Chapter 5: What are the STEM Practices?

> "Today, it is widely accepted that "STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world, relevant lessons. Students can apply science, technology, engineering, and mathematics in contexts that help them make connections between school, community, work, and the global enterprise. This enables the development of STEM literacy and with it the ability to compete in the new economy." —Tsupros, Kohler, and Hallinen, 2009. *STEM education: A project to identify the missing components*

Before reading this chapter take a moment to reflect on the four disciplines found in STEM and then jot down what you think they might all have in common. For example, do they all promote questioning and problem solving?

From Process to Practice

A new vision is emerging about the nature of science as it should be practiced in the classroom. Most teachers are aware that science is more than a body of facts; and for at least the last fifteen years, since publication of *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996), emphasis has been on the processes of scientific inquiry, such as observing, investigating, collecting data, and drawing conclusions.

In an effort to revise the earlier standards and provide a blueprint for states to collaborate and adopt common standards in science, in 2012 the National Research Council published a new guide to what all students should know and be able to do. Entitled *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012), the new Framework takes the position that inquiry processes are not sufficient. Students should also know how to apply what they learn in practical situations that they might encounter in everyday life. In order to emphasize the practical nature of these capabilities the Framework uses the term "science and engineering practices" rather than "processes." And since the practices of science and engineering are similar but not the same the *Framework* presents them side-by side. (The following statements are drawn from NRC 2012, Box 3-2, pp. 50-55. The full text is available at http://www.nap.edu/catalog.php?record_id=13165.)

Science and Engineering Practices

Practice 1: Ask questions and define problems. *Science* begins with a question about a natural phenomenon and seeks to develop testable answers to such questions. *Engineering* begins with a problem, need or desire and creates questions to better define the problem, determine criteria for a successful solution, and identify any constraints, parameters or limitations that need to be considered.

Practice 2: Develop and use models. *Science* often involves the construction and use of models and simulations to help make predictions that can be tested and to develop explanations about natural phenomena. *Engineering* makes use of models and simulations to analyze existing systems, explore modifications and test proposed solutions.

Practice 3: Plan and carry out investigations. In science, investigations are planned to answer the testable question, determine the procedures, identify the variables, define the conditions to be examined, and determine how the results will be recorded. Engineers plan investigations to learn more about the problem to be solved, identify factors that can impact results and to test possible solutions. They consider altering conditions to maximize improvements to meet the criteria and constraints within the scope of the defined problem.

Practice 4: Analyze and interpret data. Both scientists and engineers use a range of tools—including tables, graphs, diagrams, and statistical analyses to identify the significant features and patterns in the data gathered from their investigations.

Practice 5: Use mathematics and computational thinking. Both scientists and engineers use mathematics and computation as fundamental tools for representing physical variables and their relationships, and for a range of tasks, such as constructing simulations and recording and analyzing data.

Practice 6: Construct explanations and design solutions. In *science,* the goal is to construct explanations that reflect the findings of the investigation. In *engineering* the goal is to propose solutions (sometimes multiple solution scenarios) to the identified problem, satisfying different constraints or criteria.

Practice 7: Engage in argument from evidence. In *science*, reasoning and argument are essential for finding the best explanation for a natural phenomenon. In *engineering***,** reasoning and argument are used to defend the best possible solution to a problem. Engineers use systematic methods to compare alternative solutions, trading off one feature for another to optimize solutions.

Practice 8: Obtain, evaluate and communicate information. Both scientists and engineers must be able to communicate their findings clearly and persuasively, either orally or in writing, with the use of tables, diagrams, graphs, and equations. Both require the ability to derive meaning from scientific texts (such as papers, the Internet, symposia, and lectures), to evaluate the validity of the information from these sources, and to integrate that information into their findings.

Technology Practices

As explained in Chapter 1, technology in a broad sense is defined as any modification of the natural world done to fulfill human needs or desires. However, that brief definition does not do justice to the full breadth of technological systems that make up our world. Think of the global transportation system that includes hundreds of thousands of airplanes and ships, and hundreds of millions of cars, motorcycles and bikes. Or, consider the global system for growing, processing and transporting food, or the system of medical care that includes hospitals, doctors, nurses, medical schools, medical equipment suppliers, pharmaceutical companies, drugstores, medical insurance companies, and professional organizations for the people that work in different sectors of the medical economy. Equally complex are systems for growing, processing and distributing food and clean water, producing usable energy from natural resources, building cities and towns, and so forth.

In order to appreciate how thoroughly technologies pervade our lives, try the following thought experiment.

A Thought Experiment about Technology

Imagine that all of the technologies around you were to disappear. What would be missing from your life right now? What would you see? How would your life be different? Take a minute and jot down your ideas, then read on to see how others have responded to this question.

Responses to the Thought Experiment

"My computer will disappear. I guess I don't have to answer email today."

"Hey, my cell phone just disappeared."

"The electricity went out too—no more lights, no air conditioning."

"Actually this entire building has been designed and built to provide shelter. So I guess the whole building is gone."

"What about the plants? They're natural, aren't they?"

"No, not really. Most are species from other places that were carried here on ships and planes. Others are modified by selective breeding or grafting."

"Hmmm, what happened to my clothes? They're made out of natural fibers!"

"Maybe so, weaving and knitting are technologies."

"So, here we are. No clothes and surrounded by trees since we have no axes to cut them down. How do we eat? Hmm, maybe those squirrels have some ideas…."

The NRC's *Framework* (National Research Council 2012) does not identify "technology practices." However, it clearly defines technology broadly, and several of the core ideas that all students should learn involve technology. Following is a set of four essential practices that the authors of this book have drawn from the *Framework* and other related materials that we believe are consistent and parallel to the "science and engineering practices" that are identified in Chapter 3 of the *Framework*.

Practice 1: Become aware of the web of technological systems on which society depends. When most people think about "technology" they generally envision computers or other digital tools. However, it is important that we enable our students to think more broadly and become aware of the vast number of interrelated technologies around them. Reflection is the key here, as it is important for students to start with aspects of the world that are familiar, and to recognize that if they were created by people, to serve human needs and desires, then they are *technologies*. Activities like the thought experiment above can help students begin to see the technologies that surround them, but it may take a variety of different activities for them to appreciate the full complexities of technological systems.

Practice 2: Learn how to use new technologies as they become available. "Technology education" in schools today usually refers to teaching students how to use computers for all sorts of different purposes, from finding and vetting sources of information, to using computers much as scientists do, to make measurements, collect data and to immediately represent and display information in multiple graphic formats. However, an essential characteristic of technology is that it is always changing, so that learning to use today's tools is not sufficient. We cannot fully prepare students to engage in tomorrow's technologies because we don't know what they will be. In order to equip our students to adjust to a world of changing technologies we need to help them learn how to learn new technologies, to choose the technology that is most appropriate to a given task, to examine ways that others have used the technology, to start with simple tasks and apply the technology to progressively more complex tasks, to take advantage of tutorials and manuals, and so on.

Practice 3: Recognize the role that technology plays in the advancement of

science and engineering. The role of technology in advancing science is well known through stories in the history of science. For example, Galileo would not have observed mountains and craters on the Moon without the telescope. Similarly, today's astronomers depend on advanced technologies like the Hubble Space Telescope, while medical researchers employ genetic engineering to create new medicines. The engineers who design these technological devices, systems, and processes are equally important in advancing our knowledge of the natural world as the scientists who use them. Science also helps to advance the work of engineers. Aerospace engineers apply the discoveries of Newton and Einstein to launch satellites into space, while materials engineers apply their knowledge of chemistry to create concrete and steel with properties needed to build modern highways and skyscrapers. In other words, engineers design the technologies that scientists use to advance science, while scientists provide engineers with knowledge of the natural world they need to design new technologies.

Practice 4: Make informed decisions about technology, given its relationship to society and the environment. From the invention of stone tools and fire, technological changes have brought about changes in the way people live. These changes have accelerated in recent decades, as the development of airplanes, cell phones, and computers have brought people together in ways never possible before. Similarly, technological developments have impacted the environment as farms, factories and cities have displaced forests and wetlands. As human populations have grown, the impacts on the global environment have increased. Consequently, it is important for everyone to recognize both the positive and negative consequences of technological decisions, and to make informed decisions. This idea was captured in a statement by the National Academy of Engineering in their report, *Technically Speaking: Why All Americans Need to Know More About Technology* (page 12).

> "As far into the future as our imaginations take us, we will face challenges that depend on the development and application of technology. Better health, more abundant food, more humane living and working conditions, cleaner air and water, more effective education, and scores of other improvements in the

> human condition are within our grasp. But none of these improvements are guaranteed, and many problems will arise that we cannot predict. To take full advantage of the benefits and to recognize, address, or even avoid the pitfalls of technology, Americans must become better stewards of technological change."

Taken together, these ideas raise the importance of technology education in the classroom to the same level as science. However, it is not the same technology that was taught in decades past. Today technology education means helping students become aware of the technological world they live in, how technology and science support each other, how to learn to use new technologies as they become available, and how technological decisions we make as individuals and as a society can impact our lives and the lives of our children.

Mathematical Practices

The Common Core State Standards movement gained momentum in 2009 when the National Governor's Council and the Council of Chief State School Officers decided that it was time for the states to work together and adopt the same educational standards so that students who move from one state to another will not have to repeat the same units, or miss out on key concepts and skills. The development of these standards was guided by the latest research in how students learn, effective instructional models from various states and input from multiple organizations and the public. Most states have already adopted these Common Core State Standards in mathematics and English language arts, so that curriculum developers, teachers, and creators of assessment instruments will all be on the same page about what students should learn and how they should be assessed.

In the area of Mathematics, the development of mathematical progressions presented a clear set of shared goals for what knowledge and skills student should acquire. In addition to these expectations, the Common Core State Standards for Mathematics prescribed a set of standards for 'mathematical practice', which describe the varieties of expertise that educators should seek to develop in their students as they grow in their mathematical abilities and understanding. As you read through these Standards for Mathematical Practice, below, notice that these practices emphasize the importance of using mathematics in everyday life in a way that connects very closely to the other STEM practices listed above. (The following statements are abbreviated from the *Common Core State Standards: Mathematical Practice*, 2011. The full text can be found at: http://www.corestandards.org/the-standards/mathematics/introduction/standards-for-mathematical-practice/).

Practice 1: Make sense of problems and persevere with solving them. Mathematically proficient students start by explaining to themselves the meaning of a problem and looking for entry points to its solution. They check their answers and they continually ask themselves, "Does this make sense?"

Practice 2: Reason abstractly and quantitatively. Mathematically proficient students make sense of quantities and their relationships in problem situations. They know how to use and manipulate the different properties of operations and objects in order to solve problems.

Practice 3: Construct viable arguments and critique the reasoning of others. Mathematically proficient students understand and use reasoning to analyze situations, make conjectures and build a logical progression of statements to support their thinking. They listen or read the arguments of others, decide whether the arguments make sense, and ask useful questions to clarify or improve the arguments.

Practice 4: Model with Mathematics. Mathematically proficient students can apply the mathematics they know to solve problems arising in everyday life, society, and the workplace.

Practice 5: Use appropriate tools strategically. Mathematically proficient students consider the available tools when solving a problem. They are able to use technological tools to explore and deepen their understanding of concepts.

Practice 6: Attend to precision. Mathematically proficient students try to communicate precisely to others, calculate accurately and efficiently, and express numerical answers with a degree of precision appropriate for the problem context.

Practice 7: Look for and make use of structure. Mathematically proficient students look closely to discern a pattern. They can see complicated things as single objects or as being composed of several objects in order to better understand how to solve more difficult problems.

Practice 8: Look for and express regularity in repeated reasoning. Mathematically proficient students notice if calculations are repetitive, and look both for general methods and for shortcuts in solving more complex problems.

Connections Among the STEM Practices

The following chart lists all of the STEM practices, slightly rearranged to highlight ways in which they are similar or complementary. For example, practices in science, engineering and mathematics all involve modeling. Both engineering and mathematics require students to define and solve problems. Science, engineering, and mathematics require students to learn to engage in constructive argument, while technology and mathematics both call for students to learn to use technological tools appropriately, and the ability to use tools is essential for carrying out investigations and analyzing and interpreting data in science and engineering.

Science	Engineering	Technology	Mathematics
Ask questions.	Define problems.	Become aware of the web of technological systems on which society depends.	Make sense of problems and persevere in solving them.
Develop and use models.	Develop and use models.		Model with Mathematics.
Plan and carry out investigations.	Plan and carry out investigations.	Learn how to use new technologies as they become available.	Use appropriate tools strategically
Analyze and interpret data.	Analyze and interpret data.		Attend to precision
Use mathematics and computational thinking.	Use mathematics and computational thinking.	Recognize the role that technology plays in the advancement of science and engineering	Reason abstractly and quantitatively.
Construct explanations.	Design solutions.		Look for and make use of structure.
Engage in argument from evidence.	Engage in argument from evidence.	Make informed decisions about technology, given its relationship to society and the environment.	Construct viable arguments and critique the reasoning of others.
Obtain, evaluate, and communicate information.	Obtain, evaluate, and communicate information.		Look for and express regularity in repeated reasoning.

Figure 5.1 Connections Among the STEM Practices

Concluding Thoughts

Whenever we take apart the four STEM fields there is always the danger that they be viewed separately, rather than integrated seamlessly. The real power in STEM teaching comes from the connections among the fields, and how they support and strengthen each other, as illustrated in the above table.

This concludes an overview of the STEM practices—the capabilities that our students are expected to gain over thirteen years of schooling. It is not expected that students will learn them all in any given year, but rather as they progress from year to year, and develop these "habits of thinking" as they grow in their maturity and experience.

Reflections

After having read this chapter do you see any advantage to calling what students should be able to do in science and engineering "practices" rather than "processes?" How so?

Which of the practices do you routinely teach? Which do you rarely teach?

What are your thoughts about the matrix that concludes the chapter? Do you see connections by looking across the rows? Is this helpful to you in any way?

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