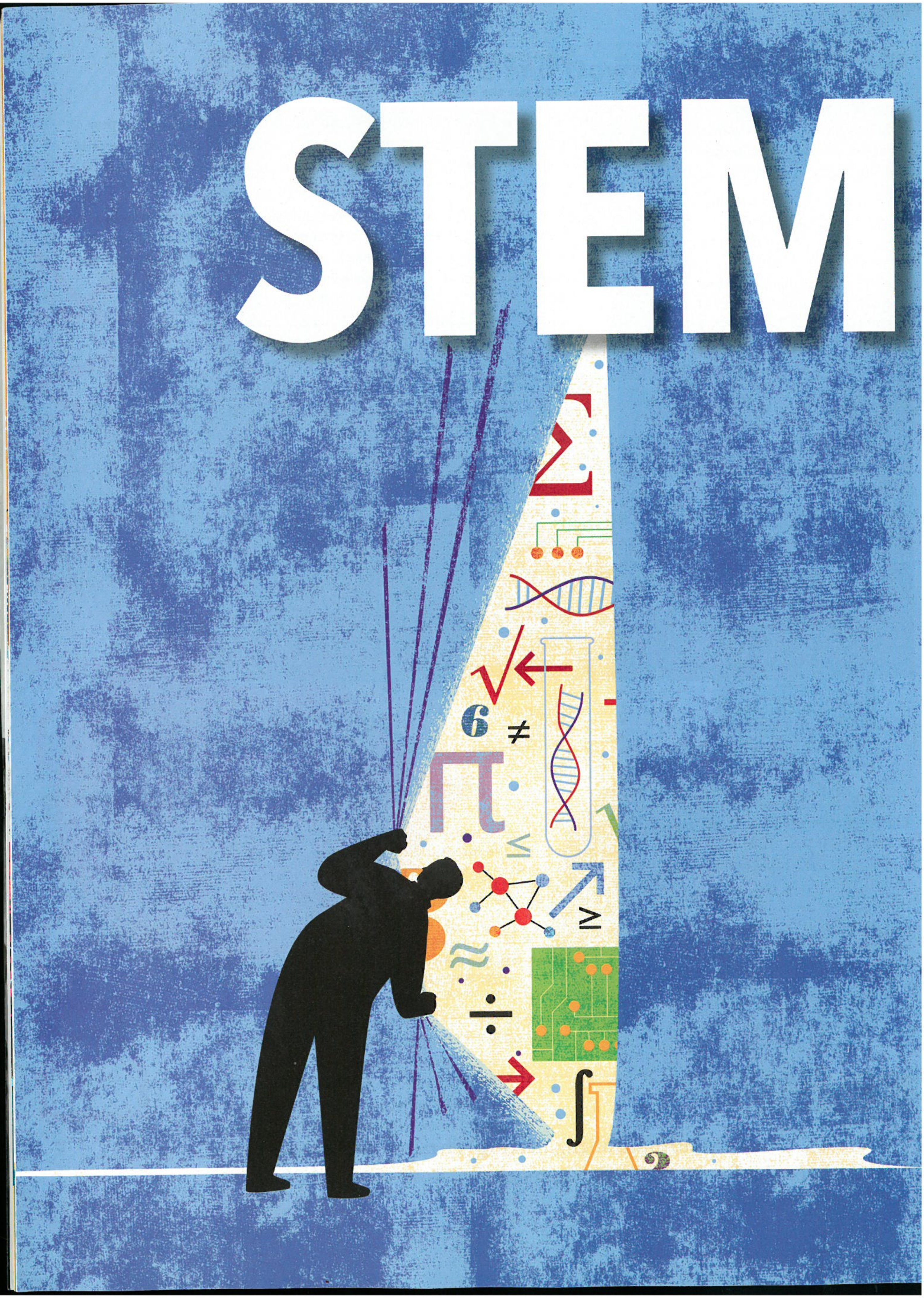

STEM

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.

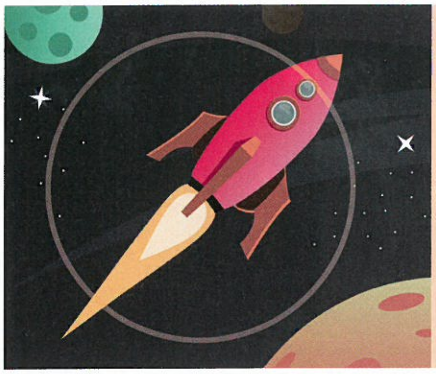
Jo Anne Vasquez

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).



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*

BEATRIZ GASCON J/SHUTTERSTOCK

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).

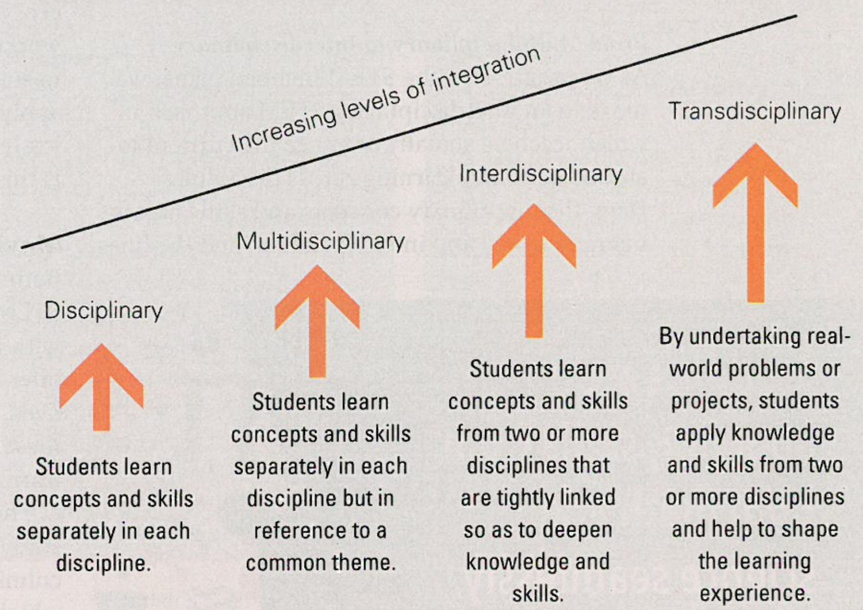
Then the class compiles all the data into one graph that represents the data from all the groups. To do so, they have to debate and decide issues related to the science and math concepts they are learning. For instance, the students see that one group's set of data differs greatly from the others, and 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



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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.

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*.

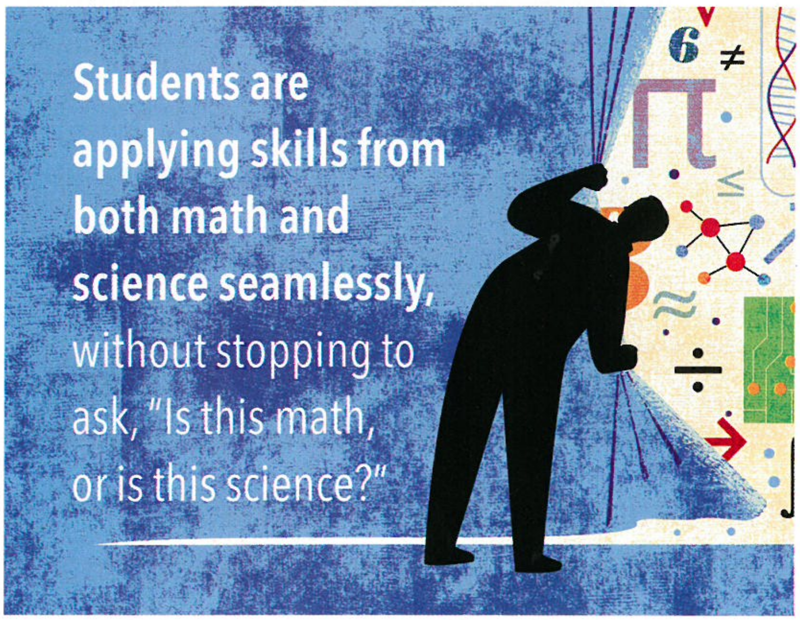
When students ask, "Why do I have to learn this?" a **STEM experience provides** them with **an answer.**

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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