teachers must be identified and given professional development and support; belief systems about who can do computer science must be continually reexamined; and, state, local, and district policies must support making computer science part of the academic core.

In Los Angeles, one key to getting ECS into schools was the successful petition to the University of California Office of the President for the course to count toward college admission. At the district level, Todd Ullah, former LAUSD Director of Science, helped us design the school implementation procedures.

Principals are asked to identify teachers to attend the professional development at no cost to the school, and the principals then commit to placing ECS on their schools' master schedule. These principals are also asked to identify a diverse range of teachers—especially those most open to inquiry practices and familiar with or eager to learn about computer science. We prioritize underserved schools and those with high numbers of low-income black and Latino students, and counselors help ensure gender equity in the classes. District leadership, local superintendents, and principals' organizations receive ongoing updates about the status of the course.

One introductory high school course is not enough to engage a broader segment of the student population in computer science. The National Science Foundation (NSF) has been supporting the creation of a high school pathway including both ECS and a newly designed advanced placement course called Computer Science Principles (www.csprinciples.org). Like ECS, the new CS Principles course, designed through a collaboration between the NSF and the College Board, focuses on the big ideas of computer science and computational practices. The NSF has also been the launching pad for a CS10K campaign to get 10,000 more computer science teachers into schools (http://cs10kcommunity.org). The Computer Science Teachers Association (http://csta.acm.org); the Association for Computing Machinery (www.acm.org); and others have been active in these and related efforts.

Building on this foundation, the recently formed nonprofit organization Code.org is designing elementary coding courses and middle school curriculum to be integrated into math and science classes, as well as supporting ECS and AP Computer Science Principles at the high school

Video Bonus

See ECS students in action in a video from the National Science Foundation at www.nsf.gov/news/special_reports/science_nation/intotheloop.jsp

level. Code.org has been effective in building momentum around computer science education throughout the United States. The organization has launched a national social media campaign about the importance of computer science for all students, a campaign that has impacted state legislation and school district offerings around the country. (For details, see www.code.org.)

State, local, and district policies have been drafted to make computer science a core class that counts as an academic credit toward graduation. Politicians, including state representatives and the U.S. president and vice president, have been speaking on this issue. President Obama recorded a video message during Computer Science Education Week 2013 encouraging all students to study computer science (www.whitehouse.gov/blog/2013/12/09/don-t-just-play-your-phone-program-it); and Vice President Biden spoke passionately about the need for computer science education at the 2014 National Governors Association meeting.

An Equity Imperative

Computer science knowledge cannot be reserved for elite students who have prior experience, interest, and parental resources. Computer science education must be provided for all students. To broaden participation in computer science programs in schools, we must make it our mission to build talent among all our students, not just to identify talent in a few. As the issue of computer science education gains momentum and attention, it is crucial that a commitment to computer science for all stay in the forefront of these efforts. EL

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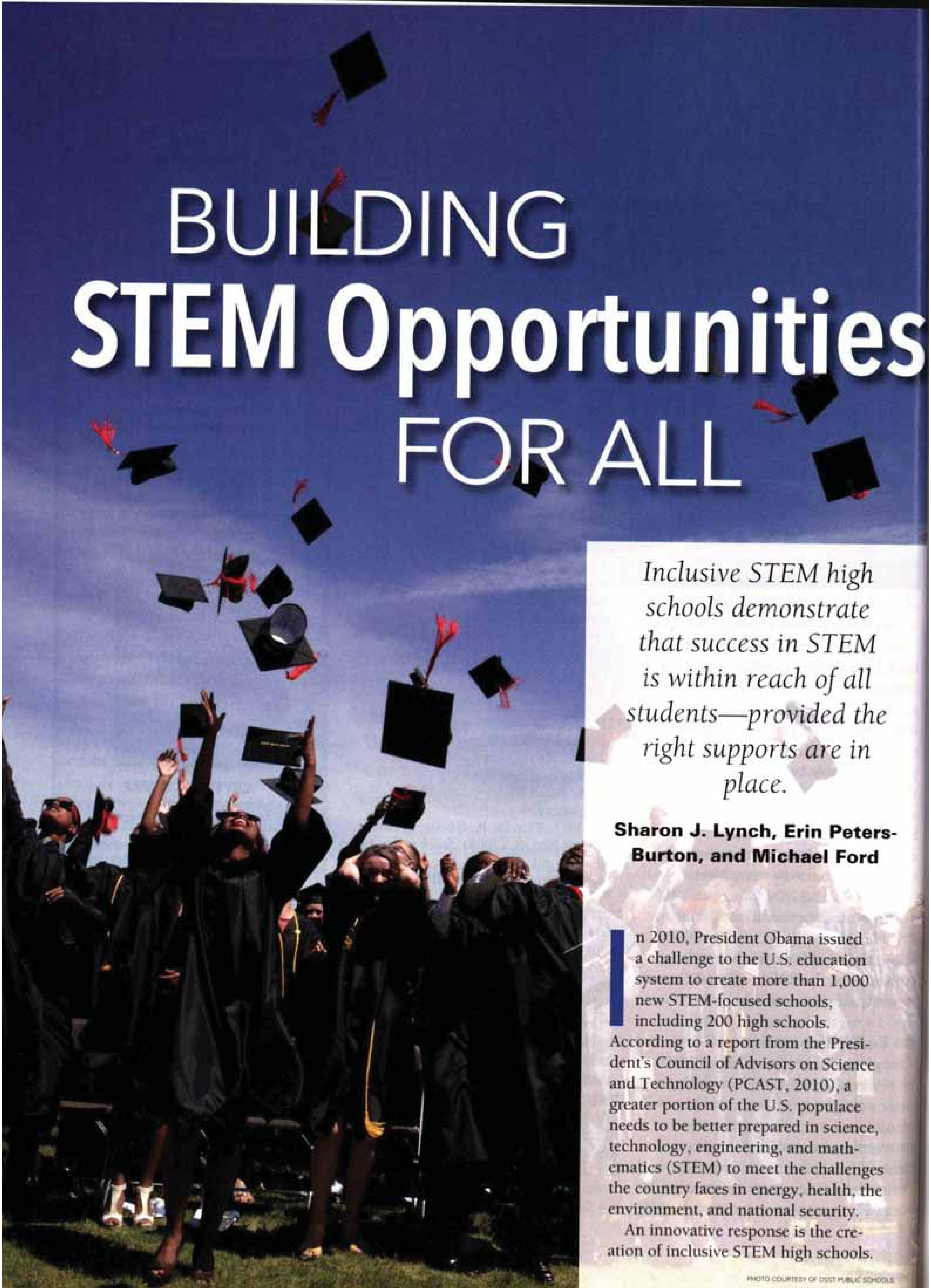

BUILDING STEM Opportunities FOR ALL

Inclusive STEM high schools demonstrate that success in STEM is within reach of all students—provided the right supports are in place.

Sharon J. Lynch, Erin Peters-Burton, and Michael Ford

In 2010, President Obama issued a challenge to the U.S. education system to create more than 1,000 new STEM-focused schools, including 200 high schools. According to a report from the President's Council of Advisors on Science and Technology (PCAST, 2010), a greater portion of the U.S. populace needs to be better prepared in science, technology, engineering, and mathematics (STEM) to meet the challenges the country faces in energy, health, the environment, and national security.

An innovative response is the creation of inclusive STEM high schools.

PHOTO COURTESY OF DSST PUBLIC SCHOOLS

These schools are a relatively new feature of the U.S. education landscape and can have policy implications for school reform, STEM initiatives, and improving opportunity to learn. They may also point the way for high schools of the future.

Inclusive STEM high schools are stand-alone schools, schools within schools, or school programs that accept students on the basis of their interest in STEM rather than on the basis of aptitude or prior achievement. Inclusive STEM high schools prepare students with the mathematics and science experiences they need to succeed in a STEM college major through a program of greater depth and breadth than is typically required for high school graduation (Lynch, Means, Behrend, & Peters-Burton, 2011).

The Many Faces of Inclusive STEM High Schools

Inclusive STEM high schools enroll students from groups underrepresented in STEM professions through an application process that doesn't require high test scores before high school entry (Means, Confrey, House, & Bhanot, 2008). These schools are designed to develop students' STEM expertise rather than to select students already identified as gifted and talented or as high achieving in STEM. In 2008, there were approximately 100 inclusive STEM high schools in the United States (Means et al., 2008). Currently, there are probably three to four times that number.

Inclusive STEM high schools can be found in a wide range of environments. They may be catalyzed by statewide STEM school initiatives established through boards of education, as we see in Texas, Ohio, and North Carolina. Similar efforts to create such high schools are underway in 16 other U.S. states through the multistate STEMx network (www.stemx.us).

Inclusive STEM high schools can be individual public charter schools with a STEM theme or members of a STEM charter school network, such as the New Tech Network (www.newtechnetwork.org). Some career and technical education high schools have STEM-related themes (for example, health sciences, engineering, or agriculture); some of these can be classified as inclusive STEM high schools because they were designed to be both college preparatory and focused on STEM.

Some magnet schools also target STEM-related themes. For instance, Connecticut has several magnet schools that can be classified as inclusive STEM high schools, and the state is using them to respond to court-ordered desegregation (Thomas, 2013) as they improve opportunities

PHOTO COURTESY OF DSST PUBLIC SCHOOLS

The curriculum is linked to **real-life experiences** that **require students to perform as responsible individuals operating in collaborative groups.**

"Learning Center" programs that focus on topics that range from biomedical engineering to energy and the environment. Learning Center experiences include collaborative classes with students and teachers at another local high school as well as related courses at Ohio State. Students participate in job shadowing throughout their Learning Center experiences so they can see real-world applications of their studies.

For instance, in the Bodies Learning Center, a program that integrates biomedical technologies and college coursework, students work with medical residents at the local hospital. They visit related job sites, such as dental labs, a manufacturing center for artificial limbs, and veterinary clinics. For their 3-D art class, they use clay to create anatomical models of bodies with organs.

In their senior year, students continue with college courses as they participate in internships and conduct capstone research projects. One student visited Wright-Patterson Air Force Base to learn about aeronautical engineering; he then went to the NASA Glenn Research Center to speak with engineers about their day-to-day work.

Metro principal Aimee Kennedy explained how Learning Center themes were designed:

> We find a career area in our local context that has possibility for growth. Then we find what college classes people in that career area take. Then we find a high school class that is a bridge to real-world experience. By the end of the year, the kids have grown into mini-professionals who can do a research project under the guidance of the professionals in that area.

The Metro teaching staff is eclectic, ranging from first-year teachers from strong teacher-preparation programs to experienced STEM teachers and career changers with job experience in STEM fields. Some teachers have the know-how and community connections to direct complicated, integrated STEM programs, such as Learning Centers. In addition, Metro has STEM tutors, teaching assistants, and in-house advisors from Ohio State to guide early college experiences.

On the Ohio School Report Card for 2012–13 (n.d.), Metro earned *A* grades for achievement and gap closing. The school had high percentages of students at the advanced, accelerated, or proficient levels. Also, when student subgroups were disaggregated according to income, race, ethnicity, and disability, all subgroups attained the required 80 percent passing rate (Han et al., 2014).

These schools are designed to **develop students' STEM expertise** rather than to select students already identified as high achieving.

Denver School of Science and Technology: Stapleton

This engineering-focused STEM public charter high school in Denver, Colorado, was funded by the Denver Public School District construction bond funds and outside sources, such as the Bill and Melinda Gates Foundation (Spillane et al., 2013). The school serves approximately 875 students.

Designed as a STEM school, the school's light-filled open design leaves structural elements, such as pipes and light fixtures, exposed. There are spacious traditional classrooms as well as open structures called pods where students can spread out to do STEM projects. Jumbo monitors in the hallways scroll lists of students who are scheduled for tutoring after school. Huge banners extend from the rafters displaying the school's core values of respect, responsibility, integrity, courage, curiosity, and doing your best. Next to each value is an image of a student who has exemplified the value.

The school's mission is to provide a rigorous college-preparatory curriculum and achieve a 100 percent graduation rate. More than 50 percent of its students come from subgroups underrepresented in STEM majors and careers. Thirty-five percent are Hispanic, and 26 percent are black. Forty-five percent of students come from low-income families. From 2008 to the present, the school has been the highest-performing secondary school in the district. For seven consecutive years, 100 percent of the senior class has been accepted to a four-year college or university (DSST Public Schools, 2014).

The teachers tend to have strong backgrounds in STEM content and real-world STEM experience, and they're encouraged to infuse their own experiential knowledge into the curriculum, which is strongly influenced by collaboration with the department of engineering at the nearby University of Colorado, Boulder. The university helped design the initial engineering courses offered at the school, and some university faculty and graduate students taught the elective engineering courses in the school's early years.

Each year, the 9th grade class is invited to the college campus for a college tour and a hands-on engineering design project in which they help build levies with the university engineering faculty. In 11th grade, "Learning Center" programs that focus on topics that range from biomedical engineering to energy and the environment. Learning Center experiences include collaborative classes with students and teachers at another local high school as well as related courses at Ohio State. Students participate in job shadowing throughout their Learning Center experiences so they can see real-world applications of their studies.

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Each year, the 9th grade class is invited to the college campus for a college tour and a hands-on engineering design project in which they help build levies with the university engineering faculty. In 11th grade, for students and strengthen local economies.

Some turnaround schools have adopted a STEM focus to improve student achievement. Many appear to be converted neighborhood schools, and, unlike other STEM schools, students attend only by choice.

Inclusive STEM high schools require careful planning and development and often new resources. Some research shows that becoming a STEM school in name only is not particularly beneficial for either the school or its students (Allen Bemis, Wiley, & Eisenhart, 2014; Weis, Cipollone, & Stich, 2014).

What Makes a STEM School Exemplary?

In a recent study (Lynch et al., 2011), we set out to better understand how inclusive STEM high schools work. We selected eight exemplar schools across the United States that had established reputations and strong evidence on measures of student success. The schools all serve a wide range of students and have an even gender balance.

We began our research by looking for evidence of 10 components (see "What Makes Them Work: Ten Critical Components," p. 59). We were also open to finding other elements crucial to their success. Here are snapshots of three of the schools studied.

Metro Early College High School

Metro is not only a STEM-focused school, but also an early college high school that serves approximately 400 students. It was founded with stimulus funding from the Gates Foundation, Battelle Memorial Institute, Ohio State University, and the Coalition for Essential Schools (Han, Lynch, Ross, & House, 2014). Metro sits on a corner of the Ohio State University's campus in Columbus, a convenient location because most of Metro's students take no-cost (to them) college courses there by their junior year. Many students will graduate from Metro with two years of college credits at Ohio State, ready to enter college as juniors.

Metro has an unusual administrative structure. In 2013, Metro High School became its own independent standalone regional STEM school, run by a principal who is also its chief academic officer and superintendent. The school is governed by representatives from Ohio State University, Battelle, and local school districts. It enjoys a great deal of autonomy to flexibly respond to opportunities offered by the community and local businesses.

Students in 9th and 10th grade take rigorous core STEM classes in a program that enables them to complete all required college-preparatory science and mathematics courses, and some engineering courses, in two years. Metro also provides semester-long integrated STEM projects that involve the entire school, including the humanities program.

For example, a STEM-focused sustainability project incorporates student art. A closer look at the student-created mosaics and sculptures displayed in the hallways reveals they're made from recycled materials, such as plastic bottle tops, paper wrappers, and spark plugs. In another challenge, students are called on to design an aquarium using sophisticated materials donated by a local merchant. Students must not only integrate STEM concepts to establish a healthy aquarium system, but also write blog posts about their progress for English class.

PHOTO COURTESY OF CHICAGO HIGH SCHOOL FOR AGRICULTURAL SCIENCES

The school has a mastery learning system that requires students to pass each course with at least a 90 percent average; if students don't achieve that average, they're required to retake the class. Metro students come to understand that the content of their coursework is likely crucial to their success beyond school and that the barely passing grades that some schools allow wouldn't enable them to proceed to higher-level STEM courses.

Metro's challenging core academic program in the first two years prepares juniors to take innovative, yearlong students interested in pursuing engineering are invited back to the campus for another full day to discuss admissions to university engineering programs.

There are no remedial academic tracks. The curriculum moves from more traditional courses to experiences that require greater application of concepts through such opportunities as junior internships. For instance, one student interned in one of the toxicology labs at the medical campus of the University of Colorado, Boulder. Another student, through diligent self-advocacy, got an internship at a local TV station.

In senior year, students take applied STEM classes in biochemistry/biotechnology or engineering/physics and complete their graduation requirements with a yearlong senior project. Senior projects have included a thesis on the relationship between cholera and cystic fibrosis, experimentation with slime molds, and an investigation into local aquatic ecosystems. Such projects culminate in a 30-minute defense-style presentation to a panel of four to six adults for a summative grade.

The school mission emphasizes that STEM education is for everyone, not only the gifted and talented, and that "we can always do better." Teachers have professional development time to monitor and analyze student progress and prescribe personalized tutoring and other supports. The mastery-based learning system requires students to pass courses with a C or better. This is viewed not in a punitive way but as an opportunity to spend more time learning the material. In fact, some of the most successful students choose to attend tutoring sessions.

No geologist worth anything is permanently bound to a desk or laboratory, but the charming notion that true science can only be based on unbiased observation of nature in the raw is mythology. Creative work, in geology and anywhere else, is interaction and synthesis: half-baked ideas from a bar room, rocks in the field, chains of thought from lonely walks, numbers squeezed from rocks in a laboratory, numbers from a calculator riveted to a desk, fancy equipment usually malfunctioning on expensive ships, cheap equipment in the human cranium, arguments before a road cut.

–Stephen Jay Gould
From *An Urchin in the Storm: Essays About Books and Ideas*

Chicago High School for Agricultural Sciences

This public high school in the Chicago Public School District serves approximately 600 students. It was founded more than two decades ago, yet it still seems visionary because from the start it had a goal similar to that of newer inclusive STEM high schools: to prepare students for college through a program that focuses on STEM. The 78-acre school campus, which the school thinks of as a "land laboratory," includes a classroom building, working fields, and a large animal barn.

All students follow the same prescribed curriculum during the first two years, which consists of core college-preparatory science and mathematics courses. Ninth graders study basic agricultural science and agricultural careers and leadership, courses that were designed for urban students unfamiliar with agriculture. A 10th grade course introduces students to five career and technical education pathways—animal science, food science, agricultural mechanics, horticulture and landscape design, and agricultural finance—enabling them to make informed choices about an area of specialization for their last two years of high school.

As they engage in real-life learning in agriculture, students continue to take traditional STEM courses. For example, they learn the chemistry that undergirds horticulture, and they connect mathematics and psychology principles to commodity pricing by writing a business plan for a retail flower business. The high school has a strong relationship with the University of Illinois and a robust system of business and internship partnerships. Through such companies as McDonald's and Eli's Cheesecake, the school offers apprentice programs that involve students in summer research internships to learn about food science.

Students spend 30 minutes each day engaged in physical tasks that are part of agriculture, and involve caring for plants and animals. Students studying food science might monitor water quality and the health of the tilapia in the hydroponic farm, whereas students in animal science might clean stalls, collect eggs, or tend to the needs of the animals. When we visited, a web camera was focused on a mare about to foal; the neighborhood could watch her progress, and the students could be there for the birth. Consequences for such assignments are about more than grades—they affect living things. The school is a metaphor for a farm family; it provides a sense of place, as students care for and support one another.

The teachers, many of whom were agriculture professionals before their career switch to teaching, work closely with former colleagues in the agricultural world as well as with their current teaching colleagues to align the curriculum to industry practices and create an authentic, integrated STEM curriculum.

What Makes These Schools Tick?

Each of the eight schools we studied showed evidence of each of the 10 components that make STEM schools work. Nevertheless, four of those components have special prominence.

A STEM-Focused Curriculum

Each school has a strong college-preparatory STEM curriculum, usually requiring students to take more STEM courses than mandated by their states. Students have to pass STEM courses at a higher performance level than is typical, whether assessments are administered through a mastery learning system or through demanding performance assessments. The curriculum is linked to real-life experiences that require students to perform as responsible individuals operating in collaborative groups in the real world. The schools have expanded beyond their physical and temporal boundaries to form partnerships with industry or colleges (House & Peters-Burton, 2014). These partnerships ask high school students to do more, learn more, and perform as adults as they develop 21st century skills.

A Responsive Administrative Structure

Although each school is organized differently, all have well-defined missions developed in collaboration with the community. They're all schools of choice that have the goal of reaching underserved student groups through a rigorous STEM program. Their leadership is mission-centered.

The schools have flexible administrations that can garner community support and quickly capitalize on opportunities in the community for their students (Ford & Behrend, 2014). School leaders don't necessarily have backgrounds in STEM, but they're all strong leaders who move their schools forward. They've created systems that give teachers opportunities for leadership, creativity, and autonomy. They've developed strong relationships with the community and with industry, and they know each student and family well and are proud of their students' accomplishments.

What Makes Them Work: Ten Critical Components

1. A STEM-focused curriculum.
2. Reform-based instructional strategies and project-based learning.
3. Integrated and innovative technology use.
4. Blended formal and informal extended learning opportunities.
5. Real-world STEM partnerships.
6. Early college–level coursework.
7. Well-prepared STEM teaching staff.
8. Inclusive STEM mission.
9. Responsive administrative structure.
10. Supports for underrepresented students.

A Well-Prepared STEM Teaching Staff

The teachers have solid backgrounds in STEM, either through strong discipline-based teacher preparation programs or nontraditional routes to teaching in STEM fields. They collaborate on integrating STEM activities and curricular innovations, both inside and outside school, often including the humanities teachers. As active professionals who seek challenges and growth, the teachers are enthusiastic about teaching and often team teach or teach more than one STEM discipline.

Although modes of instruction vary, interpersonal interactions are personalized and warm. The teachers view each student as someone who can learn and develop, if given the right opportunities (Spillane, 2014).

Supports for Underrepresented Students

The schools focus their efforts on female students, minority students, and those who are first in their families to attend college (Lynch & Ross, 2014). Supports begin with recruiting and admissions systems in which students and families are given a realistic picture of the demands of a STEM high school and what it will take to ready students for college admission and success in STEM fields. Orientation and bonding activities for freshmen prepare them for new ways of learning. They stress values such as responsibility, leadership, collaboration, and courage, and the messages are often delivered through the example of older students who work with younger ones.

These schools have well-developed tutoring systems, and they monitor student progress to match students with supports through teacher-led advisories. Tracking is minimal, but sometimes special classes and doubling up on class time are necessary for certain students—especially in mathematics. The intent is always to reintegrate students into regular

classes as soon as possible.

College advising systems include guidance counselors and teachers who know families well and can match students with college opportunities that include scholarships and student loans. This personalized approach is key to the schools' supports and to their positive school climates.

A New Way of Doing High School

Inclusive STEM high schools are springing up across the United States. Such schools have real promise as valuable additions to school systems that want to increase the number of STEM-capable students in their communities and demonstrate that STEM success is within all students' reach.

They also may better fit the needs of students who can't see the relevance of traditional classes and who need more real-world challenges in school. Inclusive STEM high schools offer opportunities that can change the course of students' lives. ■

Authors' note: This research was conducted by the Opportunity Structures for Preparation and Inspiration (OSPrI) research project, with Sharon Lynch, Tara Behrend, Erin Peters-Burton, and Barbara Means as principal investigators. Funding for OSPrI was provided by the National Science Foundation (DRL 1118851). Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the position or policy of endorsement of the funding agency.

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Students will more readily engage in science when they see its relevance—to them. Here are four value-enhancing approaches to teaching science content.

Lee Shumow and Jennifer A. Schmidt

Teaching the Value

A hush fell over the trigonometry class, heads swiveled around, and my classmates stared at me (Lee), dumbfounded. A few told me later they couldn't believe I'd had the nerve to ask the teacher, with some exasperation, to explain the purpose of the function he was teaching. But I simply couldn't imagine the purpose of the abstract and tedious work we were expected to do, and I wasn't interested in doing a set of problems just for the sake of doing them. Luckily, I had an experienced teacher who provided several concrete examples that illustrated how very useful the function was in the real world. The reassurance that this was actually useful satisfied me, so I did the problems without complaint. All these years later, I still remember the respect I gained for both him and the value of trigonometry.

The fact is, most adolescents perceive little or no value in what they're expected to learn in school and, as a result, they report being bored and disconnected. Educators recognize that students who value what they're learning are more motivated and engaged in class, yet judging from the many teachers we've observed as researchers and talked with during professional development sessions, most don't know how to promote that essential motivational ingredient. In fact, many teachers describe motivation as a fairly stable trait of their students, like eye color or body type.

Thankfully, motivation isn't a trait. Rather, it's a *state*—and states are far easier to change than traits. A central purpose of our work is to empower educators to enhance their students' motivation to learn. Fostering value is one of the best ways they can accomplish this.

The Science Slump

Student engagement tends to decline as students move through middle and high school—and nowhere does it drop more dramatically than in science. The evidence and examples we draw on come from research that we and others have conducted in middle and high school science classrooms (Hulleman & Harackiewicz, 2009; Schmidt, Shumow, & Durik, 2011; Shumow & Schmidt, 2014). However, the concepts and strategies we discuss are relevant for educators across content areas and grade levels.

The fact that few adolescent students in the United States value science has long-term consequences. Jobs require more scientific knowledge and skill than ever before, and that trend is predicted to continue. Students with high scientific literacy will

# of Science

have better career options than those without.

But career readiness isn't the only reason to understand and value science. Many everyday decisions are informed by scientific literacy and by one's ability to think about and analyze situations using evidence. Concerns about the environment, the food supply, health, and energy rank high among the major issues facing communities and society. As such, scientific literacy plays a central role in preparing citizens, a fundamental purpose of secondary education.

Through our own and others' studies, we've learned a lot about why and under what conditions students value their science learning. With funding from the National Science Foundation, we observed approximately 400 science classes in diverse schools and collected in-the-moment reports from students about what they were thinking and feeling during the classes we observed. As a result, we were able to tie what was happening in the classrooms to students' motivational states and engagement.

Why It Matters

Several teachers we observed were amazingly adept at regularly promoting the value of science, both through explicit statements about why the day's content was important in life and through seemingly off-hand comments that weren't about specific course content at all.

For example, Donna, a 7th grade science teacher, asked one of her students to "explain what speed means." The student replied, "Speed is d/t—and I don't really care about speed. It's just a term we have to memorize for science. It's not really all that important to think about speed in life." To this, Donna responded,

> You play an instrument, right? Does it matter what speed you play the song? Can you play it as fast or slow as you want, and will it still sound good? Or how about getting to class on time? Do you need to be worried about speed? These two examples aren't just about science. Speed is everywhere. You use it all the time.

During this same class period, Donna learned that a student was absent from class because of an orthodontics appointment. She jokingly commented, "Don't orthodontists know that they're taking students out of science class and that science is kind of important? After all, they had to do well in science to become orthodontists!" Donna's comments were rather ordinary, but they emphasized how all aspects of students' lives related to science. Not coincidentally, Donna's students reported the highest science interest levels of all the students whose teachers and classrooms we studied.

By and large, however, teachers like Donna have been rare in our studies. We more often observed missed opportunities for teachers to promote the value of science. In some cases, teachers felt pressured to get through enormous amounts of content and believed they didn't have time to make those connections. The inevitable consequence, however, is that many students disengage from science.

SERGEY NIVENS/SHUTTERSTOCK

Poets say science takes away from the beauty of the stars–mere globs of gas atoms. I too can see the stars on a desert night, and feel them. But do I see less or more? The vastness of the heavens stretches my imagination–stuck on this carousel my little eye can catch one-million-year-old light. A vast pattern–of which I am a part.... What is the pattern, or the meaning, or the why? It does not do harm to the mystery to know a little about it.

–Richard P. Feynman
From *The Feynman Lectures on Physics*

Four Kinds of Value

Research and common sense tell us that when we see value in an activity, we're more likely to engage in it. The good news for educators is that value can take many different forms. Individuals don't have to perceive the same value in a given activity to be motivated to engage in it.

For example, one of us (Jen) is a runner. She runs primarily because she derives great enjoyment and peace from it. In contrast, a friend of hers drags herself out to run even though she finds running unpleasant; she believes that anyone who's truly fit *must* be a good runner. The two women see different value in running, but both types of value motivate them to put on their running shoes each day and ultimately make them better runners.

The same principle holds true for academics. Students don't have to all see the same value in what they're learning. Here are four different ways your students can come to value science—and four different approaches you can take to promote student engagement.

Finding It Interesting: Intrinsic Value

Not surprisingly, students who are interested in a topic are more engaged when studying it.

Some students are interested in a particular kind of music, whereas others are interested in a given sport or game. Individual interests often begin during childhood and are sustained over a lifetime. For example, E. O. Wilson, the father of sociobiology and a renowned biologist, was deeply interested in ants as a child and eventually became recognized as the world's leading myrmecologist (a zoologist specializing in ants).

Teachers who know about their students' interests can draw on those interests when teaching concepts, whether it's connecting a unit on respiration or evolution to someone's interest in fishing or relating content about acids, bases, and chemical reactions to someone's interest in cooking. Teachers can learn about their students' interests through checklists or open-ended survey questions administered early in the school year or by communicating with parents.

Interest development often begins with *situational interest* in which curiosity or wonder is aroused. Many scientists and college science majors point to a high school teacher who sparked their initial interest in science by generating situational interest.

Science teachers can do this by offering *novelty*; many amazing images and demonstrations are available to generate interest in a phenomenon. Showing dramatic video of specific weather events will certainly spark more interest in students than simply having them read textbook definitions. Yet in the numerous lessons we observed during a middle school unit on weather, we rarely saw any videos of the phenomena that students were studying.

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Personalizing and dramatizing the importance of concepts through *storytelling* also foster situational interest by appealing to students' emotions. One of the outstanding teachers we know brings the concept of homeostasis to life for her students by telling about a time she fainted in class (see www.youtube.com/watch?feature=player_detailpage&v=fx6arX83bz4).

Perhaps the most effective and underused method is for teachers to *express their own enthusiasm* for the topic. In our research, we rarely observed teachers being passionate about their subject and, instead, frequently rated teachers' level of enthusiasm as "matter of fact." Our ratings match the recent Gallup poll finding (2014) that the vast majority of teachers report being disengaged in their work.

Now, just because an academic activity is fun doesn't mean that it's necessarily interesting or engaging to students. For example, several chemistry teachers we observed chose to do a lab in which students each made their own ice cream. Unfortunately, the teachers didn't highlight the connections between making the ice cream and the chemistry concepts, vocabulary, or reasoning the students were supposed to be learning. Instead of learning about solutions, states of matter, phase transition, colligative properties, freezing point depression, and crystals, the students simply appeared to enjoy eating the ice cream they made, and they rated the activity as enjoyable but of low value.

Finding It Useful: Utility Value

Students might value their academic work because they perceive it as useful in meeting a short- or long-term goal. A physics student might find that a particular principle helps him or her hit a baseball more effectively. Students may see science as useful for solving a variety of broader problems—from reducing energy costs; to preventing accidents; to promoting good health; to improving air, soil, and water quality.

Students might also value science because it has meaning and purpose beyond their own self-interest. Adolescents are starting to turn their attention to the broader world and their place in it and are often concerned about social justice, moral ideals, and the well-being of others. They're more likely to persist in learning if they believe that what they're learning might matter in preventing or solving social or environmental problems.

For example, we observed a teacher whose students learned physical science through studying the soil from the prairie that surrounded the school, nurturing worm farms in class, growing crops with the compost from the worms, and using solar power from panels on the school roof. Using the Internet, his students shared their knowledge and expertise about high-intensity food production with a high school class in the Middle East (see http://greducation.blogspot.com/2014_02_01_archive.html). The students' realization that they could use what they were learning to help feed hungry people at home and abroad had a profound effect on their sense of autonomy and on their understanding that science has value. In the end, it increased their motivation to learn.

Some research suggests that helping students appreciate the utility value of science content might be particularly effective at promoting engagement among students who lack confidence in their science ability (Hulleman, Godes, Hendricks, & Harackiewicz, 2010; Hulleman & Harackiewicz, 2009). When students feel they're struggling at something, they tend to lose interest in it—that is, "I'm not good at math, so I'm not interested in math." Providing opportunities for students to appreciate why this challenging content is worth knowing can help them maintain their commitment to learning.

A good deal of science content is abstract, and students are unlikely to automatically connect those concepts to their experiences, goals, and the outside world without some guidance from adults. The evidence we collected in classrooms demonstrated that the more teachers talked about how science content applied to the world outside the classroom, the more their students were able to make these types of value connections *on their own*—and the more interested they were in their science education.

Strategies to Foster Value

- Identify and capitalize on students' attitudes and self-perceptions, and find ways to discover their interests, goals, beliefs, and concerns.
- Express enthusiasm and wonder for topics of study.
- Create interest during instruction through novelty and surprise.
- Include students in creating meaning.
- Draw connections between the content and its practical applications.
- Use familiar examples. When defining inertia, you might say, "You know how people and things in the car keep moving forward when you slam on the brakes?"
- Make learning emotionally compelling through telling stories.
- Make content relevant to students' families, communities, and cultures.
- Convey the purpose of what and how students are learning. In addition to knowing how the concepts they're learning matter, students also need to understand how inquiry and study skills will benefit them in the future.

Finding It Connects to a Sense of Self: Attainment Value

Before you run out and tirelessly laud the utility of science, there's one caveat here. It's counterproductive to emphasize the utility of science for reaching goals that are inconsistent with students' strongly held identity beliefs. For example, if a female student believes that working in a science field isn't part of the female gender role and her teacher exclusively highlights the value of the course content for those going into careers in the field, this student may grow increasingly uninterested in science. The teacher would need to either emphasize a value more in line with the student's identity beliefs or work on broadening the student's notions about who goes into science careers.

On the other hand, an aspiring paramedic who comes from a family with a long line of military service as medics might have a self perception of being responsible, cool under pressure, and service-minded. This student is more likely to see success in high school biology as central to fulfilling an identity than is a student who aspires to be a writer, musician, or banker.

Ideas that students have about particular socio-demographic groups can also facilitate or undermine attainment value. Recently, a high school teacher in one of our professional development workshops shared that one of his black students said that his science class was worthless to him because "I'm black. We don't do science." This is a stark reminder of how important it is to expose students to role models with whom they can identify—through stories, posters, films, or guest speakers—and take steps to combat the damaging effects of stereotypes.

Teachers can foster attainment value in several different ways. First, understanding how students perceive themselves enables teachers to help students relate to the content they teach. Asking students to identify their hobbies and career interests on surveys can help teachers identify students' self-perceptions. Second, because adolescents are still formulating their identities, teachers can offer them opportunities to explore various aspects of science through inquiry-based labs, service projects related to science, and career exploration assignments.

Finally, we've observed a handful of teachers who've created a class identity and sense of belonging that they've tied to class work. They use words like "we" and "our class." For example, in reference to an upcoming student mentoring project, the teacher said, "We'll be teaching 5th graders about invasive species. Each one of you plays an important role in making this succeed. The 5th graders depend on your knowledge, preparation, and good example."

Finding Its Relative Worth: Cost Value

Like savvy shoppers, students often weigh the relative costs of their options. Before engaging in learning, participation, and achievement, they may think about what they'll have to "pay" for it and what they'll gain in return. Video games, part-time jobs, other classes, and socializing may compete with studying for students' time and effort.

If students perceive that their science content has little value, they may calculate that the cost of engaging in it is simply too high. However, if a teacher consistently highlights the value of science in terms of students' interests, goals, self-perceptions, and daily life, it's often enough to sway this cost analysis in favor of science.

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A Worthwhile Investment

When students hold the belief, flawed though it may be, that academics have little value, it's no wonder they're disengaged from school. Fortunately, teachers have tremendous power to influence those beliefs. Investing the effort to implement the strategies we've suggested here is well worth the cost. Helping students find value in their learning activities is likely to result in increased student engagement, interest, and performance both in and out of school. EL

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Reading About Rea

Sunday Cummins

There's no doubt that students will need hands-on experiences to master the skills in science, technology, engineering, and math (STEM) that are essential for this century. As we make decisions about curriculums and school funding, we should make hands-on participation in STEM activities a priority. But we should also invite students to understand key concepts by reading, writing, and talking about the work of scientists and engineers.

Engaging with compelling texts about such professionals will help students understand the richness of scientific and engineering endeavors in real-world contexts (a major goal of the Next Generation Science Standards). An abundance of high-quality texts are available to help young people appreciate science and engineering as a set of intriguing practices that include developing theories, creating models, making inferences and predictions, talking and writing in specialized ways, and testing hypotheses through observation.

Saving the Golden Frogs

For instance, in *The Case of the Vanishing Golden Frogs: A Scientific Mystery* (Millbrook, 2011), author Sandra Markle describes how biologist Karen Lips investigated the drastic decrease in the numbers of Panamanian golden frogs in the mountain forests of the Fortuna Forest Reserve—and not only solved the mystery, but also helped protect a species.

Tapping her background knowledge, Lips generated hypothetical questions about why the frogs might be dying. She sought information from other sources—including colleagues in the field. A breakthrough in the mystery came when Lips sent several dead frogs to a pathologist who, using cutting-edge technology, noticed strange sacs in the frogs' skin. When the *New York Times* printed an article on this discovery, scientists from around the world contacted Lips because they'd made similar observations about frogs where they lived or worked.

The result was a conference in Panama on how to save the golden frogs. Eventually, an international partnership created a refuge for this threatened species. The story makes clear how Lips and the many other

growing on their skin. Then they created a refuge to save the frogs." We want students to comprehend that in addition to tapping existing knowledge, these scientists engaged in specialized practices essential to the success of their work. That takeaway would advance students' understanding of how the skills outlined in the new science standards play out in the real world.

We'll increase the chances that students who read books related to STEM professions will gain such fuller understanding if we have students read with a clear purpose, talk with peers about what they're reading, and write in response to these texts and class discussions on them. When teachers pair such activities with intriguing texts, students deepen their comprehension of science and engineering fields—and of key content and terms associated

and write responses to their readings. We introduced a set of books from Houghton Mifflin's Scientists in the Field series. Each student selected a title they wanted to read. I chose one title, *The Tarantula Scientist* by Sy Montgomery (HMH, 2004), as an anchor text.

Before we began the lessons, I asked students to write me a letter answering the question, "What do scientists in the field do?" The majority of responses included the word *study* ("scientists study things," "they study animals"). Their responses revealed that although these students seemed to understand the general work of scientists, they didn't have the language to describe or explain the specific practices of career scientists.

On the basis of this formative assessment, we developed and taught a series of lessons focused on having

Scientists

Students should read—and talk about—good texts that show scientists and engineers solving problems in the world.

scientists involved used existing knowledge and scientific approaches to develop new knowledge—and, as a result, solved an ecological problem.

It's not enough for students to just read and enjoy texts like this one. Students can take away the "story" of such endeavors and not understand what the author is saying regarding the work of professionals like Karen Lips. In other words, it's not enough for students to be able to say, "Dr. Lips discovered the sick frogs, and a team figured out that the frogs had a fungus

with these fields. Let's look at one lesson series in which I implemented this approach.

"Investigating" Tarantulas—or Dolphins

Last spring, I used books connected to STEM fields to teach a series of lessons in a 5th grade classroom at a STEM school. During the 50-minute language arts block, the teacher and I employed a reading workshop model, which included a minilesson and time for students to read, talk with peers,

students explore the term *investigate* while learning the content of their texts. Before beginning the lessons, I introduced an anchor chart headed with this student-friendly definition in large print:

> To *investigate* means to examine, study, or inquire systematically in an attempt to learn the facts about something hidden, unique, or complex.

Over the course of several lessons, we added to this chart words and phrases that helped explain how

aloud from *The Tarantula Scientist*, I placed the book on the document camera so students could see the up-close photographs of the tarantula. They were mesmerized as they heard about how arachnologist Sam Marshall methodically hunted for the burrows of the Goliath bird eater tarantula in the jungles of French Guiana.

I picked excerpts to read aloud for particular purposes. The first excerpt, I hoped, would enthrall students with the facts about this largest spider species in the world. Later, I wanted them to hear about the multiple ways Marshall investigated these creatures—both in the jungle and later at his lab in Hiram, Ohio.

Students also closely read short excerpts from *The Tarantula Scientist*, again for specific purposes. For instance, I assigned one excerpt to help students understand and articulate the mathematical methods Marshall used to both determine the numbers of these tarantulas in a given area and collect data on the spiders' physical features. Students also chose a page or section from their self-selected books to carefully read—and to talk and write about.

4. Consistently refer to an anchor chart.

An anchor chart on which you write a student-friendly definition or explanation of the focus helps students. Encouraging students to add words

FIGURE 1. Excerpts from a Student's Responses to a Text

1st response	2nd response	3rd response	4th response	5th response	6th response
(written before our first lesson): I've learned that scientists can uncover myths or prove a fact. Scientists could try to find a rare species and find some things it does, eats, etc. They could be looking for unknown animals or plants.	(written after the first lesson): I've learned a lot more now. Scientists have to have a method or a plan so they don't over count. . . . They have to uncover mysteries or find things that are not true or something complex or hidden.	I learned things about how my scientist investigates: ■ She asks other people multiple questions to learn more about these fascinating creatures. ■ She tries to find everything that has to do with a subject and then moves on in an organized way. ■ She makes precise calculations.	Every [day] she goes back to the SAME family [of dolphins] and studies what they're . . . doing—and will not miss a moment. I've noticed that my scientist is studying dolphins in a SAFE WAY. She will not hurt these creatures, but [wants to] make laws to save these rare, amazing creatures.	[When my scientist is investigating], she stays focused and *on task*. If she is looking for one thing, she stays looking for that one thing. If she sees something strange or unnatural, she *needs* to find an explanation. She takes time to adapt to the environment or habitat.	The dolphins in the story are dying rapidly. My scientist is trying to find out why, how, and if there is a way to fix that. When she thinks she's got the answer, there is always a twist. . . . But after trial and error, the dolphins in Shark Bay are staying alive!

the scientists in our books engaged in investigations. For example, the students needed help understanding what the word *systematically* meant. We engaged in a close reading of an excerpt from *The Tarantula Scientist* that described how the scientist planned to determine the number of tarantulas in a specific area of a jungle in French Guiana. This included marking off quadrants of space with bright-colored tape and then counting the tarantulas within each quadrant. As we discussed what the arachnologist was doing, we wrote additional words that surfaced during our conversation in the margins of the anchor chart near the word *systematically*—words like *order*, *method*, *plan*, and *organized*.

As the lessons progressed, students began to articulate more clearly—orally and in writing—the work of the professionals they were reading about. Figure 1 shows one student's responses to the book *The Dolphins of Shark Bay* (HMH, 2013). Notice how her first response focuses on scientists discovering new information (*uncover, looking for unknown animals or plants*). In later responses, she uses specific language to describe the work of a particular scientist (*makes precise calculations, goes back to the SAME family of dolphins and studies what they're doing*). Her later responses also included the purpose of this work—saving the dolphins—and the disposition of this scientist (*focused, nothing will stop her*).

Steps for Incorporating Texts

Following are key steps for using texts about scientists and engineers in intermediate or middle grade classrooms, as part of science instruction or during the literacy block. In the middle grades, English language arts teachers might partner with science teachers to use texts in a way that supports students' hands-on work in the science lab.

**This venture of doing, thinking, caring about science is not for the faint-hearted–
we are far better adapted to face saber-toothed cats–and yet here we are, reinventing the world and striving to improve our lot in life one scientific question at a time. It's our human nature.**

–Robert Sapolsky
From *Scientific American*, August 2012

1. Choose a focus.

The lessons just described focused on what it means for scientists or engineers to *investigate*. I chose this focus because of what our formative assessment revealed and as a result of studying the Next Generation Science Standards and the National Research Council's framework for these standards.[1] This framework describes scientists' and engineers' work as happening in three spheres of activity—investigating, evaluating, and developing explanations and solutions.

Looking over the framework document should give teachers other good ideas for a focus. Our lessons might instead have focused on what it means for scientists to evaluate something or to develop explanations and solutions.

2. Develop a text set.

Select texts clearly related to the focus you've chosen. As well as printed texts of various lengths, text sets can include relevant videos. (See "Resources for Creating Text Sets" on p. 72 for several book series and sources of videos). There should be at least one title for each student; some titles can be duplicates, but you want enough variety for each student to read more than one title. The value of a class-size set of texts is that students can engage with more than one text in multiple ways. Students might partner to read the same text, choose multiple texts to read independently, or join with several students to read parts of a particular text and discuss those excerpts as a group.

During one lesson, the 5th graders each interviewed a partner about how that student's text showed scientists or engineers at work. Then all the students wrote a response telling what they learned about how their partner's professional engaged in investigation.

You may need to modify your text set once instruction begins. As I observed individual reading conferences with students and assessed their written responses, I realized the texts from the Scientists in the Field series were too difficult for some students. So I added easier texts that were still rich in content, such as books from the Case of the Vanishing series. For one student who needed additional challenges, I found three advanced texts on the same topic—the return of the wolves to Yellowstone Park—and challenged this student to read these texts and compare their content.

3. Choose an anchor text and use it purposefully.

The anchor text serves as a launching point. Reading aloud from a good anchor text piques students' interest and motivates them to read and respond to similar texts. When I read and phrases that unpack the defined term nurtures their sense of agency and their identity as a member of a community that's making meaning.

During one minilesson, I put three students' written responses to their texts on the document camera for the class to view and consider as mentor texts. I asked students to find details, words, or phrases from these responses that we should add to our anchor chart definition. One student, for instance, said we should add the phrase "asks multiple questions." This practice affirms students' identities as critical thinkers—both the student who wrote the model response and the student who suggested the term to add.

5. Develop minilessons.

As I mentioned earlier, when the 5th graders' pre-lesson written responses about what scientists do included vague language about how scientists and engineers investigate something ("they find," "they figure out"), I created minilessons to help close these gaps in students' understanding.

For instance, I wrote my own response to an excerpt from *The Tarantula Scientist* that included sketching and labeling the investigative methods Sam Marshall used. I sketched a ruler next to a segment of a tarantula's leg, illustrating one way Marshall measured a tarantula's growth. During the minilesson, I read this excerpt aloud and shared with students my response to it. They then created labeled sketches showing specific methods the scientist or engineer they were reading about employed to investigate phenomena.

Endless Possibilities

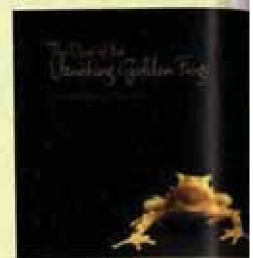
Because pre-assessments revealed that these particular students needed to understand what it means for scientists and engineers to investigate phenomena, I chose texts and lessons focused on that concept. But I could have highlighted many other aspects of these texts—and many other practices scientists and engineers engage in. In addition to helping students learn about STEM skills through hands-on projects, there are endless ways we can strengthen their understanding of STEM concepts through reading, conversation, and writing. EL

Resources for Creating Text Sets

Book Series Focused on the Work of Scientists and Engineers

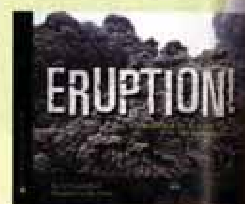
The Case of the Vanishing . . . : A Scientific Mystery Series (Millbrook Press). Sample titles (all by Sandra Markle):

- *The Case of the Vanishing Golden Frogs*
- *The Case of the Vanishing Honeybees*
- *The Case of the Vanishing Little Brown Bats*



America's Animal Comeback series (Bearport Publishing). Sample titles:

- *Gray Wolves Return to Yellowstone* by Meish Goldish
- *Black-footed Ferrets Back from the Brink* by Miriam Aronin
- *California Condors: Saved by Captive Breeding* by Meish Goldish



The Scientists in the Field series (HMH Books for Young Readers). This series also highlights the work of engineers. Sample titles (all by Elizabeth Rusch):

- *Eruption! Volcanoes and the Science of Saving Lives*
- *The Mighty Mars Rovers: The Incredible Adventures of Spirit and Opportunity*

Online Sources of Texts and Videos

- *Science News for Students* (https://student.societyforscience.org/sciencenews-students)
- *National Geographic STEM Education* (http://education.nationalgeographic.com/education/stem-education)
- *Super Science Top News* (http://superscience.scholastic.com/top_news)

EL Online

For more on how to connect reading and science, read the online-only article "Literacy and Science: Better Together" by Terry Shiverdecker and Jessica Fries-Gaither at www.ascd.org/el1214shiverdecker.

[1]National Research Council. (2012). A *framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Committee on Conceptual Framework for New K–12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

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PD ONLINE

Integrating STE&M

The STEM subjects are too often taught in isolation from one another—and from the world of work. The Linked Learning approach is changing that.

Gary Hoachlander

The need to integrate all four elements of STEM takes on urgency with the advent of the Common Core State Standards and the Next Generation Science Standards (NGSS). Whereas the Common Core standards promote much greater attention to technical reading and writing and emphasize mathematical modeling, the science standards explicitly call for more focus on engineering and design and for better integration of engineering with mathematics, science, and technology.

For a nation deeply concerned about remaining globally competitive—and raising the scientific, technological, and quantitative literacy of its population—these initiatives are indeed good news. However, realizing the promise of the Common Core standards and NGSS won't be easy. Despite more than a decade of strong advocacy by practitioners, employers, and policymakers, STEM education in U.S. schools leaves a great deal to be desired.

In too many schools, science and math are still taught mostly in isolation from each other, and engineering is absent. To be sure, in a growing number of high schools and even some middle schools, a pre-engineering curriculum is becoming more common. But more often than not, these engineering courses are offered as electives without strong connections to core courses like physics, algebra, geometry, and calculus.

Even where STEM offerings are taking root in a more coherent and integrated fashion, these courses or cross-disciplinary projects are rarely linked to the rest of the core curriculum. Schools aren't connecting STEM to English, social studies, world languages, or the visual and performing arts. To achieve the cross-disciplinary vision of the Common

Students use an endoscopy machine to complete a simulation exercise.

PHOTOS COURTESY OF HASAIN RASHEED

Core standards and the deeper learning sought through NGSS, schools need a better strategy—one that nurtures both students' and teachers' understanding of how STEM knowledge connects to other fields of knowledge. Such a strategy would accelerate progress in making high-quality STEM education an integral part of U.S. education.

One promising approach that's growing rapidly in California and in cities like Detroit, Michigan; Houston, Texas; and Rochester, New York, is Linked Learning: Pathways to College and Career. This approach transforms students' STEM learning by integrating rigorous academics with career-based learning and workplace experiences. It prepares young people for *both* college and career, not just one or the other. And it ignites students' passions by giving them meaningful learning experiences organized into career-oriented pathways in fields like engineering, health care, digital media, agriculture, the arts, and law.

What Is Linked Learning?

Students in Linked Learning programs enroll in a career-themed pathway and take a four-year (or longer) program of study focused on content and skills connected to that career. A well-designed pathway is more than a sequence of relevant career and technical courses. It also includes the full complement of core academic courses, work-based learning opportunities, and support services.

Linked Learning is an old idea getting a new execution. A century ago John Dewey advocated learning through occupations. Theme-based high schools (like Aviation High School in New York City), career academies, and industry-themed small learning communities have been part of the U.S. education landscape for some time. But more often than not, these opportunities existed in spite of the system rather than because of it. They were products of a few innovative teachers or a visionary principal. Often when their founders left their school, their innovations disappeared as well. In addition, the quality of design and implementation found in programs using a career pathways approach has been uneven at best. Frequently, "academies" or "pathways" are little more than names superimposed on traditional curriculum and teaching methods.

Linked Learning has two primary elements that distinguish it from seemingly similar approaches. First, Linked Learning is specific about what constitutes high-quality pathway design and implementation. A formal process of Linked Learning Pathway certification validates the quality of its programs and promotes continual improvement.

Although there are different ways to deliver Linked Learning, every Linked Learning pathway must offer students a comprehensive, multiyear program of study consisting of four components: (1) academic core courses in English, social studies, science, mathematics, world language, and art that emphasize real-world application in the industry that is the pathway's theme; (2) a cluster of three or more technical courses that deliver challenging technical knowledge and skill (and, where appropriate, enable students to obtain a formal industry certification); (3) work-based learning that gives students a chance to interact and solve real-world problems with working adults; and (4) personalized student supports that include college and career counseling and supplemental instruction in reading, writing, and mathematics.

Supporting this basic framework is a set of Linked Learning quality criteria that teachers and school leaders use to strengthen their pathways and prepare for formal certification. When a pathway team believes it's ready for certification review, a team of trained reviewers uses a rubric to evaluate that pathway.

Validating pathway quality is necessary but not sufficient to ensure that these kinds of opportunities are available to ever larger numbers of students and that Linked Learning programs don't become islands of excellence serving small numbers of kids. The second distinguishing feature of Linked Learning, therefore, is a commitment to implement the approach systematically *throughout* the school district and community surrounding a school that adopts Linked Learning. Districts must engage a wide range of stakeholders to create and sustain a menu of high-quality Linked Learning pathways that are accessible to any student who wants this educational opportunity.

It's worth emphasizing that adopting a districtwide system of pathways doesn't necessarily mean every school in the district must offer pathways. Nor does it mean that pathways displace all other instructional approaches. It does mean, however, that the district is committed to making pathways accessible to any student who wants this experience and that Linked Learning is an integral—and sustainable—approach within the district.

Schools that aren't ready to create formal Linked Learning pathways can benefit from adopting some of the approach's features, particularly rich, standards-based multidisciplinary projects that stress real-world application and let students engage with working adults around authentic problems. Similarly, opportunities to participate in internships with employers engaged in STEM-intensive work can help motivate students and deepen their understanding of why STEM matters and how it's used outside the classroom.

However, schools taking this less comprehensive approach should use caution. It's easy to fall into the trap of creating projects simply because they're more engaging for students (and teachers!) without paying careful attention to the standards and other learning objectives that projects should be designed to advance. Similarly, work-based learning experiences are most effective when, by design, they intentionally and immediately reinforce knowledge and skills that are part of students' classroom experience. Isolated internships, while not without value, don't have the integrative power of high-quality Linked Learning.

You look at science (or at least talk of it) as some sort of demoralizing invention of man, something apart from real life, and which must be cautiously guarded and kept separate from everyday existence. But science and everyday life cannot and should not be separated.

–Rosalind Franklin
Quoted in *The Dark Lady of DNA*
by Brenda Maddox

How Does This Approach Advance STEM?

Although it doesn't exclusively promote STEM learning, Linked Learning offers pathways in many STEM-related fields, including architecture, construction, and engineering; agriculture and natural resources; biomedical and health sciences; advanced manufacturing; digital media arts; health professions; and information technology. Because every Linked Learning pathway must incorporate all core academic subjects and connect them to real-world applications, even pathways in less STEM-dominated fields—such as law or hospitality—provide opportunities to enhance students' STEM learning.

For example, in a high school offering Linked Learning pathways in both information technology and law and justice, courses in the law and justice pathway might emphasize the growing complexities surrounding the protection of intellectual property in technology fields, such as patents on software designs or coding sequences—issues crucial to the advancement of STEM in the United States.

Such infusion of STEM throughout the curriculum happens at the School of Engineering and Sciences (SES) in Sacramento Unified School District in California, which offers a Linked Learning pathway on engineering and design for its 7th through 12th graders. The school's mantra is "Build, innovate, and design!" Starting in 7th grade, students must take engineering and design-related courses every year, along with core academic courses and requisite math and science courses that use multidisciplinary project-based learning. For high school students, the course sequence includes early college opportunities in collaboration with Sacramento City College and Sacramento State University.

A roller coaster project demonstrated the laws of motion and energy in a physics class.

The school also scaffolds an increasingly rich series of work-based learning opportunities connected to STEM fields. These experiences start with mentoring and job shadowing and evolve into internships and project-based learning opportunities that have local employers guiding and evaluating student work.

The School of Engineering and Sciences is one of several Linked Learning pathways available to students throughout the Sacramento district. Students less attracted to engineering might attend Arthur A. Benjamin Health Professions High School (HPHS), which organizes teaching and learning around careers in health care. Courses are as STEM-oriented as those at the School of Engineering and Sciences, but they focus more on community health, disease, biophotonics, and epidemiology. Once a week, both students and teachers wear scrubs as a reminder of their commitment to organize teaching and learning around the health professions.

Many other California districts use Linked Learning to offer students a rich menu of STEM-related pathways. For instance, Long Beach Unified has adopted a resolution that by 2016, 90 percent of its high school students will be enrolled in certified Linked Learning pathways that include architecture, construction, and engineering; media and communications; GREEN (Generating Respect for Earth, the Environment, and Nature); and QUEST (Questioning, Understanding, and Engaging Success through Technology). In Antioch Unified School District, students at two of the comprehensive high schools can follow pathways in Engineering and Designing a Green Environment; Environmental Studies; Leadership and Public Service; Media Technology; Law and Justice; or Biotechnology—or they can attend the theme-based Dozier-Libbey Medical High School.

In Michigan, Detroit now has eight Linked Learning high schools, offering pathways in engineering, health professions, and information technology, to name a few. In Texas, Houston Independent School District is on track to deliver Linked Learning in all its high schools.

Linked Learning and the Standards

Linked Learning and the implementation of the Common Core State Standards and Next Generation Science Standards are not competing initiatives. On the contrary, if the Common Core and the science standards represent what students need to know and be able to do, Linked Learning provides a strategy for teaching this essential knowledge and skills.

> If the standards represent what students need to know and be able to do, **Linked Learning provides a strategy for teaching this essential knowledge and skills.**

Linked Learning not only strengthens STEM instruction in traditional science and mathematics courses, but also provides a framework and rationale for developing more comprehensive programs of study. These programs not only include cutting-edge STEM-focused courses (such as in information technology or biomedicine and health), but also encourage incorporation of STEM content into core academic subjects. Schools will need such course strengthening and integration of STEM instruction to help all students master these demanding standards.

Here's an example from the Digital Media Arts Pathway at Hollywood High in the Los Angeles Unified School District. Three years ago, all seniors in this pathway were charged with creating and producing a short video trailer that they would use to pitch a full-length documentary to Hollywood studio executives. They worked on the project in teams throughout their senior year.

One group of students made a trailer for a documentary on the history of racial discrimination in Los Angeles public schools. To inform their work, they read writings by James Baldwin for their English class and studied *Brown v. Board of Education* and other court cases in social studies class—but they also drew on STEM-related knowledge to improve their product. In physics, they studied the properties of light and optics and how they affect exposure, depth of field, white balance, and other aspects of producing images with still and video cameras. In their videography class, they learned about design, lighting, sound, and using digital technologies for editing. Perhaps most important, they learned that iterative revision leads to an increasingly polished product.

Eventually, the group pitched its three-minute trailer to the vice president of MTV. When I asked them what was the most important thing this executive told them about their trailer, they all replied, "Spelling matters!" Their teacher noted that she tells the students this all the time, but it didn't sink in until they heard it from an industry professional.

This example highlights another way approaches like Linked Learning make it more likely students will master STEM skills. By connecting STEM-related course content to experiences found in the work world, the approach gives teachers an answer to students' frequent—and fair—question, "Why do we need to know this?"

Part of the Fabric

If schools continue to teach STEM content in isolation from the rest of core academic and technical curriculum—and fail to link that content to the work done in STEM-related occupations—we'll continue to marginalize STEM. Conceptually and practically, STEM is part of the rich fabric of curriculum, teaching, and everyday life. We need an approach to schooling that communicates that fact—and celebrates it. EL

Author's note: Schools and districts interested in formally adopting the Linked Learning approach should contact Brad Stam at ConnectEd (bstam@connectedcalifornia.org). Many of the resources needed to plan and implement a menu of pathways are available free on ConnectEd's website (www.connectedcalifornia.org) or through ConnectEd Studios (www.connectedstudios.org), an online platform supporting Linked Learning.

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COMMENTARY

STEM Sense & NONSENSE

Let's stop hyperventilating about STEM worker shortages and focus our efforts on improving overall STEM literacy.

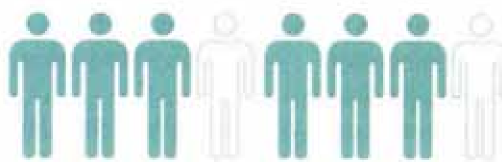
Robert N. Charette

Historians still argue over the exact date, but the tipping point may have happened late Monday afternoon on October 18, 2023. On that day, America lost the STEM War.

After years of warnings from business leaders and politicians about the "intellectual disarmament" (Gates, 2011) of the nation caused by the lack of "reverence for science and math and technology and learning" (White House, 2009), the United States finally fell hopelessly behind other nations in the "rapid and persistent worldwide advance of education, knowledge, innovation, investment, and industrial infrastructure" (Institute of Medicine, National Academy of Sciences, & National Academy of Engineering, 2010, p. *x*). As a result, the nation quickly saw its "privileged position" in the world erode (Institute of Medicine, National Academy of Sciences, & National Academy of Engineering, 2005, p. 13) and faced the end of its "high quality of life" (p. 1).

Sound farfetched?

Not if you believe the almost daily dose of mass media stories, journal articles, and industry white



papers alleging that the United States faces a STEM crisis. But the tale of seemingly insurmountable STEM woes is not new; it has been regularly repeated over the past 75 years. The myth of a science and engineering workforce crisis not only risks steering students in the wrong direction for the wrong reasons, but also undermines legitimate efforts to create a STEM-literate society.

History of the "Crisis"

The current installment of the STEM crisis narrative originated in the early 2000s with a slew of reports warning of an imminent shortfall of skilled workers. The National Association of Manufacturers (2001), for instance, asserted that unless U.S. education changed significantly, the country was facing a shortage of 5.3 million skilled workers by 2010 and 14 million skilled workers by 2015.

In 2005, a highly influential, 592-page report called *Rising Above the Gathering Storm* was published by the Institute of Medicine, National

Academy of Sciences, and National Academy of Engineering. Written by a committee of prominent businesspeople, academics, and scientists, the report painted a grim picture of the rapid erosion of the United States' lead in science and technology. The authors argued that compared with students in other countries, U.S. students were uninterested in STEM careers and poorly prepared to pursue them even if they desired to do so. China was already graduating three times as many engineers as the United States, with the gap growing wider each year.

The *Gathering Storm's* findings helped convince President George W. Bush to propose, and Congress in 2007 to approve, the America COMPETES (Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science) Act, which aimed to significantly increase funding for federal research and development as well as STEM education (Markoff, 2006).

When Barack Obama took office, he too believed that the country suffered from a STEM crisis. President Obama quickly began a series of high-profile public-private initiatives to address the problem of inadequate teaching in STEM. He issued a national challenge to prepare 100,000 effective STEM teachers, proposed putting $1 billion into the federal budget to create a STEM Master Teacher Corps, and requested $80 million for a competition by the Department of Education to improve STEM teacher preparation programs (White House, n.d.).

Each false alarm, including the one we are now experiencing, **creates an illusory demand** for scientists and engineers.

Some experts identified the root of the STEM crisis as the lack of student interest and retention—the so-called "leaky STEM student pipeline." One popular graphic, attributed to the National Center for Education Statistics and available all over the Internet (for example, at http://pdxstem.org/about-us/stem-in-oregon), shows the STEM pipeline starting in 2001 with 4 million 9th graders in U.S. schools and ending in 2011 with a trickle of just 166,530 students predicted to leave the pipeline with STEM-related college degrees.

STEM Crisis Hyperbole

Given such widespread, repeated claims, unwary observers can't be blamed if they think that a STEM crisis does exist. However, these claims don't stand up under closer scrutiny. In fact, a decade of studies of the alleged STEM crisis—performed by researchers at the Rand Corporation (Butz et al., 2004); Duke University (Wadhwa, Gereffi, Rissing, & Ong, 2007); the Urban Institute (Howell & Salzman, 2007); Rutgers (Lowell, Salzman, Bernstein, & Henderson, 2009); the Economic Policy Institute (Salzman, Kuehn, & Lowell, 2013); the University of Wisconsin–Milwaukee (Levine, 2013); Ball State University (Hicks, 2014); and the U.S. Government Accountability Office (2014), to name just a few—have been unable to find compelling evidence of any widespread shortage of STEM workers. Quite the opposite: These researchers have consistently found that the United States has an ample supply of STEM students and workers, except perhaps in a few computer technology and engineering specialty fields.

A strong indicator of a shortage in a particular labor category is a rise in wages because of increased demand. However, researchers repeatedly find that wages for STEM workers have remained stagnant for more than a decade, even for most computing work in the high-tech industry. In fact, Bright.com, a California high-tech recruiting company, admitted last year that despite the rhetoric to the contrary, only a minimal number of IT-related jobs in Silicon Valley showed skill shortages (Rouen, 2013).

Employers' complaints that they can't find enough skilled workers may reflect the reality that the struggling economy has allowed them to become much more selective in their hiring since the mid-2000s (Begley, 2005). Employers want new STEM graduates to be experienced, work-ready, and able to contribute from their first day onward—as well as to be critical thinkers, clear communicators, and innovative problem solvers. If current STEM applicants don't meet these standards, employers seem content to wait for their perfect candidate to appear (Cappelli, 2012).

In addition, employers have cut back on internal training; some surveys report that fewer than 25 percent of employees now receive employer-provided training (Büning, Cantrell, Marshall, & Smith, 2011). Recent data show that in the past decade, U.S. businesses have reduced by more than 40 percent the number of apprentices they hired. This would hardly be a logical course of action if companies were facing a shortage of qualified job applicants (Cappelli, 2014).

Even the leaky STEM pipeline is not as leaky as previously thought.

Recent data from the National Center for Education Statistics (2013) and the National Survey of Student Engagement (2013) show that attrition rates for college students majoring in STEM subjects are not nearly as high as claimed. Further, the number of students declaring STEM-related majors has been steadily rising for years (National Science Foundation, 2014); many universities are now saying that they're having difficulty handling the "tsunami" of students wanting to study popular subjects like computer science (Lazowska, Roberts, & Kurose, 2014).

It's debatable whether most of those future STEM graduates will find a job in their chosen field of study, however. The Economic Policy Institute indicates that only about 50 percent of STEM graduates are hired into a STEM job (Salzman, Kuehn, & Lowell, 2013), and 350,000 new STEM graduates are competing for about 275,000 new STEM job openings each year (Charette, 2013). Even for students with engineering and computer science degrees, hiring into the same broad field as their degree rarely reaches 70 percent.

Moving Away from STEM Nonsense

Claims of massive STEM worker shortages are nothing new, of course. Harvard's Michael Teitelbaum (2014) documents five science and engineering talent "alarm–boom–bust" cycles that the United States has gone through since the end of World War II. Each alarm was sparked by fear that the nation was falling behind a military or economic competitor and lacked the skilled citizenry to compete successfully. And each time, the cries of crisis turned out to be highly embellished or outright deceitful.

As an unfortunate side effect, each false alarm, including the one we are now experiencing, creates an illusory demand for scientists and engineers. When the boom turns into a bust, it ends up discouraging future students from pursing those careers. The dramatic growth in university students chasing computer science degrees during the 1990s dot-com boom—and the equally spectacular drop-off after the bubble burst in the early 2000s—is but one recent example (National Science Foundation, 2012).

RAZSTUDIO/SHUTTERSTOCK

Technology challenges us to assert our human values, which means that first of all, we have to figure out what they are.

–Sherry Turkle
From PBS's *Frontline*, September 2009

We don't need to raise an army of STEM saviors to protect the American way of life from destruction. We would be much better served by less hyperventilating about STEM worker shortages and more focus on improving overall STEM literacy—by a commitment to ensuring that all students have a basic mastery of STEM subjects blended with the arts and humanities.

We live in an increasingly complex, interconnected, technological world. Successfully navigating this world, not only today but into the future, requires understanding the basic science, technology, engineering, and mathematics that underpin it. Without that knowledge, to paraphrase futurist Arthur C. Clarke (2000), the products of science and engineering start to become indistinguishable from "magic" (p. 2), creating unwarranted illusions about what these products can accomplish.

But just as important as a basic knowledge of STEM is a broad knowledge of the arts and humanities. These fields, along with a foundation of STEM disciplines, enable us to reason thoughtfully about the risks, opportunities, problems, and dilemmas that the products of science, engineering, and technology impose on society.

For instance, digital technology allows for widespread sharing and communication of information, yet at the risk of the erasure of personal privacy. Genetic advances promise early detection of disease, but also raise the temptation to pursue eugenics. Robotics can increase business productivity, but at the cost of great worker unemployment. How does one properly balance the rewards against the risks that new technology creates without intimately knowing both the demands of the technology and the aspirations of humankind? Without some blended mastery of STEM with arts and humanities, students will find themselves increasingly "in over their heads" (Kegan, 1998) and poorly equipped to deal with the mental and ethical demands of the 21st century.

Various instructional and curriculum options exist for integrating STEM with the arts and humanities. The ideal would be required courses beginning in middle school and going into high school that specifically integrate the science, math, history, and English knowledge currently being taught separately within a particular grade.

The multidisciplinary approach that underpins professor David Christian's Big History Project (www.bighistoryproject.com/home) offers an example of how STEM and the humanities can be blended together to explore the full breadth and depth of a subject. Instead of treating historical facts from the sciences and the arts as disconnected pieces of some fuzzy puzzle, the Big History Project tries to show students how the ideas in these subjects are interconnected and inseparable. Although not without its own pedagogical and objectivity issues (for example, the project is underwritten by Bill Gates, and questions have been raised as to whether its funding source biases its content), the Big History Project does demonstrate how STEM and the humanities and arts can be taught in a holistic manner (Sorkin, 2014).

The Real Skill Shortage

If we truly want students who can think critically, solve problems, and communicate their thoughts clearly, then some kind of systematic, cross-disciplinary instruction is required. An integration of STEM with the arts and humanities will help students learn how to learn—which is, in my opinion, the actual skill shortage we face today.

Nineteenth-century Scottish chemist, poet, and essayist Samuel Morison Brown wrote that the scientific and engineering discoveries that were revolutionizing the society of his time demanded that schools teach all students "not mathematics, but a mathematical way of thinking, not natural history, but a classic way of thinking, and not natural philosophy, but an inductive way of thinking" (quoted in Swinton, 1860, p. 2). If we want to move from STEM nonsense to STEM sense, we would be wise to follow Brown's advice and create STEM literacy in all our children. EL

We don't need to raise an army of STEM saviors to protect the American way of life from destruction.

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Bryan Goodwin with Heather Hein

STEM Schools Produce Mixed Results

On a sunny April morning near Monterey Bay, California, droves of middle and high school students descended on Aptos High School for an underwater robotics competition. Teams of students made last-minute changes to the robots they had designed and built to compete in various "missions" based on real-life challenges confronting the U.S. Coast Guard and other maritime agencies. The students poured themselves into the task, reviewing notes taken from a 400-page, college-level textbook and perfecting their presentations to engineers from a nearby oceanographic institute, who were judging the competition.

The entire scene appeared to disprove the common perception that U.S. students aren't interested in STEM subjects. Unfortunately, statistically speaking, that perception is accurate. Science and engineering degrees account for only about 30 percent of all bachelor's degrees in the United States, compared with more than 50 percent in Japan and China (National Science Board, 2012). To better prepare students to pursue STEM college majors and careers, states and districts across the United States have created schools that focus explicitly on STEM.

> We need to reconceive STEM learning from a starting point of providing stimulating experiences that spark student interest in these disciplines.

No Simple Solutions

To date, however, such STEM academies have produced lackluster results in terms of raising student achievement. Consider three recent studies:

- A comparison of STEM and non-STEM schools in Florida and North Carolina found no evidence that students in STEM schools performed any better in mathematics (Hansen, 2014).
- Although students in 30 STEM high schools in New York City performed better than those in regular public schools overall, the researchers found that "more thorough analysis conditioning on a rich set of covariates, including previous grade test performance, reduces or eliminates this advantage" (Wiswall, Stiefel, Schwartz, & Boccardo, 2014, p. 1).
- An Arizona study tracked students' achievement before and after they transferred into nine STEM charter middle schools and two STEM magnet middle schools. After three years, students demonstrated higher achievement in the STEM charter schools (but no gains in the magnet schools), but researchers cautioned that the gains might simply reflect performance bumps (and selection bias) they observed in *all* students who transferred to new schools, regardless of the schools' focus (Judson, 2014).

Another question we might ask about STEM schools is whether they increase the likelihood that students will pursue STEM-related college majors or careers. One study of 1,250 students in eight selective STEM schools found that among their students who went on to graduate from college, nearly two-thirds (64.9 percent) received their degrees in STEM fields, far above the national average of 30 percent. However, when the study looked at the trajectories of students who entered selective STEM schools for reasons other than deep interest in STEM, it found that these students were no more apt to pursue STEM careers than students of similar ability who attended regular schools (Subotnik, Tai, & Almarode, 2011). On the basis of this research and other studies, a panel commissioned by the National Research Council (2011) concluded that "there are no systematic data that show whether the highly capable students who attend

[STEM] schools would have been just as likely to pursue a STEM major or related career . . . if they had attended another type of school" (p. 8).

It's What Happens Inside That Matters

A shortcoming of many of these studies is that they do little to describe what may or may not be going on *inside* STEM schools. To peer into this black box, the previously referenced survey of 1,250 students also looked at which forms of instruction in STEM schools were most strongly tied to students pursuing STEM majors in college. The most significant predictor of students' continued interest in STEM, the study found, was whether students had rich research experiences in high school, such as original scientific investigations or engineering design projects. Such experiences made students, on average, 1.77 times more likely to pursue STEM majors and careers (Subotnik, Tai, & Almarode, 2011).

The National Research Council's 2011 synthesis of research and commissioned papers on STEM schools concluded that to spark student interest in STEM, instruction must help students grapple with big ideas and fundamental questions about the natural world and experience real-world applications of their knowledge. "However," the report observed, "this type of STEM instruction remains the exception in U.S. schools" (p. 19).

According to the study, the most significant obstacle to providing students with the kinds of rich STEM learning experiences that enhance interest in STEM may be our current assessment and accountability schemes. Many statewide tests rely heavily on multiple-choice items that limit the "content and complexity of what [states] test" (National Research Council, 2011, p. 21).

In many cases, schools have responded to accountability pressures by doubling down on rote learning and test prep. For example, a study of 51 STEM academies in Texas, which were ostensibly created to promote project-based learning, found that many of them were employing a traditional pedagogy that included explicit preparation for statewide tests (Young, House, Wang, Singleton, & Klopfenstein, 2011). These schools were operating in a compliance mind-set and employing uninspired approaches to teaching and learning, said the researchers.

Was this kind of **learning** possible precisely because it **occurred outside the regular school day**?

Rekindling Student Interest in STEM

The insipid teaching approaches employed by some STEM schools contrast sharply with the energy and excitement of the Monterey underwater robotics competition, which provided exactly the kind of authentic learning that research links to student interest in pursuing STEM careers. Perhaps the most intriguing aspect of the competition, though, was that it occurred on a Saturday and was not part of any regular school curriculum, which raises the question: Was this kind of learning possible precisely because it occurred *outside* the regular school day, away from the pressures of content coverage, test preparation, and Carnegie units?

If so, then perhaps we need to step outside these constraints and reconceive STEM learning from a starting point of providing stimulating experiences that spark student interest in these disciplines. That may be a tall order. But if our students are clever enough to figure out how to build robots and navigate them through underwater trials, surely we can figure out how to put the joy of discovery and invention into STEM learning. EL

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SHOW & TELL: A VIDEO COLUMN

Doug Fisher and Nancy Frey

STEM for Citizenship

The case for STEM education for all students is a strong one. Some advocates stress the United States' need for a workforce that can compete in a global economy. They also point to the potential of STEM education to increase economic equality; blacks and Hispanics, who are currently underrepresented in STEM careers, greatly increase their earnings when employed in the fields of science, technology, engineering, or math (Beede et al., 2011).

But preparing students for future employment is not the only rationale for STEM education. Even though not all graduates of schools with robust STEM programs will choose to pursue careers in these fields, improved STEM education can help all students learn to apply logic and reasoning to solve complex problems. In addition, many educators view STEM as an ideal platform for developing students' communication, collaboration, creativity, and critical-thinking abilities (Partnership for 21st Century Skills, 2011).

> We should prepare *all* members of the next generation to be informed citizens who can understand complex STEM-related issues.

All students—whether or not they pursue careers in science, technology, engineering, and math—will be consumers of news and information on STEM issues that will directly affect their lives. Beyond developing skilled professionals, we need to develop a skilled electorate that can apply knowledge, examine issues, and pose questions to politicians and policymakers. For instance, there has been an ongoing debate on the merits and risks of hydraulic fracturing (sometimes called *fracking*) to obtain natural gas in shale and coal seams. Most of us are not experts in drilling techniques, yet we can take the time to investigate the issue, listen to proponents and detractors, filter out biased claims, and form opinions that are based on evidence.

Critical Thinking for an Informed Society

One hallmark of an informed citizen is the ability to develop his or her own views by evaluating and reflecting on evidence rather than automatically accepting someone else's position. Such critical thinking requires intellectual skills that transcend a specific knowledge base. According to Richard Paul and Linda Elder (2009, p. 4), a "well cultivated critical thinker"

- Raises vital questions and problems.
- Gathers and assesses relevant information.
- Comes to well-reasoned conclusions and solutions.
- Thinks open-mindedly about alternative systems of thought.
- Communicates effectively with others to figure out solutions to complex problems.

These characteristics echo the principles of close reading of informational text. Close reading requires students to systematically explore text using three major questions: *What does the text say?* (literal); *How does the text work?* (structural); and *What does the text mean?* (interpretative or inferential). Students explore these questions through extended teacher-facilitated discussions

WATCH the Video | See how a skilled teacher connects science learning with critical thinking and civic responsibility at www.ascd.org/el1214fisherfrey.

with their peers. As they engage in deep analysis to interpret the text, they may move toward a fourth question: *What does the text inspire me to do?* This last question can lead students to a number of different actions, including writing, debating, and exploring the topic in more depth.

See It in Action: Confronting Real-World Problems

Many students grasp for relevance in the subjects they study in school. They ask themselves, When will I ever use this? Courses that integrate STEM with other disciplines like language arts and social studies enable students to apply their learning to authentic problems.

Teachers of these courses can find applications of their content in the media every day. News stories about genetically modified foods, oil spills, renewable energy, endangered species, and viral epidemics are golden opportunities to engage students in close reading and writing about science, technology, engineering, and math.

You can observe one such lesson in the video that accompanies this month's column (www.ascd.org/el1214fisherfrey). Eleventh grade chemistry teacher Angie Holbrook is leading her students through a close reading of a speech on climate change that President Obama delivered in June 2013. Her students previously studied the relationship of carbon dioxide to pollution and ocean acidification by reading a journal article on the subject. Armed with this information, they now examine the president's arguments regarding climate change and his plan to address the problem. They talk about the speech's purpose, the audiences to whom it was

Many educators view STEM as an ideal platform for developing students' communication, collaboration, creativity, and critical-thinking abilities.

intended to appeal, and whether the president presented factual evidence to back up each claim. After this close reading, the students wrote letters to policymakers about climate change using evidence from their study of ocean acidification.

Prepared for Action

Graduating more students who are prepared to pursue STEM careers is an important goal. But it's not the only goal of STEM education, nor should it be the single measuring stick we use to gauge success. We should prepare *all* members of the next generation—not just our future scientists, computer programmers, engineers, and mathematicians—to be informed citizens who can apply the critical-thinking skills needed to understand complex STEM-related issues and to act accordingly. EL

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Doug Johnson

The Responsive Staff Meeting

"If I die, I hope it's during a staff meeting because the transition to death would be so subtle."
—*author unknown*

Can school leaders use interactive technologies to make staff meetings and professional development presentations feel less deadly dull?

In his *Free Technology for Teachers* blog, Richard Byrne gives the following reasons for enhancing classroom discussions by using technology to create a *back channel*—an online discussion that accompanies the face-to-face one, simultaneously or as an online continuation of the discussion:

- The back channel gives shy students a place to ask questions and contribute to conversations.
- Students who process information by asking questions can ask an unlimited number of questions without dominating the classroom conversation.
- Comments in the back channel help us gauge students' interest in and prior knowledge of a topic.
- Looking at comments as the discussion or activity unfolds lets us gauge the activity's effectiveness in real time.
- The back channel extends conversations beyond the classroom hour or school day.[1]

Try substituting *teacher* for *student* and *meeting* for *classroom* in Byrne's list and you'll see how encouraging teachers to interact—with the content and one another—through technology during meetings or inservice trainings can enliven them.

Three Reasons to Invite Technology

Many teachers embrace the use of technology to promote discussion, engagement, and real-time assessment in the classroom. Yet turning to technology in staff meetings, inservice trainings, and other gatherings of adults is often ignored or even viewed negatively. Leaders seem to think that when e-mail and other "distractions" are available, staff members, like kids, won't be capable of paying attention.

Technology should be not only allowed, but also encouraged in meetings and workshops for adults for three reasons:

Technology should be not only allowed, but also encouraged in meetings and workshops for adults.

1. We can model technology use.
School leaders can demonstrate the device management techniques that we expect teachers in 1:1 and Bring Your Own Device programs to master. We can model how to communicate expectations to students. ("Please put your device in listening mode." "Share good websites you find.") Meeting goers can practice working collaboratively on documents, communicating respectfully in the back channel, and engaging in other responsive activities.

Teachers teach the way they learn best. If they get a chance to experience learning through effective digital tools and online interactions, they're more likely to try such practices in their classrooms.

2. We can create meaningful meetings.
Devices let leaders create interactive meetings rather than reading aloud from PowerPoint slides. Here are some tech tools exemplary teachers leverage to make classes more engaging. Consider how you might use these tools to promote interaction in faculty meetings, all-staff presentations, and inservice sessions.

- *Response systems.* With such systems, a leader or trainer poses a question to the group; each participant answers on an individual device (preserving anonymity); and results are immediately tabulated and displayed to the entire group as a bar graph, chart, comment list, or other format. Some systems use dedicated devices with interactive whiteboards, and some have teachers use personal devices (like laptops or smartphones) and software applications with web-based feedback tools—such as Socrative, Poll Everywhere, Google Forms, and GoSoapBox.

- *Cloud-based tools for collaboration.* Imagine if, during inservice presentations, teachers spent time exchanging feedback on lesson plans connected to the strategy just presented. Or imagine if, during faculty meetings, they collaborated in small groups on a master scheduling document—which was then saved to the school's network. Google Apps for Education, Microsoft 365, and Zoho, among other products, are effective ways to share work and provide comments online. These tools let people share at a variety of levels—view, comment, edit, or chat.

- *Online tools to meet—and brainstorm.* Nifty tools like Padlet, MindMup, and TodaysMeet enable a group of people to share plans and ideas online in real time. Padlet offers advantages over paper-based brainstorming: Users can add photos and graphics to their "sticky notes," electronic "walls" can be saved for later viewing, and the notes can be easily sorted and categorized.

- *Built-in cameras and microphones.* Many schools choose tablet computers rather than laptops because they have built-in rear-facing cameras and microphones. When kids record their own actions during learning activities, these devices become formative assessment tools of the highest order. Adults can use them for formative assessment of their teaching, too. Record a lesson or an interaction with a student, and then view it with peers (or share the recording online) for comments, feedback, and discussion.

- *Web-based creation software.* When you do need to present a chunk of information, make your presentation look professional and awesome. Animoto, Prezi, Wordle, VoiceThread and a multitude of infographic creators like Creately make doing so relatively simple. Some, like VoiceThread, enable users to comment online within the presentation.

In professional development exercises, we might give participating teachers a quick tutorial on, say, Prezi, then have them communicate their ideas and demonstrate their learning to the group with pictures and sounds as well as words.

Making It Happen

What School and District Leaders Can Do

- Create staff meeting norms that allow the constructive use of technology.
- Model effective device management strategies in meetings.
- Use the tools teachers are expected to use in the classroom in staff meetings and inservices.

3. We can hold paperless meetings. Instantly modifiable and full of links to further information, online documents are more current, more useful, and easier to find again when needed. Our district uses Google Docs to create and share agendas, schedules, and informational materials pertinent to meetings. Rather than printing documents out, participants bring a device to meetings and refer to documents online. We provide updated information for participants online after meetings. Plus, this sends an environmental message.

Getting Real

We school leaders must be the change we want to see in our school, to paraphrase Mahatma Gandhi. We have to model good technology use in all human interactions—including classes, meetings, and professional development events.

Technology use can even help us differentiate instruction for adult learners. If schools use content and course management systems like Moodle, teachers can assess their own skills and place themselves in the right professional development course or session. When online courses or activities at a variety of skill levels are available, nobody gets bored or frustrated.

Do we really think teachers will try to integrate technology into their classrooms when encouraged to do so by an administrator who only uses paper handouts and lectures at meetings? Get real. EL

[1]Byrne, R. (2013, June 13). 5 Benefits of using backchannels in the classroom [blog post]. Retrieved from *Free Technology for Teachers* and www.freetech4teachers.com/2013/06/5-benefits-of-using-backchannels-in.html

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Thomas R. Hoerr

Dress Code!

"I shouldn't know what color underwear you are wearing." That quote by one of my teachers is how I ended the dress code guidelines memo that I sent to my staff.

I spent much more time and emotional energy developing the memo than I had expected, and I was pleased with the absence of any pushback when I finally sent it. In hindsight, the experience offered some obvious management lessons. What did I learn?

1. *The little issues are really the big ones.* Educators have spent a lot of time implementing the Common Core State Standards and working to raise student achievement. That's appropriate because success in these areas goes a long way to determining the quality and reputation of our schools. But the "little things"—from designing worthwhile faculty meetings to having snacks in the lounge—help determine how people feel about their jobs. If these little things aren't handled well, they can become big things.

If the little things aren't handled well, they can become big things.

2. *"Measure twice, cut once."* This carpenter's aphorism speaks to being extra careful before you take an irreversible step. In my mind, it means being sure I need to intervene before I intervene. It's tempting to get involved in everything, but a lot of issues will resolve themselves without my intervention. (Or maybe they don't need resolution.)

My school is a casual place—I'm the only person who wears a tie—and we've never had a staff dress code beyond being "neat and clean." Yet it seems to me that we should dress differently when working in a school than when going to the beach or a nightclub or working in the yard, and my gut told me that what some people were wearing to work could become a big issue. But before making a statement, I discussed the issue with some staff members to determine whether others shared my concern. Their comments and raised eyebrows told me that, as a leader, I needed to speak up.

3. *Our decision is almost always better than my decision.* Although I always like my ideas, I'm aware that my decisions become wiser—more likely to be respected and followed—if I've listened to others and pulled in their ideas. This isn't just true for me; in *The Wisdom of Crowds* (Doubleday, 2004), James Surowiecki makes the case that our decision making is improved when we listen to others, especially those who may not see things the way we do.

In this case, I wrote a draft of our dress code guidelines and shared it with some teachers. By doing so, I was not only getting their input, but also alerting them to what would be happening and garnering support. Their feedback endorsed my points, but a couple of people suggested that the guidelines be even more restrictive. Several noted that my guidelines only applied to women: "What about the men?" one teacher wrote. Another said that although she wasn't aware of any men dressing inappropriately, we should be proactive and address this before a problem developed. Of course, they're right, I thought. I was pleased that I had reached out for feedback, but then a teacher asked me about the ages of the teachers to whom I had sent the draft. "Does the group reflect a cross section of our faculty?" she asked. Gulp, no.

4. *Who is the "our" in "our decision"?* I had sent the draft memo to teachers who have been in my school more than 15 years. These teachers have a wealth of experience and bring seasoned judgment to any issue, but their sense of what's appropriate to wear to work may not be the same as that of those who are in their 20s. If I really want to benefit from the wisdom of the crowd, I need to reach out to those who may see things differently.

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Carol Ann Tomlinson

The Kind of STEM Teachers We Need

In a preschool class a few years back, I watched 3-year-old twin boys puzzle over a pulley with a plastic bucket on it. They were absorbed by the contraption for the full 10 minutes that I watched them. One boy would tug on the pulley cord, and the bucket would rise. Both boys would look up for several seconds, then the other one would tug on his side of the pulley cord and the bucket would descend. Another pause, this time to look down. Silence. They were not simply jerking a cord for the sake of pulling it. They were inquirers on the verge of figuring out something deeply important to them at the moment.

After a time, their teacher knelt on the floor beside them and asked, with her full attention on their faces, "What are you thinking?" One boy replied, "The bucket goes up and down on purpose." The second said, "It happens every time." For several minutes, the teacher posed questions and follow-up questions and added conjectures of her own. Together, they tested the capacity of the pulley to lift objects in the bucket. One of the boys mused, "This pulley makes me strong and tall." I wanted to stay in the room a lot longer than my schedule said I could.

> Give me teachers who relentlessly cause kids to wonder.

More recently, I watched an elementary math teacher lead her students in an inquiry about prime numbers. Her questions were carefully calibrated to guide and provoke reasoning. Ultimately, students began to ask one another questions rather than only answer the teacher's questions. At one point, a girl was puzzled by a peer's explanation and said to him, "Could you help me understand your thinking? If I use your logic, every number will be a prime number." With confidence, the boy began to illustrate his thinking by writing on the board as he spoke. Soon, there were pauses in his explanations, then a restart, then a sputter. Then he faced his inquisitor and said with poise, "I believe I need to disagree with myself at this point."

I watched an English teacher and her middle school students look at photographs the kids had taken in the schoolyard the day before. They had hunted for images to photograph that spoke to them in some way. "How did the textures of the object affect you?" she asked at one point. At another time, she said, "I think I see contrasting feelings in your explanation. Did you sense that as well?" Later, a student remarked, "I like the contradictions in my image, or maybe they are just contrasts. I like the idea of looking at one thing and coming away with mixed feelings."

These teachers, in my book, were all STEM teachers, although only one of them was teaching a class in math, science, engineering, or technology.

The Teachers I'd Put My Money On

I'm great with the idea of STEM for all students. I get the need for a society to have a sustained crop of scientists, mathematicians, engineers, and experts in technology who move forward the frontiers of its national and international prospects. I'm skeptical, however, that course taking in STEM areas will, by itself, yield what we need in terms of thinkers and innovators for tomorrow.

Instead, I'd put my money on a broad cohort of teachers in every subject who dedicate themselves to the full engagement of young minds in whatever they teach. Give me teachers who relentlessly cause kids to wonder—who ask *why?* and *how did that happen?* and *what if?* as though those questions were the lifeblood of learning.

Give me teachers who insist that students observe and do so systematically; teachers who say, "You must question what you see and what

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The Kind of STEM Teachers We Need

Continued from p. 91

you hear"; teachers who make it imperative that students find the patterns in everything—and explain what those patterns reveal.

Give me teachers who say to their students, "Don't just provide facts. Build a case. Evaluate claims by holding them up against solid evidence. Seek more evidence. Question the assumptions of others—and question your own assumptions."

Give me teachers who push their students to dig deeper, look at the other side of things, learn to tolerate mental messiness and ambiguity, and value truth more than right answers. And give me teachers whose classrooms and lives commingle logical thinking, divergent thinking, and critical thinking—educators who teach students to be aware of their own thinking and how it can serve

These 3-year-olds were inquirers on the verge of figuring out something deeply important to them.

them poorly or well.

Once the United States has classrooms, buildings, grade levels, and departments stocked with such teachers, we'll have STEM for all students. We'll have producers, consumers, and connoisseurs of pivotal ideas. We'll have thoughtful readers and viewers of television, and we'll have solid citizens. Good stuff!

I've always liked John Muir's assertion[1] that "when we try to pick out anything by itself, we find it hitched to everything else in the universe." We'll get the crop of STEM graduates we need not so much when we mandate courses in certain disciplines as when we support teachers in *all* subjects to help their students develop the attitudes and habits of mind at the core of seeing—and seeking to understand—what's all around us in the world. And I'd bet those same habits will lead students to be wise stewards of that world. EL

[1]Muir, J. (1988). *My first summer in the Sierra.* Boston: Houghton Mifflin, p. 110.

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Dress Code!

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Sure enough, after I shared the draft memo with some younger teachers, a few items changed. "Does what kind of sandals I wear really make a difference?" a teacher asked. Not really, I decided. Another teacher wanted to make sure the guidelines were appropriate for teachers who spent much of the day engaged in physical activities with kids or sitting with them on the floor. The resulting memo that I sent was stronger because it included these additional perspectives.

5. Explain why and explain again. Whenever we place a restriction on behavior, we need to give the rationale. "Because I said so" doesn't cut it

"Because I said so" doesn't cut it today (and I'm not sure that it really ever did).

today (and I'm not sure that it really ever did). I explained that we need a dress code because we always want to present a professional appearance—even if it's casual. We don't want to dress in a way that causes others to question our judgment. After sending the memo, I raised the issue at a faculty meeting and asked if there were any questions or comments. I got lots of affirmative nods and a few "makes sense" comments.

Now you can see why this issue took more time and energy than I anticipated. What could have been a big deal remained a little thing. And I hope that the teacher's comment that ended the memo also elicited a smile. EL

Author's note: Readers who would like a copy of the dress code guidelines should send me an e-mail at trhoerr@newcityschool.org.

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Tell Me About . . .

How STEM Instruction Should Change

Start Early

The earlier we can get our children to experience STEM instruction, the better. STEM education should begin in the elementary grades. Our K–6 school became a STEM school three years ago, and the transformation was astounding. Through problem-based learning projects, our students take charge of their learning—they learn how to take risks, collaborate, and solve problems. We have students wading in local lakes and streams looking for macro invertebrates to determine the cleanliness of our water system.

—Angel Blakeley, 4th grade teacher, Washington STEM Academy, Warsaw, Indiana

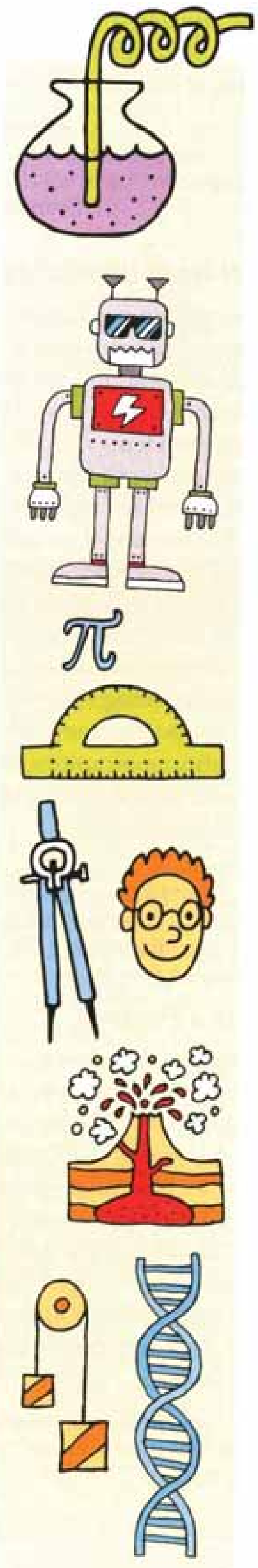
Bring in University Partners

For high school students, STEM instruction needs to include access to scientific research facilities in colleges and universities. Partnerships with college and university researchers stimulate our students to develop skills that prepare them for college work in science and careers in scientific and technology fields. Mentorship is a key component that will change STEM instruction so that more students have the support and role models they need.

—Linda Miller, assistant principal, Martin Luther King Jr. Academic Magnet, Nashville, Tennessee

Help Students Break the Code

Every child needs to learn how to code at an early age. Code is the language we use to talk to computers; it runs everyday objects like cars, phones, websites, bank cards, and medical equipment, yet most of us do not know how to read and write code. Our society has a shortage of qualified coders, yet we are not teaching coding in our schools. By starting early, we could help more students find meaningful work. Coding is about making a difference in the world; it is about using tools to find solutions to problems and to create useful changes in worldwide communication, education, and quality of life.



—Diane Boulanger, French immersion teacher, Peel District School Board, Ontario, Canada

Don't Call It STEM

I would stop using the term *STEM* instruction, which places the emphasis on science and math college majors or career areas. Instead, we should call it *millennial* instruction and emphasize the importance of design thinking, critical reasoning, and problem-solving skills, which are important for all contributing global citizens today and tomorrow. Putting the focus on developing grit and perseverance through problem solving will help students succeed in high school and college.

—Becky Ashe, principal, Knox County Schools, Knoxville, Tennessee

Put It All Together

Instead of breaking down math, science, and so on into subject areas that are taught independently from one another, replace the class period structure with entire days dedicated to collaboratively solving a single, complex problem. Critical-thinking and problem-solving skills are best taught through an interdisciplinary approach, tying multiple subject areas together by requiring students to recall prior knowledge and apply what they know to new situations.

—Nicholas Cammarano, instructional technology resource teacher, New Kent County Public Schools, New Kent, Virginia

Give Students the Keys

I would love to see STEM instruction really put the keys of the class in the students' hands.

Our students today are so used to assignments that come with detailed instructions. They need to have more projects in which the teacher just supplies the problem that they need to solve and lets the students find the solutions themselves. I've found that some of my students are frustrated with this approach at first, but they become more comfortable with it along the way.

—Christopher Laney, STEM teacher, Novi Middle School, Novi, Michigan

Raise Career Awareness

We need to help students examine the diversity of career options that are available through STEM. Many students don't realize how many college majors and career pathways demand STEM experience. To launch the conversation with students, we can talk about how STEM complements their personal interests and strengths. For example, if a student loves sports, we can talk about the importance of understanding biology for training and math for game strategy. We can also highlight how STEM is necessary for jobs students might not expect—for example, carpentry, media arts, and welding. To learn more, see *A Spotlight on Science Learning: The High Cost of Dropping Science and Math* (www.letstalkscience.ca/our-research/spotlight2013.html).

—Bonnie Schmidt, president and founder, Let's Talk Science, London, Ontario, Canada

Draw on the Arts

The arts build many habits of mind that are necessary for STEM learning; for example, in arts classes students learn to be creative, to brainstorm multiple solutions to a problem, to communicate those ideas to other stakeholders, and to persist through a piece of work. STEM can easily evolve into STEAM by providing students with a problem-based arts experience that can help them become independent thinkers and give them the confidence and ability to identify problems, develop solutions, and implement those solutions for the betterment of our communities.

—Nicholas Gehl, department chair of fine arts, Evanston Township High School, Evanston, Illinois

Make It Transdisciplinary

STEM instruction needs to be transdisciplinary. The work that students do should combine all core subjects, and preferably electives as well. We need to give students real-world scenarios they can work through the way engineers, scientists, technicians, and other STEM workers do—calling on math, language, science, and social sciences skills. Curriculum teams at the middle school level give teachers the flexibility to do this kind of transdisciplinary learning. Unless high schools incorporate teaming to provide more holistic opportunities, high school students will get a watered-down version of STEM.

—Jane Laux, 7th grade STEM language arts teacher, Liberty Middle School, West Fargo, North Dakota

Make It a Project

STEM must be more integrated throughout the curriculum and must begin earlier. The instructional strategy that makes most sense in the delivery of information and that answers the students' natural question, "Why do I have to learn this?" is project- or problem-based learning. By satisfying children's natural curiosity, we also teach people how to be lifelong learners.

—Lucy Helveston, mentor teacher, STEM Works, Laurel, Mississippi

Build Partnerships

STEM instruction needs to better prepare students for college and career. We need to collaborate with organizations of higher learning, as well as business organizations, to align our practice. We are doing this in Arlington Independent School District. We collaborate with the University of Texas at Arlington and many local businesses, including Lockheed, to add rigor so students receive true STEM education. We are on the road to preparing all students for the 21st century college classroom and the workforce.

—Kelly Hastings, principal, Young Junior High, Arlington, Texas

Read more educator ideas about STEM learning at www.ascd.org/el1214tellmeabout. See upcoming questions and share your story at www.ascd.org/tellmeabout.

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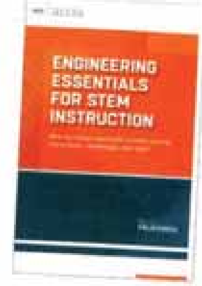
Join us for the 70th ASCD Annual Conference and Exhibit Show to be held March 21–23, 2015, at the George R. Brown Convention Center in Houston, Texas. The theme of this year's conference is "Leading Disruptive Innovation." Choose from more than 350 sessions, and spend three days exploring innovative teaching strategies, lesson planning ideas, and classroom management techniques. If you're interested in science, technology, engineering, and math (STEM), here's a sampling of two sessions that offer expert insights:

- *Inclusive STEM-Focused High Schools.* This presentation will synthesize findings from eight case studies funded by the National Science Foundation of exemplar inclusive STEM-focused high schools from around the United States.
- *Building a Robust STEM Program from the Ground Up.* This school district—90 percent of whose students receive free and reduced-price lunch—was committed to developing a more rigorous curriculum that would successfully prepare its students for college and career. An integral component of the process was the district's commitment to establishing a STEM program from the ground up.

To register for the 70th ASCD Annual Conference and Exhibit Show, go to http://annualconference.ascd.org.

New ASCD Resource on STEM



Are you looking for ways to incorporate real-world problem solving in your classroom? Are you struggling with how to include the "E" in your STEM instruction? Start with this new offering:

- *Engineering Essentials for STEM Instruction: How Do I Infuse Real-World Problem Solving into Science, Technology, and Math?* (ASCD Arias, 2014) by Pamela Truesdell. Stock No. 114048. Price: $12.99 (members and nonmembers).

ASCD Events Calendar

Sign up now for these upcoming conferences and Professional Development Institutes (PDIs). For details on conferences, visit www.ascd.org/conferences. For PDIs, visit www.ascd.org/institutes.

PDI: Disrupting Poverty: Turning High-Poverty Schools into High-Performing Schools

Dec. 2–3 San Diego (La Jolla), CA
Dec. 9–10 Atlanta, GA
Jan. 20–21 Phoenix, AZ
Feb. 3–4 Tampa, FL
Feb. 12–13 Las Vegas, NV

PDI: Differentiated Instruction and the New Standards: Helping All Learners Succeed with Challenging Content

Dec. 3–4 Long Beach, CA
Dec. 11–12 Atlanta, GA
Jan. 22–23 Phoenix, AZ
Feb. 10–11 Las Vegas, NV

PDI: FIT Teaching: An Introduction to the Framework for Intentional and Targeted Teaching

Dec. 2–3 San Diego (La Jolla), CA
Dec. 3–4 Long Beach, CA
Jan. 20–21 Phoenix, AZ
Feb. 5–6 Tampa, FL
Feb. 10–11 Las Vegas, NV

PDI: Building Teachers' Capacity for Success: A Collaborative Approach for Coaches and School Leaders

Dec. 1–2 Long Beach, CA
Dec. 4–5 San Diego (La Jolla), CA
Dec. 11–12 Atlanta, GA
Jan. 22–23 Phoenix, AZ
Feb. 3–4 Tampa, FL
Feb. 12–13 Las Vegas, NV

PDI: Essential Questions: Opening Doorways to Student Understanding

Dec. 2 Long Beach, CA
Dec. 4 San Diego (La Jolla), CA
Dec. 9 Atlanta, GA
Feb. 5 Tampa, FL
Feb. 6 Tampa, FL

PDI: Engaged and Inspired: High-Impact Strategies to Motivate and Challenge Each Learner

Dec. 1 Long Beach, CA
Dec. 5 San Diego (La Jolla), CA
Dec. 10 Atlanta, GA

70th ASCD Annual Conference and Exhibit Show (www.ascd.org/annualconference)

March 21–23, 2015
Houston, TX

EL Takeaways

6 Strategies FOR STEM EDUCATION

Computer science is generally identified with a narrow stratum of our student population, but all students today need to learn about it.

—Jane Margolis, Joanna Goode, and Jean J. Ryoo, p. 48

STEM is part of the rich fabric of curriculum, teaching, and everyday life.... Schools should be connecting STEM to English, social studies, world languages, or the visual and performing arts.

—Gary Hoachlander, p. 74

Application is at the heart of STEM education. When students ask, "Why do I have to learn this?" a STEM experience provides an answer.

—Jo Anne Vasquez, p. 10

We would be much better served by less hyperventilating about STEM worker shortages and more focus on improving overall STEM literacy.

—Robert Charette, p. 79

Perhaps the most effective and underused method for getting students to value science is for teachers to express their own enthusiasm for the topic.

—Lee Shumow and Jennifer A. Schmidt, p. 62

Engineering activities should embrace failure and cast it as a learning opportunity. We should communicate that students don't fail, the design fails.

—Christine M. Cunningham and Melissa Higgins, p. 42

Source: The collective wisdom of authors published in the December 2014/January 2015 issue of *Educational Leadership*, "STEM for All" (Volume 72, Issue 4).