DESIGNING MEANINGFUL STEM LESSONS

Milton Huling and
Jackie Speake Dwyer

NSTA press
National Science Teachers Association

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Arlington, Virginia

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FOREWORD

STEM—it seems to be in the air. It is featured in newspaper articles. Anchorpeople work the acronym into stories used to describe school programs. Policy makers take every opportunity to feature it when discussing schools. Meanwhile, scientists, engineers, mathematicians, and computer scientists are left scratching their collective heads when the acronym appears, as the notion seems to have emerged overnight, like a ring of mushrooms.

What is STEM, and what should it mean for education? Although the notion seems to be almost everywhere in the early part of the 21st century, there are very few serious treatments about what this notion is and what it may bring to the world of K–12 education. Indeed, it seems that anytime a discipline of science, mathematics, engineering, or technology is featured in a lesson, it is called STEM. So, what does this construct bring to education? Is it a passing political fad, an idea constructed as a rhetorical tool to draw attention to a project or lesson? Or is there something more to the construct?

Authors Milt Huling and Jackie Speake Dwyer weigh into this discussion, suggesting that STEM instruction must involve something more than simply including one or more STEM disciplines. In *Designing Meaningful STEM Lessons*, the authors approach STEM instruction from a science educator's point of view, arguing that in a STEM lesson, the "integration of math, technology and engineering should be used to support the learning of a science concept." To allow for this emphasis, Huling and Dwyer propose StEMT—an instructional model that begins with the well-known and well-established learning cycle and embeds an engineering challenge into the "elaborate" phase. This introduction is accompanied by a number of examples of "StEMTified" lessons to highlight the potential of this instructional model.

Designing Meaningful STEM Lessons brings clarity to the sometimes murky STEM conversations in ways that will be helpful to teachers and administrators alike. Informed by research findings and the practicalities of the work in schools and situated in national conversations around the *Next Generation Science Standards,* the StEMT instructional model and the activities Huling and Dwyer offer will be useful to a wide swath of K–12 science teachers.

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Editor, *Science Education*
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PREFACE

As educators who are deeply involved in science instruction, we (the authors) understand the value of STEM as a focus in curriculum. As central office administrators, we work with and support STEM academies and STEM classes. Our district has embraced STEM just like every other school district in the nation. STEM curriculum as a core concept is extremely attractive—it embraces all of the curricula that will help our students succeed in life. School administrators and school boards easily understand that STEM is a means to engage and attract the best and brightest students. We have a good understanding of what goes into STEM and the things that you need for it, but the process of implementing STEM curriculum within the classroom is quite nebulous on the best of days. There is a dilemma for all educators and learners when crafting a response to the question, "What does STEM look like in the classroom?" The easy, truthful (and educationally unhelpful) response is that STEM is simply any configuration of the disciplines with little regard for the outcome of the lesson. In other words, anything can be called STEM as long as it incorporates one, some, or all of the four disciplines commonly associated with STEM.

Although the concept of STEM being whatever you need it to be sounds wonderful at a philosophical level, application of such a vague notion quickly becomes problematic when paired with the expectations of targeted and rigorous quality instructions. Building a race car is a great way for students to learn problem-solving skills, but in the absence of a framework for science education, it is just a cool project.

States have tried to address this gap by designing and adopting their own individual state standards for science, and the development of *A Framework for K–12 Science Education* (*Framework*; NRC 2012) has recently led to the integration of engineering practices as a way to enhance science instruction and to integrate the components of STEM, specifically the engineering component. The great thing about science standards in all states is that the big ideas are mostly consistent. It is how we teach and frame the content that makes a significant difference in student learning and retention of important science concepts. Standards are the framework, pedagogy is the method of delivering the content to students, and STEM provides the integral component of real-world application for learning. Many articles have been written describing STEM as a solution to problem solving or a way to help students become better problem solvers. For example, many references have been made to problem-based learning or project-based learning (PBL). Although these types of instructional methods are often mentioned, most articles focus on the integration of the components of STEM with little regard for how the instruction must occur.

It is here that our work begins with re-envisioning STEM. Within our method, research-based instructional methodologies are not abandoned; rather, they are embraced within the STEM framework that includes the relevance from the engineering component. In fact, our method infuses everything the science education community has learned through decades

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of researching how children learn (e.g., Carey 1991, 1999; Chinn and Brewer 1993; Driver 1989; Driver et al. 1996; Posner et al. 198; Sinatra and Chinn 2011). Our goal was to design a simple, practical process for implementing meaningful STEM activities in the classroom. Our methodological process for doing STEM mirrors all we know about how students learn: It includes a problem for which the lesson is built, and it incorporates engineering practices and design processes into the sciences to enhance their relevance. We now have an intuitive foundation on which to build authentic intermediate elementary and middle school STEM lessons through the process of STEM that is not labor intensive and can be used with existing science lessons.

We have shared our vision at many trainings within our district as well as with the Florida Association of Science Supervisors. Just as in our first training, the participants were shocked at the simplicity of our concept, as it gave meaning to an otherwise nebulous concept. More recently, we were having a conversation with a colleague and the topic of STEM came up. We provided the Cliff Notes version on how STEM was a "process and not a thing" to better illustrate the connections of the disciplines and the flow of the process. The response: "That is the best explanation of how STEM should be taught that I have ever heard. You need to write a book for teachers." And so *Designing Meaningful STEM Lessons* was written. We hope elementary and middle school teachers enjoy the book and that it helps to bring STEM learning to life in their classrooms, easily and effectively.

Special Attributes of the Book

- Ready-to-use lessons targeting students in grades 4–8 are correlated to the *Framework* disciplinary core ideas (NRC 2012). According to the *Framework*, disciplinary core ideas should have **broad importance** across multiple sciences or engineering disciplines or be a **key organizing concept** of a single discipline; provide a **key tool** for understanding or investigating more complex ideas and solving problems; relate to the **interests and life experiences of students** or be connected to **societal or personal concerns** that require scientific or technological knowledge; and be **teachable** and **learnable** over multiple grades at increasing levels of depth and sophistication. In this book, disciplinary core ideas are grouped into three domains: the physical sciences; the life sciences; and Earth and space science. The fourth domain—engineering, technology, and applications of science—is embedded into the lessons and is not a separate domain.
- Standards-based instruction: Because science content is fairly consistent from state to state, this book will focus on the disciplinary core ideas as identified in the *Framework* (NRC 2012). The big ideas of science are consistent—it is how we teach this content that makes a significant difference in student learning and retention of important science concepts.

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- Constructivism is a philosophy about learning that suggests that learners need to build their own understanding of new ideas. Two of the most prominent constructivist researchers are **Jean Piaget** (stages of cognitive development) and **Howard Gardner** (multiple intelligences).
- Inquiry: The National Science Education Standards (NRC 1996) define inquiry as

A set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a rich understanding of concepts, principles, models, and theories. Inquiry is a critical component of a science program at all grade levels and in every domain of science, and designers of curricula and programs must be sure that the approach to content, as well as the teaching and assessment strategies, reflect the acquisition of scientific understanding through inquiry. Students then will learn science in a way that reflects how science actually works. (p. 214)

- *5E Instructional Model:* The Biological Sciences Curriculum Study (BSCS), a team led by Principal Investigator Roger Bybee, developed an instructional model for constructivism called the "Five Es." Although the BSCS 5Es and inquiry are not synonymous, the 5E Instructional Model is based on constructivist theories and enhances student inquiry through a series of planning strategies. It works well with StEMT lesson design, but is not the only model that works, because constructivism through any model is synonymous with good teaching.
- *Claims, Evidence, Reasoning (CER):* There is a plethora of research to support that learning content through processes are important in science, and when students construct scientific explanations, through discourse or writing, they learn important concepts (Krajcik and Sutherland 2009, 2010; McNeill and Krajcik 2009, 2012; NRC 1996, 2000, 2012). When writing scientific explanations, students apply scientific ideas to answer a question or solve a problem using evidence. Students construct scientific explanations that result in demonstrating mastery of a specific learning goal and ultimately, in life and the real world, must use evidence to communicate their ideas to other people. Engaging in scientific explanations improves students' ability to reason and become more adept at critical and analytical thinking (McNeill and Krajcik 2009, 2012). When students justify their claims with evidence and reasoning, teachers gain insight into students' thinking and understanding. By integrating the disciplinary core idea with the targeted engineering practice, a learning goal can be designed and formed into a guiding question that students can answer through discussion or by using claims, evidence, and reasoning. See Appendix A (p. 189) for a sample CER rubric.

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ABOUT THE AUTHORS

Dr. Milton Huling is a nerd … and proud of it. Milt loves modeling instruction in classrooms and making science come to life for students. Milt received a Bachelor of Science degree from Southern Illinois, Edwardsville, in Earth space/geology. He received a master's degree in science education from Florida State University along with the additional course work to become a certified teacher. Milt received a Ph.D. from the University of South Florida in curriculum and instruction with an emphasis in science education.

Milt's teaching career spans 14 years, starting in Illinois and continuing in Florida. He has been with the same Florida school district for 10 years. He has spent six of these years teaching physics and Earth science at the high school level. For the past four years, Milt has served as the District Secondary Science Coordinator and more recently as the District Elementary Curriculum Specialist.

On a daily basis, Milt designs curriculum and liaisons with the district's technology departments to deliver resources to both teachers and students. Milt also serves the school administration and teachers by developing and facilitating professional development opportunities.

Dr. Jackie Speake is a science geek … and proud of it. Jackie loves science and believes that everyone can learn through science exploration, even if they aren't a geek or a nerd. Science is for ALL! Jackie received her Bachelor of Science degree from the University of Maryland, College Park (go Terrapins!), in marine biology. After three years as a field biologist for the Maryland Department of Natural Resources, two years as a water chemistry lab technician at the National Aquarium in Baltimore, and three years as a field biologist with the Florida Department of Environmental Protection, Jackie decided to go back to school in 1997 to get her Master of Education degree in secondary science curriculum from the University of South Florida (USF) and became a certified high school biology teacher. As a lifelong learner who really enjoys collaborating and learning with colleagues, Jackie returned to USF to study education policy and leadership and received her doctorate in 2011.

Jackie's 20-year education career ranges from high school teacher; district curriculum specialist in a Florida district with 18,000 students; state of Florida Department of Education science program coordinator; and senior director for science in a large Florida school district with more than 100,000 students. She now works with a district science team to facilitate the development and implementation of curriculum, assessments, inquiry lessons, professional development, and community partnerships.

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ABOUT OUR APPROACH

You might pick up this book because you are on the continuing search for ways to teach STEM, as we (the authors) have been on for many years. If you are looking for an effective way to teach STEM, you may be thinking, "I know what STEM is, so what is different about this approach?" In the following pages, we will answer those two important questions and give you step-by-step directions on how to use our approach to integrate STEM using our approach into your classroom instruction. You will also see the term "StEMT" pop up within various conversations within the book. You may wonder, What is StEMT? StEMT is our way of making sense of STEM as a process, which is really at the heart of our vision. We are definitely not out to challenge the acronym that has become so much a part of the educational vernacular. When you see this term within the book, it is to purposefully guide you to a new way of thinking about STEM as an instructional approach.

This is not a book that replaces integration or is juxtaposed to STEM. We are huge proponents of STEM education, and we believe in integration, but only if it is done in a meaningful way. We also believe that STEM is students learning the skills and mindset necessary to become the next generation of engineers, scientists, and mathematicians. Although STEM as a concept has become mantra-like within the educational landscape, teachers have nothing to guide them in gaining an understanding of what it looks like to be included in their classrooms on a daily basis. It is this problem for which we have a solution. That solution is StEMT. Again, please do not run out and change your school signage or even your stationery. StEMT is a way that helped us think about the process of a STEM lesson. StEMT as a process offers clarity on how to build the lens for teachers and students to use when approaching problems in a way that applies the skills and tools of STEM. StEMT offers a structured approach that provides a clear process for designing effective, meaningful STEM lessons. The seemingly simple reframing of how we think about STEM provides us with the tools to take the nebulous concept of STEM and transform it into a conceptual framework.

StEMT (or STEM if you still prefer) is about effective, relevant science instruction that provides real-world experiences for every child. Experiences with STEM must be available to all students. StEMT is *not* an instructional model; it is a conceptual framework, and its purpose is to help teachers effectively teach STEM concepts by providing a mechanism to link science and mathematics to activities that promote constructivist learning to allow students to be cognitively challenged through questioning and problem-solving opportunities. StEMT fits into research-based instructional models that already exist and is an integral part of good instruction. In fact, by StEMT*ifying* your lessons, you make the lesson both relevant and exciting for students. Our goal is to help teachers increase the efficacy of their current science lessons by substituting StEMT into a portion of their existing lessons. Before we get to lesson development, it is important to understand the creation of the StEMT conceptual framework and to do that, you must understand its origins.

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The StEMT Idea

Almost every educator can describe a nightmare scenario in which he or she is providing professional training to peers and has inadvertently misspelled something in the presentation. Most people feel discomfort when someone we work with presents something that is misspelled in their work. With that as a frame, the first discussion of StEMT as an approach occurred during a professional development presentation given by Dr. Milton Huling. Picture a large die being extracted from the back of Milt's SUV. Its size was carefully matched to the cargo area of the vehicle. In fact, to ensure a perfect fit, it was constructed in the parking lot of a local Lowe's. Made of PVC pipe and wrapped with red-and-white plastic tablecloths, the sides were adorned with numbers. The cube was carried into the school and placed on the front table in the school's teacher training room. As Milt carried the large colorful die into the school, it drew everyone's attention, including that of his colleague, Dr. Jackie Speake.

The presentation began with the usual welcomes and introductions. Jackie looked up at the first slide in bewilderment. "Why does the first slide say, 'StEMT?' " she asked. Milt's explanation detailed that his recent readings had led him to recognize that to truly incorporate STEM into a typical science classroom, the whole concept needed to be re-envisioned. The only way to get this across to teachers in a professional development setting was to make it dynamic. If technology is the solution to a human problem and most papers about STEM mention problem solving as a component, it only makes sense that the solution to the problem must be the technology that is produced. *This is in conflict with the view that the "*T*" in STEM is all about integration of technology and not a solution to a problem.*

Dr. Huling's presentation itself included activities designed to parse out the difference between a scientific question and a question about the development of technology. The activity was drawn and modified from a Nature of Science activity called *The Cube* (Lederman and Abd-El-Khalik 2002) and the *Three Cube Method* (Lederman, n. d.). Once teachers have a conceptual understanding of the difference between science and technology, it is much easier to understand how math and engineering (the tools) are used to bridge the divide. Science provides the basic knowledge through inquiry. With understanding of scientific principles in hand, only then can we use, or apply, this knowledge toward the development of a technology (i.e., a solution to a problem). The mathematics and engineering are the means of getting from science understandings to technology.

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S^T Science infusing (raised through the power of) Technology (a.k.a. *Good Science*)

E Engineering design process

M Mathematical practices and habits of mind

T Technology as a product or solution to a problem

This migration from principle to application, we feel, is critical to provide the relevance to the learning of science that is often lacking within many science classrooms. StEMT as a process, as opposed to STEM as a thing, also has the potential to enrich the science knowledge of students. In this way, StEMT/STEM does not broaden the curriculum. Instead, it acts as a focus.

It was the initial reception by educators of the StEMT training at one elementary school that set the stage for an expansion of STEM trainings on the StEMT process. These trainings occurred at multiple levels: district trainings, state conferences, and mathematics and science partnership activities. Within our district, we use StEMT as the approach to teach STEM, which is logical, especially if we think in terms of problem-based learning.

The reframing of the approach and the technology for teachers has accentuated that the importance of technology is not how it is used within the lesson—it is more so that technology (or the solution to the problem) is the outcome of instruction. It is not to say that integrating technology is not critical because it is essential for students to be exposed to the use of technology. More important, however, is what question is answered as part of the StEMT lesson, and the designing of StEMT questions is critical to helping teachers implement STEM in their own classrooms.

All lessons have been adapted from multiple open education resource sites, and most of the base activities are those you will recognize that have been circulating for years and have been effective for many educators across the nation. More often than not, we adapted the StEMT activities from the lessons we design for Polk County public schools.

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CONNECTIONS TO STANDARDS

Lessons by Disciplinary Core Idea (DCI) From *A Framework for K–12 Science Education* (NRC 2012)

Chapter	Lesson Title	Grade	Disciplinary Core Idea and Component
7	To Infinity and Beyond	3–6	Earth and Space Sciences: Earth and the Solar System (ESS1.B)
	Oh, How the Garden Grows	3–6	Earth and Space Sciences: Earth Materials and Systems (ESS2.A)
	Separation Anxiety	3–6	Earth and Space Sciences: Natural Hazards (ESS3.B)
	The Human Factor	3–6	Earth and Space Sciences: Human Impacts on Earth Systems (ESS3.C)
8	Cell-fie	5–8	Life Sciences: Structure and Function (LS1.A)
	Itsy, Bitsy Spiders	5–8	Life Sciences: Interdependent Relationships in Ecosystems (LS2.A)
	Gobble, Gobble, Toil and Trouble	5–8	Life Sciences: Ecosystem Dynamics, Functioning, and Resilience (LS2.C)
	Designing the Super Explore	5–8	Life Sciences: Inheritance and Variation of Traits (LS3.A and LS3.B)
	It's a What?	5–8	Life Sciences: Natural Selection (LS4.B)
9	Is It Air or Wind?	3–6	Physical Sciences: Structure and Properties of Matter (PS1.A)
	Aircraft Catapult	3–6	Physical Sciences: Forces and Motion (PS2.A)
	Keepin' It Cool!	3–6	Physical Sciences: Conservation of Energy and Energy Transfer (PS3.B)
	The Pitch in the Wave	3–6	Physical Sciences: Wave Properties (PS4.A)
	Mirror, Mirror, on the Wall	3–6	Physical Sciences: Electromagnetic Radiation (PS4.B)
Integrated Into Lessons			Engineering design (ETS1) and links among engineering, technology, science, and society (ETS2)

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CONNECTIONS TO STANDARDS

Standards for Mathematical Practice

The eight standards for mathematical practice as identified by the *Common Core State Standards for Mathematics* (NGAC and CCSSO 2010) are as follows:

1. Make sense of problems and persevere in solving them
2. Reason abstractly and quantitatively
3. Construct viable arguments and critique the reasoning of others
4. Model with mathematics
5. Use appropriate tools strategically
6. Attend to precision
7. Look for and make use of structure
8. Look for and express regularity in repeated reasoning

Science and Engineering Practices

The eight practices of science and engineering that *A Framework for K–12 Science Education* (NRC 2012) identifies as essential for all students to learn are as follows:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

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National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010. *Common Core State Standards.* Washington, DC: NGAC and CCSSO.

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CHAPTER 6 Correlation to *A Framework for K–12 Science Education*

The 2012 publication *A Framework for K–12 Science Education* (*Framework;* NRC 2012) outlines the three dimensions that provide students with a context for the content of science, demonstrate how science knowledge is acquired and understood, and show how the sciences are connected through concepts that have universal meaning across the disciplines:

- Scientific and engineering practices;
- Crosscutting concepts that unify the study of science and engineering through their common application across fields; and
- Core ideas in four disciplinary areas: physical sciences; life sciences; Earth and space sciences; and engineering, technology, and the applications of science.

To support students' meaningful learning in science and engineering, all three dimensions need to be integrated into standards, curriculum, instruction, and assessment. Engineering and technology are featured alongside the natural sciences (physical sciences, life sciences, and earth and space sciences) for two critical reasons: to reflect the importance of understanding the human-built world and to recognize the value of better integrating the teaching and learning of science, engineering, and technology (*Framework;* NRC 2012).

The scientific and engineering practices identified in the *Framework* are the major practices that scientists employ as they investigate and build models and theories about the world and a key set of engineering practices that engineers use as they design and build systems. The practices specify what is meant by inquiry in science and the range of cognitive, social, and physical

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practices that it requires (NRC 2012). As in all inquiry-based approaches to science teaching, the expectation is that students will engage in the practices. Students cannot comprehend scientific practices without directly experiencing those practices.

Science and Engineering Practices (Framework, Dimension 1)

1. Asking questions (science) and defining problems (engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, information and computer technology, and computational thinking
6. Constructing explanations (science) and designing solutions (engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Mathematical Practice (Common Core State Standards)

1. Make sense of problems and persevere in solving them
2. Reason abstractly and quantitatively
3. Construct viable arguments and critique the reasoning of others
4. Model using mathematics
5. Use appropriate tools strategically
6. Attend to precision
7. Look for and make sense of structure
8. Look for and express regularity in repeated reasoning

The practices, whether engineering, science, or mathematics, are the process standards of problem solving, reasoning and evidence, communication, modeling, and applications.

Evaluating the Fidelity of 5E Inquiry and StEMT

The *Common Core State Standards for Mathematics* (*CCSS Mathematics*; NGAC and CCSSO 2010) are an integral part of learning and doing mathematics and need to be taught with the

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same intention and attention as mathematical content. The science and engineering practices (Dimension 1: Practices) identified in the *Framework* (NRC 2012) are derived from those that scientists and engineers actually engage in as part of their work. The mathematics, science, and engineering practices are not intended to be taught as stand-alone lessons. The practices are an integral part of learning and doing in all content areas and need to be taught with the same intention and attention as the content standards. Opportunities for students to immerse themselves in these practices and to explore why they are central to mathematics, science, and engineering are critical to appreciating the skill of the expert and the nature of his or her enterprise. Mayes and Koballa (2012) illustrated one way the practices can be aligned (see Table 6.1, p. 30).

School districts across the nation use evaluation systems for instructional personnel that focus on specific domains of teacher and student behaviors. For the purposes of this discussion, the *Teacher Evaluation Model* (Marzano 2007) and *The Framework for Teaching* (Danielson, 2013) will be referenced in the teacher behaviors for effective instructional delivery and facilitation, specifically *Domain 1: Classroom Strategies and Behaviors* (Marzano) and *Domain 3: Engaging Students in Learning* **(**Danielson). However**,** the process of administrator classroom walkthroughs and what they should "look for" in a 5E instructional delivery model that integrates the StEMT process are applicable to any evaluation model. The *Look Fors* for student behaviors (Table 6.2, p. 31) and teacher behaviors (Table 6.3, p. 31) that reflect sound habits of mind and support the implementation of the 5E instructional model and StEMT process are adapted from the *Framework* Science and Engineering Practices (SEP) and *Common Core State Standards for Mathematics* (MP).

The graphic in Figure 6.1 (p. 32) shows the relationships and convergences (commonalities) found in the *CCSS Mathematics* (designated as MP), the English Language Arts Proficiency Development Framework (ELA practices designated as EP), and the science and engineering practices identified in the *Framework* (designated as SEP).

Notice that the center where the three converge require the use of evidence to assert a claim through reasoning:

- EP 1: Demonstrate independence.
- MP 3: Construct viable arguments and critique reasoning of others.
- EP 3: Respond to the varying demands of audience, task, purpose, and discipline.
- SEP 7: Engage in argument from evidence.

The practices, crosscutting concepts, and disciplinary core ideas (NRC, 2012) have application across all domains of science and mathematics:

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Table 6.1. Alignment of science, engineering, and mathematical practices

Science and Engineering Practices (*Framework, Dimension 1*)	**Mathematical Practices** (*CCSS*)
1. Asking questions and defining problems 3. Planning and carrying out investigations	Make sense of problems and persevere in solving them.
2. Developing and using models 3. Planning and carrying out investigations 5. Using mathematics and computational thinking	Reason abstractly and quantitatively.
5. Using mathematics and computational thinking 6. Constructing explanations and designing solutions 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information	Construct viable arguments and critique the reasoning of others.
2. Developing and using models 3. Planning and carrying out investigations	Model with mathematics.
2. Developing and using models 3. Planning and carrying out investigations 4. Analyzing and interpreting data	Use appropriate tools strategically.
3. Planning and carrying out investigations 8. Obtaining, evaluating, and communicating information	Attend to precision.
4. Analyzing and interpreting data 6. Constructing explanations and designing solutions 7. Engaging in argument from evidence	Look for and make sense of structure.
5. Using mathematics and computational thinking 6. Constructing explanations and designing solutions	Look for and express regularity in repeated reasoning.

Source: Adapted from Mayes and Koballa (2012).

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Table 6.2. Student behaviors incorporating science, engineering, and mathematics

Students should
• Ask questions, define problems, and predict solutions/results (SEP.1/MP.1). • Design, plan and carry out investigations to collect and organize data (e.g. science notebook/journal) (SEP 3/MP 1). • Develop and use models (SEP 2/MP 4). • Obtain, evaluate, and communicate information by constructing explanations and designing solutions (SEP 8/MP 3). • Be actively engaged and work cooperatively in small groups to complete investigations, test solutions to problems, and draw conclusions. Use rational and logical thought processes, and effective communication skills (writing, speaking and listening) (SEP 7, SEP 8/MP 3). • Analyze and interpret data to draw conclusions and apply understandings to new situations (SEP 4/MP 5). • Use mathematics, information technology, computer technology, and computational thinking in a creative and logical manner (SEP 5/MP 2). • Acquire and apply scientific vocabulary *after* exploring a scientific concept (SEP 6/MP 7).

Table 6.3. Teacher behaviors correlated to Marzano (2007) and Danielson (2013) evaluation models

Teachers should
• Integrate real-life applications and subject matter to exemplify how the disciplines co-exist in actual practice (*relate and integrate the subject matter with other disciplines and life experiences*). • Incorporate experimental design and engineering design processes for all students (*engaging students in learning*). • Deliver standards-based curriculum using appropriate pedagogy/instructional materials. • Introduce scientific vocabulary ***after*** students have had the opportunity to explore a scientific concept (*integrating content area literacy strategies and application of the subject matter*). • Ask guiding questions to facilitate discussion and active engagement in inquiry, scientific process, and problem solving (*using questioning and discussion techniques*). • Facilitate questioning and testing solutions to problems. Encourage collaboration so all group members are actively engaged (*communicating with students* and *employ higher-order questioning techniques*). • Move around the room, guiding cooperative learning groups in formulating solutions and using manipulatives/technology (*establishing a culture for learning, respect, and rapport*). • Use formative and summative assessments that focus on problem solving and deep understanding rather than memorizing facts.

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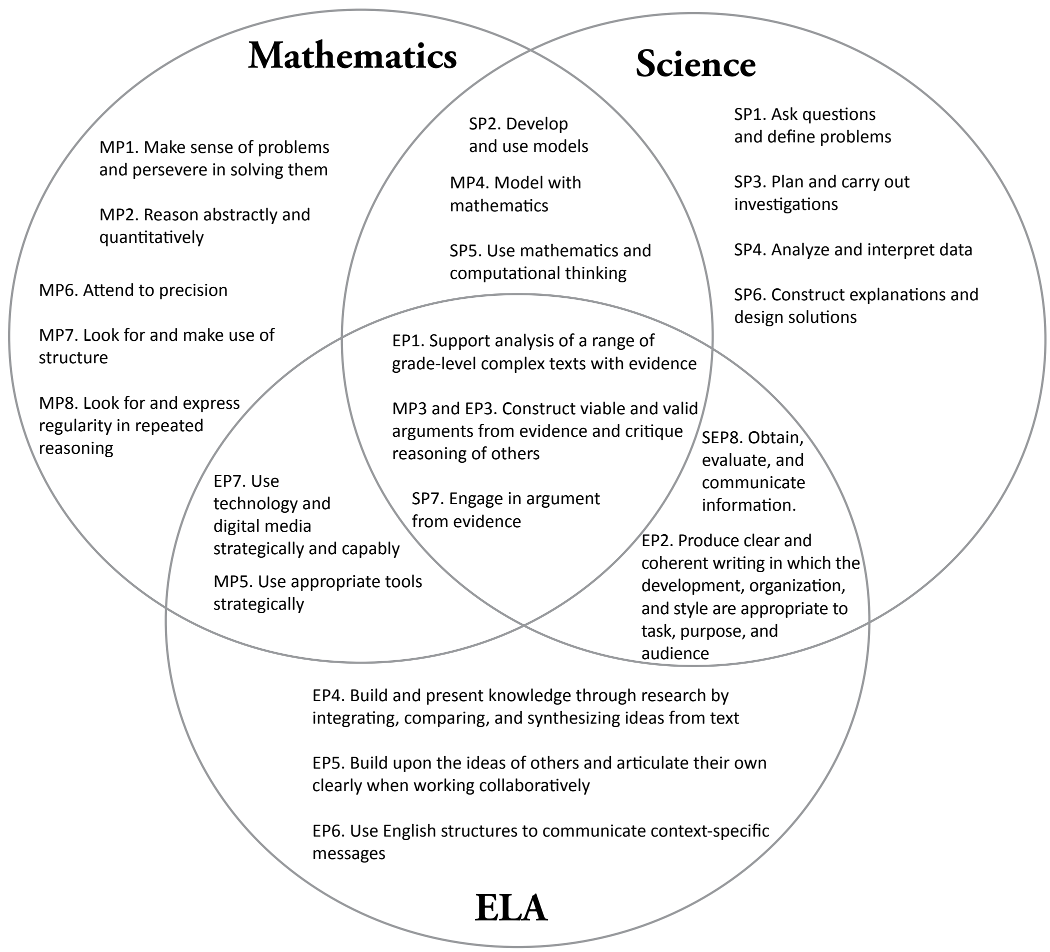
Figure 6.1. Commonalities among the science, mathematics, and English language arts (ELA) practices



Source: Adapted with permission from Cheuk (2013).

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Dimension 1: Science and Engineering Practices (identified in Table 6.1 on p. 30 and Figure 6.1 on p. 32)

Dimension 2: Crosscutting Concepts

- *Patterns*
- *Cause and effect: Mechanism and explanation*
- *Scale, proportion, and quantity*
- *Systems and system models*
- *Energy and matter: Flows, cycles, and conservation*
- *Structure and function*
- *Stability and change*

Dimension 3: Disciplinary Core Ideas (organization of StEMT lessons in the next three chapters)

STEM education should focus on a limited number of disciplinary core ideas and crosscutting concepts, be designed so that students continually build on and revise their knowledge and abilities over multiple years, and support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design (NRC 2012). The *Framework* defines a core idea for K–12 science instruction:

- Have broad importance across multiple sciences or engineering disciplines or be a key organizing principle of a single discipline.
- Provide a key tool for understanding or investigating more complex ideas and solving problems.
- Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge.
- Be teachable and learnable over multiple grades at increasing levels of depth and sophistication—that is, the idea can be made accessible to younger students but is broad enough to sustain continued investigation over the years.

Integration should be intentional and seamless across representations and materials. These multi-day units must also provide explicit support for students as they build knowledge and skill within and across disciplines. All StEMT lessons are correlated to the practices, disciplinary core ideas, and crosscutting concepts in the *Framework*.

Connecting ideas across disciplines is challenging when students have little or no understanding of the relevant ideas in specific disciplines and do not use their disciplinary knowledge in integrated contexts. Students need support to elicit the relevant scientific or mathematical

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ideas in an engineering or technological design context, to connect those ideas productively, and to reorganize their own ideas in ways that come to reflect normative scientific ideas and practices (NRC 2012).

The next three chapters contain sample lessons that have gone through the process of being StEMT*ified*. The basic premise or activity in the lessons are not unique—many of these lessons have been used by teachers across the nation for many years, in some form or another. Where appropriate, free open educational resources (OERs) are referenced. The important piece on which to focus is the process of embedding the engineering component into more traditional lessons. By some definitions of STEM, the lessons we have started with could be thought of as STEM lessons, but without the engineering component they may lack a way to elicit the real-world discussion and relevance of engineering design for student learning. It is this facet of student understanding that is critical to long-term retention of important concepts.

A quick word of caution before you begin using the following lessons, which come from our own experiences in the classroom. You will need to answer for yourself this question: *Do your students really understand the engineering design process?* If the answer to this question is *no* or even *maybe*, we would urge you to review the process with your students before you embark on these lessons. The good news is that students will come to an understanding quickly.

The StEMT*ified* sections of each lesson the adhere to the following format from TeachEngineering.org:

- *Step 1: Ask—Practice of asking questions (science) and defining problems (engineering)*

Students will ask questions, define problems, and predict solutions/results (SEP 1; MP 1). What is the problem to solve? What needs to be designed and who is it for? What are the project requirements and limitations? What is the goal?

- *Step 2: Research and Design—Practice of planning and carrying out investigations*

Students will be actively engaged and work cooperatively in small groups to complete investigations, test solutions to problems, and draw conclusions. Use rational and logical thought processes, and effective communication skills (writing, speaking and listening) (SEP 7, SEP 8; MP 3). Students collaborate to brainstorm ideas and develop as many solutions as possible.

- *Step 3: Plan—Practice of constructing explanations and designing solutions*

Students will design, plan, and carry out investigations to collect and organize data (SEP 3; MP 1). Students will compare the best ideas and then select one solution and make a plan to investigate it.

- *Step 4: Create—Practice of developing and using models*

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Students will obtain, evaluate, and communicate information by constructing explanations and designing solutions (SEP 8; MP 3). Students will develop and use models (SEP 2; MP 4). Students will build a prototype.

- *Step 5: Test and improve—Practice of obtaining, evaluating, and communicating information*

Students will analyze and interpret data to draw conclusions and apply understandings to new situations (SEP 4; MP 5). Does the prototype work, and does it solve the need? Students communicate the results and get feedback and analyze and talk about what works, what does not work, and what could be improved.

One of the easiest ways we have found to demonstrate the engineering process is merely by putting a twist on the common paper airplane challenge that most of us are familiar with. We start off by helping students make a paper airplane. In a predetermined test area within the classroom, students verify that their planes can fly. Now is when you provide the challenge. Students are given a starting point to launch their airplanes. They are also given a landing zone. Next they are given the path the plane must take before it can land in the predetermined area. Most of the time, we keep this simple and have the students modify their plane so it can make a gentle curve. Students will quickly see that their first attempts did not work. Using what they learned, they will now make modifications to their original design in order to get the appropriate outcome. Although this task may seem simple, it does provide the students the understanding about engineering design they need in order to be successful on these next lessons. Again, we have learned the hard way not make assumptions about what students know.

Teacher briefs precede each lesson to explain our vision for each lesson with regard to its instructional target and also to provide some helpful tips to be successful with the lesson. In general, our lessons are provided as examples of how to take your existing lessons and turn them into STEM lessons by inserting an engineering design challenge. Our lessons are aligned to the *Framework* (NRC 2012), but this method would work with any set of standards. Individual lessons typically only target a portion of a larger concept. Those specific targets will be described within the teacher briefs. We have included a direct URL link to aligned CK-12 FlexBooks if additional background knowledge about a specific topic for students (and teachers) is needed.

All of the lessons have been tested by classroom teachers or instructional coaches. Feedback has been very positive regarding student learning and especially participation, which is music to our ears. In most cases, these lessons were tested in our district's most challenging schools (those with more than 70% of students receiving free and reduced-price lunch). As expressed previously, we are believers that ALL students must experience STEM, and perhaps the most deserving of highly engaging science lessons are these students living in high-poverty areas.

We hope you have as much fun implementing the lessons as we had designing them.

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DESIGNING MEANINGFUL **STEM** LESSONS

"Building a race car is a great way for students to learn problem-solving skills, but in the absence of a framework for science education, it is just a cool project."
—Authors of *Designing Meaningful STEM Lessons*

Here's the help you need to ensure that your STEM-related lessons are much more than just cool projects. As the title says, this book shows you how to make STEM meaningful for teaching and learning science. Best of all for busy teachers, it provides examples that are easy to follow, can be used with existing science lessons, and can help your students gain content knowledge.

The book introduces a conceptual framework that keeps science front and center as you embed engineering, technology, and science applications in your lessons—similar to how you would embed literacy skills. *Designing Meaningful STEM Lessons* does the following:

- Provides 13 ready-to-use lessons in physical science, life science, and Earth and space science.
- Retains the cool factor through lessons with titles such as "Cell-fie" and "Aircraft Catapult."
- Correlates with *A Framework for K–12 Science Education,* takes a constructivist approach, and operates within the 5E instructional model.

The authors are veteran science educators who have honed their framework through extensive state and district training sessions. They know that for teachers who want to deliver rigorous, high-quality instruction, "the process of implementing STEM curriculum within the classroom is quite nebulous on the best of days." By helping you think about STEM as a "process and not a thing," *Designing Meaningful STEM Lessons* offers clear-cut ways to bring STEM learning to life in your classroom, easily and effectively.

Grades 3–8

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