STEM Thinking!

One of the things that I've been focused on as President is how we create an all-hands-on-deck approach to science, technology, engineering, and math... We need to make this a priority to train an army of new teachers in these subject areas, and to make sure that all of us as a country are lifting up these subjects for the respect that they deserve."

President Barack Obama
Third Annual White House Science Fair, April 2013

BY
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"STEM Thinking will encourage teachers involved in teaching some aspect of STEM to interact with other teachers involved in STEM.

INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) is a term seen almost daily in the news. It is a term with many meanings, but it is often directed at those involved in education and focuses on improving how STEM education is developed and delivered so that the U.S. can build a globally competitive workforce. For example, the recently released *Next Generation Science Standards* (*NGSS*, 2013a) discuss the need for new science standards by noting a reduction of the U.S.'s competitive economic edge, lagging achievement of U.S. students, the need to prepare for STEM careers needed in the modern workforce, and the need for an educated society that is literate in science and technology.

STEM is involved in almost everything we do. In 2009, President Obama launched the Educate to Innovate initiative to move American students from the middle to the top of the pack in science and math achievement over the next decade (The White House, n.d.). Learning about the attributes of STEM and how they are connected can help promote innovation (Holt, Colburn, & Leverty, n.d.).

Teachers involved in STEM education must take the challenge of learning more about the STEM areas and begin showing students how they are connected. To begin this transformation, teachers must become STEM Thinkers who can show their students how STEM is involved in most of the products and systems they use in their daily lives. STEM Thinking can be defined as "purposely thinking about how STEM concepts, principles, and practices are connected to most of the products and systems we use in our daily lives."

At the collegiate level, STEM education encourages students to pursue STEM careers in order to meet the growing need for trained professionals in these areas. The focus of this article is on teachers at the primary and secondary levels (i.e., P-12) who are involved in teaching about one or more of the STEM areas in their classrooms. These teachers, who come from a variety of STEM education areas, are typically involved in using hands-on and inquiry-based learning strategies that challenge students to solve real-world problems and explore their curiosities of the natural and human-made worlds. Today in our schools, teaching about STEM can take place in many general education and career and technical education subject areas such as agriculture, science, health, technology and engineering, and family and consumer science.

WHY BECOME A STEM THINKER?

Teachers who become STEM Thinkers can actively promote the concept of STEM Thinking to their students who will begin to learn and appreciate the interconnectedness of STEM and how it impacts their lives. Students who become STEM Thinkers may be able to gain a better understanding of the concepts, principles, and practices of STEM as they begin to see the "big picture" of STEM, and may develop an interest in pursuing a STEM career.

There are many concepts, principles, and practices taught in STEM, and often these ideas "crosscut" among the STEM disciplines. For example, "pressure" is equally important in science and engineering in developing new technology (e.g., a lightweight airplane) and can mathematically be determined. The following are examples of popular concepts, principles, and practices associated in the STEM areas:

Science

- Experimentation and The Scientific Method
- Natural World
- Energy and Matter
- Force and Pressure
- Hydraulics and Pneumatics

Technology

- Developed by Science and Engineering
- Human-Made World
- Positive and Negative Impacts
- Extending Human Potential
- Tools and Materials
- Computers

Engineering

- Engineering Design
- Creating Technology
- Inventions and Innovations
- Applying Math and Science
- Systems and Systems Thinking
- Materials and Properties

Mathematics

- Numbers and Operations
- Formulas
- Patterns and Relations
- Measurement
- Geometry
- Drafting (2D and 3D)

STEM Thinking can promote learning about how STEM is connected to familiar technologies, such as the jet airplane.

STEM Thinking can lead teachers to become STEM integrators who can teach students how to apply STEM subject matter in a variety of "real-world" inquiry-based learning activities. For example, a teacher practicing STEM integration may develop a lesson on greenhouses and have students use the "scientific method" to measure temperatures during different environmental conditions, and then challenge students to use the "engineering design" process to build a greenhouse that keeps the temperature in a specified range.

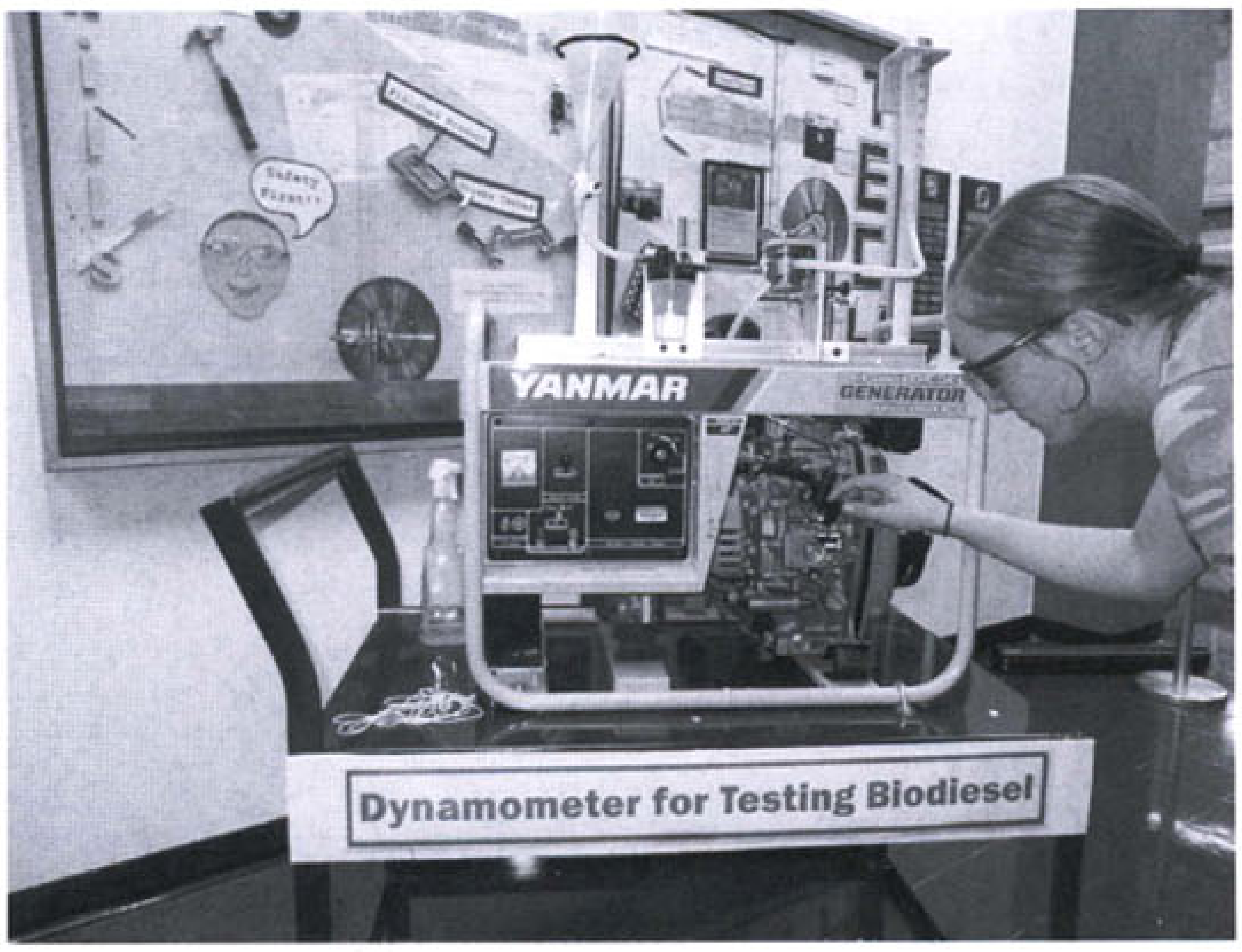
STEM integration is a curricular approach that combines the concepts of STEM in an interdisciplinary teaching approach (Wang, Moore, Roehrig & Park, 2011). Satchwell and Loepp (2002) describe an integrated curriculum as "one with an explicit assimilation of concepts from more than one discipline." In a STEM-integrated setting, Laboy-Rush (n.d.) notes that, "Integrated STEM education programs apply equal attention to the standards and objectives of two or more of the STEM fields" (p. 3).

In trying to define STEM integration, most argue a need for making connections across the STEM disciplines, but no one clear definition exists. Sanders' (2009) views on integrative STEM education involve purposely creating connections between science and technology and promoting an idea of "purposeful design and inquiry" that combines technological design with scientific inquiry. The authors of the recent report, *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research,* were unable to achieve consensus on a concise and useful definition of integrated STEM education and note "there is little research on how best to do so or on whether more explicit connections or integration across the disciplines significantly improves student learning, retention, achievement, or other valued outcomes" (NAE & NRC, 2014, p. 23).

STEM Thinking also helps to promote STEM literacy. A basic definition of STEM literacy is being able to "know, understand, use, and evaluate the STEM concepts, principles, practices, artifacts, and phenomena being studied." *Knowing* involves being able to identify the idea or topic being studied. *Understanding* involves describing how it works or operates and being able to transfer this understanding to various situations. *Using* deals with being able to operate it. *Evaluation* deals with assessing the item or topic being studied and making a judgment as to its impacts, which may be positive or negative in nature. For example, a STEM-literate person would be able to identify a technological artifact such as a tablet computer, describe how it works, use it, and discuss its impacts on society.

STEM literacy combines the literacy requirements of each of the STEM areas. Developers of STEM standards provide concise definitions of literacy in their related area of study. For example, in technology and engineering education, technological literacy has been described as "one's ability to use, manage, evaluate, and understand technology" (ITEEA, 2000/2002/2007).

You for Youth, sponsored by The U.S. Department of Education, promotes learning in after-school hours and has developed 21st Century Community Learning Centers to promote learning in a variety of subject areas, including STEM. You for Youth (n.d.) provides a good definition of STEM literacy, noting that it "relates to a student's ability to understand and apply concepts from science, technology, engineering, and mathematics



STEM Thinking may help students to better learn and understand how systems are connected.

in order to solve complex problems" and providing good basic literacy definitions for each of the STEM areas as shown below.

- Scientific literacy is the ability to use knowledge in the sciences to understand the natural world.
- Technological literacy is the ability to use new technologies to express ideas, understand how technologies are developed, and analyze how they affect us.
- Engineering literacy is the ability to put scientific and mathematical principles to practical use.
- Mathematical literacy is the ability to analyze and communicate ideas effectively by posing, formulating, solving, and interpreting solutions to mathematical problems.

STEM Thinking also promotes systems thinking. Systems thinking involves considering all the parts of a system that make up a whole (e.g., a home's air conditioning system is made up of many parts including a thermostat, compressor, and blower). When learning about systems, students learn concepts related to the purpose of the system, subsystem interactions, and system processes that include inputs, outputs, feedback, and control (NAGB, n.d.). Learning about systems thinking is important and will be a major area addressed in the first-ever national assessment in Technology and Engineering Literacy. In 2014, the National Assessment of Educational Progress (NAEP), commonly called the Nation's Report Card, will begin assessing, at the eighth grade, students' literacy in the major areas of (1) Technology and Society, (2) Design and Systems, and (3) Information and Communication Technology (NAGB, n.d).

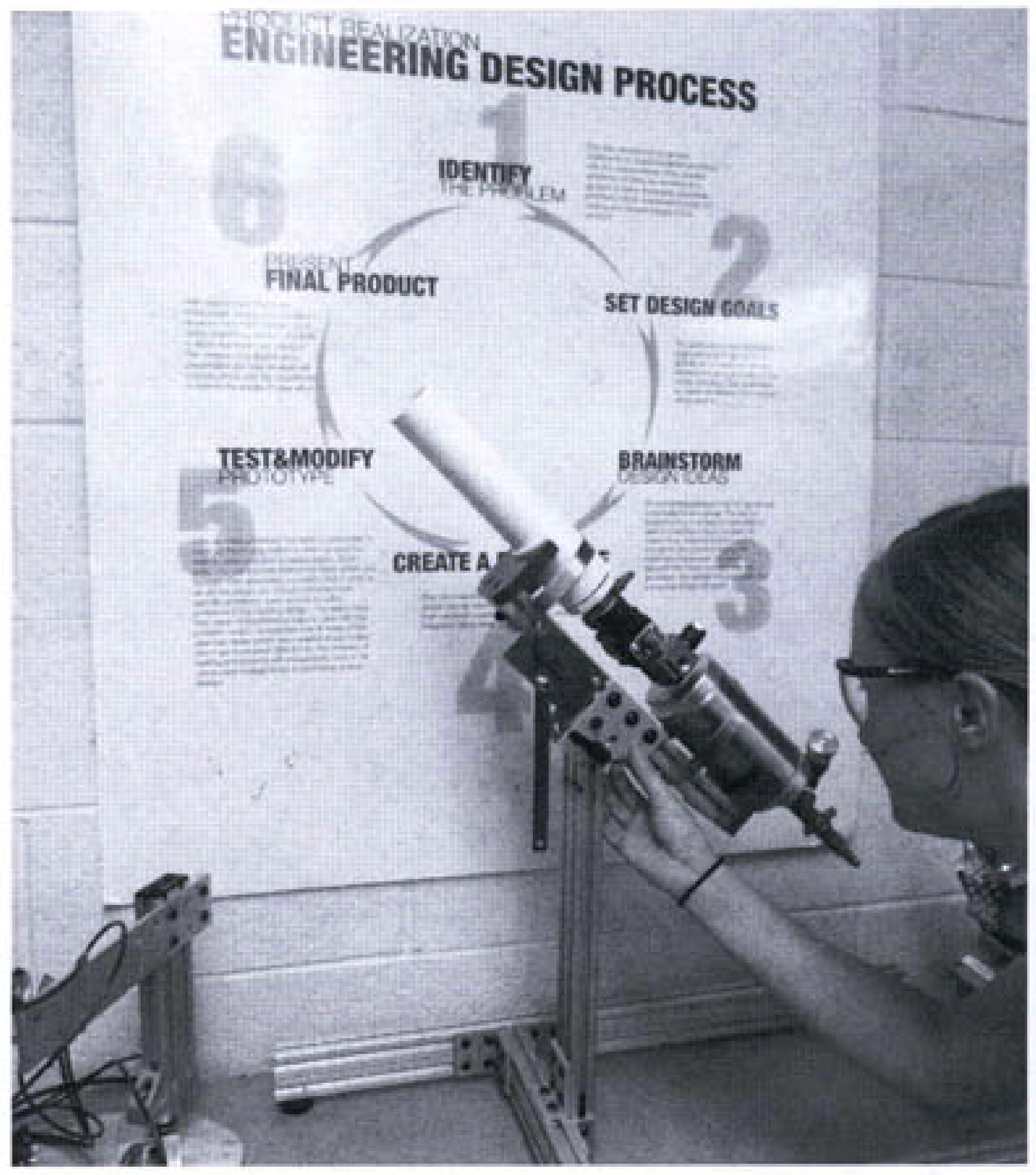
STEM EDUCATION

To become a STEM Thinker, it is helpful to have a little background on the term STEM and a good understanding of the meaning of STEM education. In his discussion on *Advancing Stem Education: A 2020 Vision*, Bybee (2010) provides an excellent discussion on the use of the term STEM. He notes the term "had its origins in the 1990s at the National Science Foundation (NSF) and has been used as a generic label for any event, policy, program (e.g., STEM Academy), or practice that involves one or several of the STEM disciplines." He also observes that it is a "slogan that the education community has embraced without really taking the time to clarify what the term might mean when applied beyond a general label, and in the U.S. the term is often interpreted to mean science or math, and seldom does it refer to technology or engineering" (p. 30).

There are many definitions and interpretations of STEM education and no clear consensus on its meaning. For example, STEM education could refer to a stand-alone STEM course (e.g., physics or calculus) or a program of study that includes a variety of courses from the STEM areas. Although there is no clear consensus on the meaning of STEM education, the term is often used in a context that emphasizes an immediate need to improve education in STEM. Tsupros, Kohler, and Hallinen (2009) provide an often quoted definition of STEM education: "an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise, enabling the development of STEM literacy and with it the ability to compete in the new economy."

Today, improving STEM education is promoted by all professional organizations involved in STEM education (e.g., National Science Teachers Association) in addition to other national organizations that promote STEM education (e.g., the STEM Education Caucus, the STEM Education Coalition, and the Triangle Coalition for STEM Education). For example, the STEM Education Caucus seeks to strengthen STEM education at all levels (K-12, higher education, and workforce) by providing a forum for Congress and the science, education, and business communities to discuss challenges, problems, and solutions related to STEM education. The STEM Education Caucus notes that there is a pressing need for STEM education in the U.S. because "today, an understanding of scientific and mathematical principles, a working knowledge of computer hardware and software, and the problem-solving skills developed by courses in STEM are necessary for most jobs." The Caucus further states that STEM education is responsible for providing our country with three kinds of intellectual capital: (1) scientists and engineers who will continue the research and development that is central to the economic growth of our country, (2) technologically proficient workers who are capable of dealing with the demands of a science-based, high-technology workforce, and (3) scientifically literate voters and citizens who make intelligent decisions about public policy and who understand the world around them (STEM Education Caucus, n.d.)

STEM education should promote STEM integration that shows how the components are connected. In the U.S., almost all K-12 schools require the core STEM subject areas of math and science and offer a variety of courses in these areas. Technology and engineering education is offered in varying degrees around the nation, with most courses in these areas being offered as electives. However, at the 6-12 grade levels, STEM courses are typically taught in "silos" by teachers who often have discipline-specific training, but limited opportunities to learn how the STEM areas are integrated together. In the elementary grades, if



STEM Thinking can be promoted through STEM problem-solving activities that require students to apply the engineering design process.

STEM is taught, it will typically be taught by a classroom teacher who works in a predominately self-contained classroom. In the future, STEM education may consist of stand-alone STEM courses taught by "STEM teachers" who have received in-depth training in all the STEM areas. Also in the near future, STEM education may broaden to include additional subject areas. For example, there is a movement in the U.S. by some to add art ("STEAM") to show how art and design help bring creativity and innovation to STEM (STEM to STEAM, 2013).

National curricula that promotes STEM integration at both the primary and secondary levels continues to be developed by various organizations as STEM education becomes a priority across the nation. At the national level, examples of organizations aggressively developing integrated STEM curricula include Project Lead the Way (PTLW), the International Technology and Engineering Educators Association's Engineering byDesign™ (EbD™) curricula, and the Engineering the Future and Engineering is Elementary curricula projects, developed by the Boston Museum of Science.

At the university level, STEM education encourages students to pursue STEM careers in such areas as engineering, computer science, science, agriculture, and mathematics. Careers in these areas are in high demand, and workers are needed to help keep the U.S. competitive with the rest of the world. For example, the most recent Bureau of Labor Statistics (BLS) occupational projections for the period 2008–18 suggest that total employment in occupations that NSF classifies as science and engineering will increase at more than double the overall growth rate for all occupations (NSF, 2012).

STEM is involved in the building, operating, and maintaining of complex systems.

STEM education and building a STEM-educated workforce is important to the U.S. as well as many other nations around the world that understand that STEM professionals working together will be needed to solve many of the global issues and problems the world faces today (e.g., global warming, air and water pollution, clean drinking water, and food security). Today, in many areas of the world, improving STEM education has become a priority. For example, in Europe, "inGenious" is the European coordinating body in STEM Education with a goal to reinforce young Europeans' interest in science education and careers and thus address anticipated future skills gaps within the European Union (inGenious, n.d.). In Asia, the Association of Southeast Asian Nations (ASEAN) economic community (AEC) is working toward transforming ASEAN into a single market and production base by 2015. Important to this transformation is improving STEM education in the region. For example, in January 2013, Thailand's Institute for Promoting Science Teaching and Technology (IPST) sponsored an all-day roundtable meeting to address the need to develop a STEM workforce in ASEAN countries through world-class quality STEM education (IPST, 2013).

BECOMING A STEM-THINKING TEACHER

Becoming a STEM-Thinking teacher is not difficult; however, it will challenge many teachers to step outside their "subject comfort zones." In the U.S., the primary STEM subjects are often taught in "silos," with little interaction occurring between subject teachers. STEM Thinking will encourage STEM teachers to interact with other STEM teachers.

Those involved in teaching in STEM areas who wish to become STEM Thinking teachers must first begin by accepting the challenge to want to learn more about how STEM concepts, principles, and practices are connected to most of the products and systems we use in our daily lives. At a minimum, STEM Thinking teachers will need to learn to accurately define and describe the components of STEM, be able to implement inquiry-based learning into their programs, and be able to show STEM Thinking in action.

Advanced STEM Thinking teachers will know how to develop and deliver integrated STEM curricula. In order to do that, teachers will be need to have a very good understanding of the standards covered in each of the STEM areas and know how to develop standards-based curricula. They will need to learn about the various instructional strategies, teaching methods, and assessment techniques that are commonly used in the STEM areas. They should also have a very good understanding about career options available in STEM and its related areas.

THE COMPONENTS OF STEM

STEM Thinkers need to develop a good awareness of each of the components of STEM. A STEM Thinking teacher must be able to able to clearly and quickly define the STEM components. A basic definition of each of the STEM areas is as follows:

- **Science**: study of the natural world.
- **Technology**: modifying the natural world to meet the needs and wants of society.
- **Engineering**: using math and science to create technology.
- **Mathematics**: a language of numbers, patterns, and relationships that tie science, technology, and engineering together.

To gain in-depth knowledge of each of the STEM areas, teachers are encouraged to review the national standards associated with each of the disciplines. All of the STEM areas except engineering have national content standards that are used to identify what is important to teach in that area. Standards identify the content that students should know and be able to do in order to become literate in a particular area of study.

National standards in math (*Principles and Standards for School Mathematics*) are available from the National Council of Teachers of Mathematics (NCTM). In addition, to try to build consistency and quality in the teaching of math and other subjects in the U.S., the Common Core State Standards Initiative (CCSS) has been adopted by 45 states and provides a detailed set of grade-by-grade standards that can be immediately adopted as a state curriculum document (AMTE, n.d.). In technology and engineering education, content standards (*Standards for Technological Literacy: Content for the Study of Technology*) are available from the International Technology and Engineering Educators Association (ITEEA). The recently released standards in science education (*Next Generation Science Standards*) are available from the National Science Teachers Association (NSTA).

INQUIRY-BASED LEARNING

STEM Thinking teachers use inquiry-based learning strategies and know the popular approaches used in the teaching of science, technology, and engineering. Inquiry-based learning describes approaches to learning that are based on the idea that when students are presented with a scenario or problem and assisted by an instructor, they will identify and research issues and questions to develop their knowledge or solutions (Inquiry-based Learning, n.d.).

Science education uses a form of inquiry-based learning known as "scientific inquiry." In technology and engineering education, a popular approach to solving problems is known as "engineering design." Both approaches are similar in nature, with the major differences being how the problems or questions are asked and solved, remembering that science explores the natural world and that technology and engineering focus on the human-made world. *Next Generation Science Standards* (2013c) notes that "scientific inquiry involves the formulation of a question that can be answered through investigation, while engineering design involves the formulation of a problem that can be solved through design."

Presented in *A Framework for K–12 Science Education* (NRC, 2012) are the multiple ways in which scientists explore and understand the world and the multiple ways in which engineers solve problems. A STEM Thinking teacher would be able to describe the practices used by scientists and engineers to explore the world and solve problems as follows:

- Asking questions (science) and defining problems (engineering)
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics, information and computer technology, and computational thinking
- Constructing explanations (science) and designing solutions (engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

In the building of this boat, how important is it that the student knows about concepts, principles, and practices of STEM?

In the teaching of STEM, students can learn to apply inquiry-based learning approaches through a variety of instructional methods. One very popular approach that STEM Thinking teachers would use is Problem-Based Learning (PBL). PBL promotes developing critical thinking and problem-solving skills as students are challenged with real-world problems to solve, and it can be used to investigate scientific or technological problems.

To investigate a scientific problem or question (e.g., What type of insulation container will keep ice from melting for the longest time?), the scientific method can be used. The scientific method is a very controlled approach to investigating problems and typically requires following a set of prescribed steps that include stating a hypothesis, conducting an experiment, analyzing the data, and reporting the findings.

To investigate a technological or engineering-related problem (e.g., a need exists to build a small ice container that can be used to transport medicine that needs to be refrigerated), the engineering design approach can be used. In technology and engineering education, students are often presented with an engineering or technological problem to solve as an engineering design challenge that presents the context of the problem, the problem, and the criteria and constraints that must be adhered to when solving the problem. Engineers face many challenges and problems that must be solved when developing a new technology. To help them solve these problems, engineers apply mathematical and scientific principles (e.g., calculus and physics).

The engineering design process is fundamental to technology and engineering and is a problem-solving approach that is presented in many similar variations. In ITEEA's *Standards for Technological Literacy* (*STL*) (ITEA/ITEEA, 2000/2002/2007), many of the standards are focused on learning about design, how to do design, and learning about the designed world (e.g., construction and manufacturing). *STL* describes an "engineering design" process that engineers use when developing a new technology that includes:

- Defining a problem
- Brainstorming
- Researching and generating ideas
- Identifying criteria and specifying constraints
- Exploring possibilities
- Selecting an approach
- Developing a design proposal
- Making a model or prototype
- Testing and evaluating the design using specifications
- Refining the design
- Creating or making it
- Communicating processes and results

Both the scientific method and engineering design promote active, hands-on, experiential student-centered learning that requires students to apply what they are learning in the classroom. Hands-on learning using real-world problems motivates students to learn the materials and helps to develop an understanding of the content being learned. It should be noted that *NGSS* (2013b) "represent a commitment to integrate engineering design into the structure of science education by raising engineering design to the same level as scientific inquiry when teaching science disciplines at all levels, from kindergarten to Grade 12" (p. 10).

How was STEM involved in the making of the original Coca Cola formula? How is STEM connected to the making, filling, distribution, and possible recycling of the glass soda bottle?

When using inquiry-based learning in the classroom, STEM Thinking teachers must continually remember to assess students using both formative and summative assessment methods that can be used by teachers to adjust student learning. For example, formative assessment methods such as asking students to reflect on how they are doing or reviewing their lab notebooks can help teachers to understand the approaches students are using to solve the problem. Summative assessment would involve tests of the materials presented or evaluation of the completed models or prototypes built to address the problem.

STEM THINKING IN ACTION

In the classroom, STEM Thinking teachers can put STEM Thinking into action, beginning with a lesson objective of purposely showing students how STEM concepts, principles, and practices are connected to most of the products and systems they use in their daily lives. In this STEM Thinking example, the object to be examined is a glass Coca-Cola bottle.

Although the U.S. uses mostly plastic bottles for soft drinks, many places in the world use glass bottles that can be recycled and refilled to help keep the cost of soda down. Another purpose of using the glass bottle is to help students become global thinkers. Too often students become U.S.-centric in their thinking, and providing them with global perspectives in the classroom can help them to realize and understand that the world is connected and comprised of a variety of cultures, norms, and practices that may be different from their own.

The lesson would begin by showing students a Coca-Cola bottle and having a discussion that addresses questions such as where it came from, why glass is being used, whether they think it may taste different, and why the U.S. uses mostly plastic or aluminum for soda and other beverages. Note: many large supermarket stores in the U.S. sell glass soft drink bottles that have been imported from Mexico.

After the discussion on use of the glass bottle, the teacher would present a discussion on how the object is connected to each of the STEM areas and encourage students to become STEM Thinkers and identify other STEM connections. Shown on page 15 are some STEM connection examples for the Coca-Cola glass bottle.

Science Connections

- Scientists used "natural ingredients" to develop the formula for the soda drink.
- Science was needed to develop glass that is made using natural ingredients such as sand.

Technology Connections

- The glass bottle was invented long ago. It is an example of a technology that was developed to hold liquids.
- An innovation of the glass bottle is the plastic bottle.
- Manufacturing technology is used to make the bottles.
- Transportation technology is used to deliver the bottle to the store.

Engineering Connections

- Engineers used engineering principles and practices to develop the technology needed to mix and fill the glass bottles with soda.
- Engineers and scientists worked together to develop methods to clean and sanitize the bottles so that they could be safely reused.

Mathematics Connections

- Proper measurements were needed in the development and design of the glass bottle.
- Math is used to measure the amount of liquid in the bottle.

At the end of the STEM Thinking lesson, students could be given an "engineering design challenge" that requires the use of engineering design to solve an identified problem. Examples of engineering design challenges for the Coca-Cola bottle might be to develop a holder for it so it does not tip over when bumped, a way to protect it, a way to automatically dispense a prescribed amount of soda, or a way for a disabled person to open it with one arm. In addition, students could learn to use the scientific method by setting up a taste test (e.g., between different brands of cola, or the same type of cola, but from a different country).

CONCLUSION

Teachers involved in teaching some aspect of STEM in their classrooms or programs are encouraged to become STEM Thinkers. STEM Thinking is a skill that promotes purposely thinking about how STEM concepts, principles, and practices are connected to most of the products and systems we use in our daily lives. Teachers who become STEM Thinkers are then able to transfer this skill to their classrooms where they teach their students to become STEM Thinkers, helping them gain a better understanding of the materials being covered and preparing them for life and careers in the 21st century that are heavily influenced by science, technology, engineering, and mathematics.

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