

Chapter 12

Teaching and Learning with Technology in Science, Engineering, and Mathematics

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Learning Outcomes

After reading this chapter and completing the learning activities, you should be able to:

- 12.1** Distinguish three approaches to STEM integration for use in different teaching contexts. (ISTE Standards for Educators: 1—Learner)
- 12.2** Identify implications for technology integration of each current issue that science teachers face. (ISTE Standards for Educators: 1—Learner; 5—Designer)
- 12.3** Select technology integration strategies that can meet various needs for instruction in science curricula. (ISTE Standards for Educators: 1—Learner; 2—Leader; 3—Citizen; 4—Collaborator; 5—Designer; 6—Facilitator; 7—Analyst)
- 12.4** Identify implications for technology integration of each current issue that engineering teachers face. (ISTE Standards for Educators: 1—Learner; 3—Citizen; 4—Collaborator; 5—Designer)
- 12.5** Select technology integration strategies that can meet various needs for instruction in engineering curricula. (ISTE Standards for Educators: 1—Learner; 2—Leader; 3—Citizen; 4—Collaborator; 5—Designer; 6—Facilitator; 7—Analyst)
- 12.6** Identify implications for technology integration of each current issue that mathematics teachers face. (ISTE Standards for Educators: 1—Learner; 5—Designer)
- 12.7** Select technology integration strategies that can meet various needs for instruction in mathematics curricula. (ISTE Standards for Educators: 1—Learner; 2—Leader; 3—Citizen; 4—Collaborator; 5—Designer; 6—Facilitator; 7—Analyst)

Technology Integration in Action: Hot and Cold Data

GRADE LEVELS: 7–9

CONTENT AREA/TOPIC: Physical science, engineering, mathematics

LENGTH OF TIME: Three weeks

PHASE 1 Analysis of Learning and Teaching Assets and Needs

Step 1: Analyze problems of practice (POPs)

Ms. Belt and Mr. Alter, a physical science teacher and mathematics teacher, respectively, at Pinnacle Middle School, are aware of the need to integrate engineering into their science and mathematics curriculum. At the same time, they are transforming their curriculum to provide more hands-on learning opportunities to address the ongoing challenge of making abstract science and mathematics concepts more concrete and visual.

Step 2: Assess technological resources of students, families, teachers, and the school

The students at Pinnacle are allowed to use their own devices during breaks, lunch, and after school. However, some teachers have harnessed their power for small web-based tasks during classes, which students appear to support. About half of the students have smartphones, while the other half of the students do not. Of the student population, 50% or more qualify for free or reduced lunch, indicating a low family socioeconomic status. The teaching staff knows that it is important for the school to provide technology-rich learning experiences so that all students develop digital literacy skills and experiences. Both teachers have moderate experience with various technologies, such as virtual manipulatives, online content for science and math, and software that supports knowledge practice. Each had also experimented with small-group collaborative projects within their classrooms. The school was fairly well-resourced with several desktop computer labs and several tablet carts available for teachers to sign up to use. One of the tablet carts was dedicated to each subject area team, so between Ms. Belt and Mr. Alter, they had access to two of the carts. The school had recently passed a bond, and so the teachers were expecting some new resources.

Step 3: Identify technological possibilities

In an integrated team meeting that the science and mathematics teachers held monthly, the district curriculum specialists came and revealed that new calculator-based laboratories (CBLs), funded by the bond, had just arrived. The specialist demonstrated how CBLs can capture temperature data and display it in graphs and spreadsheets. Ms. Belt and Mr. Alter realized that activities with CBLs provided a natural link between science, engineering, and mathematics studies.

Although they knew that a collaboration across classrooms would involve more time for planning and coordination, Ms. Belt and Mr. Alter were excited to develop a science, technology, engineering and mathematics (STEM) integration lesson involving the use of CBLs. Having students use CBLs would be an ideal way to give them hands-on insights into the relationship between these curricular areas. Ms. Belt and Mr. Alter also agreed that CBL activities would address the challenge of making abstract science and mathematics concepts more concrete and visual. They felt that having students collect and analyze their own data would give students authentic, hands-on application of these concepts in a realistic setting. The teachers decided that a unit using CBL probes that measure temperature would be a good first activity. Students would be working as engineers to test products for the purpose of writing a *Consumer Reports* type article. The students would take temperature measurements with the CBL probes and then use engineering and mathematical procedures to graph and analyze the resulting data as a way to model the science.

PHASE 2 Design of the Integration Framework

Step 4: Decide on learning objectives and assessments

Ms. Belt and Mr. Alter decided that they would assess student progress in four areas: performing CBL tasks, conducting experiments, interpreting data from experiments, and reporting on experiments. The teachers decided on the following outcomes and objectives they wanted students to achieve and outlined assessment methods to measure students' performance on each:

Outcome: CBL procedures.

- **Objective** Each student will score at least 85% on a performance test designed to measure competence with CBL procedures.
- **Assessment** A checklist with points assigned for successful completion of each task.

(Continued)

Outcome: Conducting experiments.

- **Objective** All students will demonstrate that they can work in collaborative groups to complete the steps in an assigned experiment and keep notes capturing their experimental processes by achieving a rubric score of at least 85% on their work.
- **Assessment** A checklist with points assigned for each step done correctly; a rubric to assess the quality of students' experiment notebook.

Outcome: Interpreting data from experiments.

- **Objective** All students will demonstrate the ability to review and interpret data derived from experiments by correctly answering at least eight of ten questions requiring data interpretation.
- **Assessment** A mid-unit test in which each student reviews example charts and answers questions on how to interpret the data.

Outcome: Reporting on experiments.

- **Objective** All students will demonstrate that they can synthesize and communicate results from a CBL experiment by working in groups to develop a presentation of findings.
- **Assessment** A rubric to assess the collaborative group presentation.

Step 5: Design integration strategies and determine relative advantage

Ms. Belt and Mr. Alter decided to team teach the unit to emphasize important links between the content areas. Working together, they designed the following sequence of activities:

Week 1—Introduce the unit with a *Consumer Reports* type scenario: Each maker of camp stoves claims that its product heats water faster than their competitors do. The various stoves used three different fuels: white gas, kerosene, and butane. The students have to establish which manufacturer is correct and write their findings for their *Consumer Reports* magazine. Show the YouTube videos: "Eureka! Episode 20 Measuring Temperature" and "Eureka! Episode 21 Temperature vs. Heat." Demonstrate how students can use the CBL to collect data and how it displays temperatures in graph form. Demonstrate how to calibrate a CBL and discuss how to interpret CBL data.

Week 2—To set the stage for the main experiment, have students develop and carry out initial heating/cooling experiments and present findings. As Ms. Belt helps small collaborative groups prepare materials for the next set of experiments, Mr. Alter has students do individual performance checks on CBL procedures, while providing additional instruction as needed. Each small collaborative group is assigned a heating/cooling experiment, for example, heating bolts of various sizes and adding them to beakers of water. Ask, for example: Does the water temperature in a beaker increase more when two small metal bolts are added or when one large bolt is added? Each group completes its assigned experiment, answers the question, communicates its findings, and presents the findings to the class by inserting spreadsheet and graphed data into a presentation. Each student in the class individually prepares a final summary of all the experiments based on the presentations.

Week 3—Students carry out the final experiment in three large groups. Using camp stoves borrowed from a local sporting goods store, they heat water to boiling using the CBL probes to make measurements. They collaboratively conduct the step-by-step procedures for hands-on experiments, write their findings, present them to the whole class, hold a whole-class discussion to interpret results, and write a summary in their notebooks. Each group works with the data to explore linear, quadratic, and exponential functions of graphed data. Finally, students work in pairs to answer questions on the meaning of the graphs. They complete the mathematical analyses and presentations. Finally, they take end-of-unit tests.

Relative Advantage

This project was aimed to integrate science, math, and engineering and to provide hands-on learning that made abstract concepts more concrete. Together, Ms. Belt and Mr. Alter RATified the proposed Hot and Cold Data project. Figure 12.1 shows the RATification aspects of instruction, student learning, and curriculum that they believed would be impacted by the interview project. They were delighted to see some amplification and transformation of instruction, learning, and the curriculum in their plan. They felt there was relative advantage to engage in the Hot and Cold Data project.

Step 6: Prepare instructional environment and implement lesson

Mr. Alter and Ms. Belt prepared the classroom by setting up beakers, hot plates, and CBLs. A local sporting goods store loaned them three different camp stoves for the experiments. They tested each of the CBLs and made sure they

Figure 12.1 Ms. Belt and Mr. Alter's RATified Hot and Cold Data Lesson

Instruction	Learning	Curriculum
<p>Replacement Technology is a different means to same end.</p> <p>Amplification Technology increases or intensifies efficiency, productivity, access, capabilities, etc., but the tasks stay fundamentally the same.</p> <p>Transformation Technology redefines, restructures, reorganizes, changes, and creates novel solutions.</p>	<ul style="list-style-type: none"> • CBL probes allow for easy data collection and analysis of scientific phenomena • Productivity software helps note-taking, summaries, and final communication (presentation) of findings from experiment • CBL activities make abstract science and math concrete • Cloud-based productivity tools allow for collaboration with scientists and engineers 	<ul style="list-style-type: none"> • Interdisciplinary project includes science, math, technology, and engineering concepts
<ul style="list-style-type: none"> • Situate experimental problem with real-life technical and engineering problem: camper stove functionality 		

worked. They designed and copied each of the performance measures and made copies of lab sheets needed during the experiments. Finally, they bookmarked the YouTube sites with videos they wanted to show so they could access them quickly.

PHASE 3 Post-Instruction Analysis and Revisions

Step 7: Analyze lesson results and impact

At the end of the unit, Mr. Alter and Ms. Belt reviewed students' products and discussed how the unit had worked. They were happy with the overall performance of the class. They were impressed by how engaged students had become in using the CBLs to gather and analyze data and pleased with the level of collaboration they observed while the small groups were conducting experiments. Perhaps most encouraging, two female students seemed especially excited by the work they had done; they asked the teachers to give them information on STEM careers.

Step 8: Make revisions based on results

Ms. Belt and Mr. Alter concluded that this type of multidisciplinary, STEM integration unit worked very well. They decided to plan other CBL experiments to be carried out on a long-term basis and at locations outside the classroom.

Step 9: Share lessons, revisions, and outcomes with other peer teachers

Mr. Alter and Ms. Belt and a few of their students were invited to come to the school board meeting to provide examples of how the bond funds for this project were supporting learning in the classroom. After that meeting, the two teachers submitted a proposal to the conference of the National Council of Teachers of Mathematics (NCTM) to share the lesson and outcomes with mathematics teachers.

SOURCE: Based on concepts from *The Heat is On! Using the Calculator-based laboratory to Integrate Math, Science, and Technology* by Joanne Caniglia and *Heat vs. Temperature: What's the Difference?* by Karen Campbell.

Introduction

This chapter has seven major sections. The first section introduces the **science, technology, engineering, and mathematics (STEM)** fields and articulates how teachers can go about STEM integration. The next two sections review the major issues in science education that shape how technology can be integrated and describe integration strategies for this area. The following four sections describe the major issues and integration strategies for engineering and mathematics education, respectively. Notice that each content area section also provides a rubric for self-assessment of growth in how well a teacher is able to use technology in each area of science, engineering, and mathematics. Major advancements in technological development have led scientists, engineers, and mathematicians to carry out professional work and investigations with support of various technologies. In turn, K-12 STEM standards now position technology as essential for

learners to advance their conceptual knowledge and develop scientific, mathematical, and engineering practices. Although this chapter introduces issues, challenges, and technology integration strategies for each specific STEM field separately, the most important big idea is to consider how STEM fields can be integrated as is illustrated in the first section. Success for all students lies in being able to navigate the integration of the STEM disciplines to solve real-world problems we face as well as to recognize how each discipline approaches problems.

Introduction to STEM and STEM Integration

Concern about America's future ability to compete in STEM has increased. Achievement gaps in science and mathematics are well documented with particular recognition of a continued underrepresentation of female and minority STEM professionals. When compared with boys, girls' interest in science decreases as they enter middle school. This trend continues throughout the rest of their education; for example, 57% of all bachelor's degrees are conferred on females, but within STEM fields, females receive only 35% of the bachelor's degrees (Musu-Gillette et al., 2016). Thus, women continue to be underrepresented in STEM fields (Bayer Corporation's Facts of Science Education, 2010; Committee on Science, Engineering, and Public Policy, 2011; Engineering in Massachusetts Collaborative (EMC), 2003). This trend could have serious consequences for the long-term economic and national security of the country. Providing all students with access to quality education in the STEM disciplines is important for the nation's competitiveness. However, identifying the most successful approaches in the STEM disciplines is challenging. The reality is that success for all students lies in being able to navigate the integration of the STEM disciplines, which is representative of real-world problems we face, as well as recognizing how each discipline approaches problems.

National calls for integrated STEM teaching have come through multiple reports and documents. For example, *A Framework for K–12 Science Education: Practices, Crosscutting Concepts and Core Ideas* (National Research Council [NRC], 2012) calls for adding engineering design into science education at a level that is as prominent as scientific inquiry. Going one step further, the report *STEM Integration in K–12 Education: Status, Prospects, and an Agenda for Research* (National Academy of Engineering [NAE] & NRC, 2014) proposed a framework for integrated STEM education that includes goals for students and educators, outcomes for students and educators, the nature and scope of STEM integration, and a guide for implementing STEM integration. These reports provide both the advantages of integrating the STEM disciplines for student learning, as well as the need for students to understand the nature of the individual STEM disciplines when they are not integrated.

What Is STEM Integration Instruction?

There are three types of STEM integration (Moore, Tank, Glancy, Siverling, & Mathis, 2014):

- STEM content integration
- STEM context integration
- STEM tool/application integration

Teachers can use one of these STEM integration approaches, blend them, or use different approaches in different situations to provide students with appropriate learning environments to meet the learning objectives of a course.

STEM CONTENT INTEGRATION STEM content integration is a way of teaching that merges learning objectives from multiple STEM disciplines. For example, a life science teacher might have her students design a better process for extracting DNA. This takes

first an engineering design view to redesign an inefficient process (which is a technology). The students must learn about DNA and cell biology in order to understand the current technology and then redesign it. Furthermore, mathematical principles are at play as students design to maximize high levels of surface area of the pieces of material from which the DNA will be extracted. Therefore, the teacher would have learning objectives related to engineering design, biotechnologies, cell biology, and mathematics. Examples such as this show how teachers can address a realistic problem through teaching the standards from multiple disciplines and stressing how each is useful for the problem at hand. It is also representative of how real-world STEM problems are pursued and solved.

Content integration is the most difficult to achieve when applying STEM integration. To achieve content integration with all of the STEM disciplines, six tenets need to be considered to achieve the highest quality STEM integration experience for the student. The learning experience for the students should include:

1. **Context**—A meaningful, motivating, and engaging context so that students have ways to personally enter into and participate in the activity (Brophy, Klein, Portsmouth, & Rogers, 2008; Carlson & Sullivan, 2004; Frykholm & Glasson, 2005).
2. **Engineering design of technologies**—An engineering design of relevant technologies for a compelling purpose that involves problem-solving skills and ties to context (Morrison, 2006).
3. **Redesign**—The opportunity for students to learn from failure and redesign (Moore, Guzey, & Brown, 2014).
4. **Mathematics and science content**—Appropriate standards-based mathematics and science content (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Harris & Felix, 2010; Mehalik, Doppelt, & Schunn, 2008; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010; NGSS Lead States, 2013).
5. **Student-centered pedagogy and evidence-based reasoning**—Teaching content with student-centered pedagogies (Furner & Kumar, 2007; Smith, Sheppard, Johnson, & Johnson, 2005; Stinson et al., 2009) including evidence-based reasoning (Mathis, Siverling, Glancy, Guzey, & Moore, 2016) to connect science and mathematics to engineering design.
6. **Teamwork and communication**—An emphasis on teamwork (Carlson & Sullivan, 2004; Selingo, 2007; Smith et al., 2005) and communication (Dym et al., 2005; National Governors Association, 2010; NAE & NRC, 2009; Selingo, 2007).

The national calls from the *STEM Integration in K–12* document and the *Framework for K–12 Science Education* report support a STEM curriculum that engages students in the power of the integration of these multiple disciplinary areas.

STEM CONTEXT INTEGRATION STEM context integration puts the learning emphasis on one discipline while using contexts from other disciplines to frame the lesson to create meaning, relevance, and/or motivation to solve a problem. For example, a mathematics teacher asks students to participate in a problem-solving activity that examines the size of leaves from trees over multiple years set in the context of studying global warming in a citizen science project. Here, the context is science, but the content is measurement and descriptive statistics from mathematics.

STEM TOOL/APPLICATION INTEGRATION STEM tool/application integration suggests that a tool or application of one discipline, such as a simulation technology, is used within the teaching of another discipline in order to help students learn the latter discipline's content. Many of the examples throughout this book are considered tool or application integration. Integrating an educational technology into a science or mathematics class in order to teach science or mathematics is such an example. The sections

Video Example 12.1 Middle School Students Work with Robots

In this video, watch how mathematics is integrated into an engineering task involving robotics. Here the teacher wants the students to understand measuring and implementing angles, as well as learn computing and engineering design.



on science and mathematics instruction later in this chapter provide good examples of tool/application integration.

Technology provides powerful learning tools for engaging students in investigating more complex ideas and problem solving to reveal important interactions among the disciplines while engaging students in student-centered STEM instruction. Harris and Rooks (2010) found that these tools allow classrooms to become more oriented toward the student and involve authentic research and communication activities supported by searching web databases and using model-building software and tools to collect data and describe findings. In fact, students use the same tools as professionals in the field. Owston (2009) found another important role for technology, such as vod/podcasting and videoconferencing, in supporting student-centered, science inquiry learning in programs for all children that sought to improve mathematics and science teaching at the high school, middle school, and upper elementary levels. The Technology Integration in Action scenario at the beginning of the chapter exemplifies STEM integration with explicit educational technology integration. This activity uses context integration as it integrates mathematics content, science content, engineering contexts, and educational technology integration. However, it does not address all of the six tenets described above to meet content integration. In this example, Ms. Belt and Mr. Alter chose to focus on engineering analysis rather than engineering design in order to highlight the mathematics and science principles they wanted students to learn. The sections in this chapter will focus on the integration of educational technologies in each of the STEM disciplines, which represents the tool/application integration approach. However, we urge teachers to work toward STEM content integration and to consider all the strategies introduced in this chapter as possibilities to be applied in a STEM integration learning environment.



Check Your Understanding 12.1

Issues and Challenges in Science Instruction

The growing national concern that the United States is not adequately preparing students, teachers, and professionals in STEM areas has resulted in new standards and recommendations for revising the science curriculum. The appropriate role for technology in helping to meet science education needs is the focus of this section.

Accountability for Standards in Science

The *Framework for K–12 Science Education* (National Research Council [NRC], 2012) was the foundation for the development of the *Next Generation Science Standards* (NGSS Lead States, 2013). The Next Generation Science Standards (NGSS) are organized by two main categories:

1. **Performance expectations**—The performance expectations are statements that the NGSS equates to previous states' standard statements. (NGSS Lead States, 2013).
2. **Learning goals**—The learning goals are designed to connect the performance expectations to the three areas identified in the *Framework for K–12 Science Education*: *science and engineering practices*, *disciplinary core ideas*, and *crosscutting concepts*. The learning goals help teachers, administrators, curriculum designers, and assessment developers understand the intent behind performance expectations.

The science and engineering learning practices (S&EP) of the *Framework* and NGSS include:

- S&EP1. Asking questions (science) and defining problems (engineering)
- S&EP2. Developing and using models
- S&EP3. Planning and carrying out investigations
- S&EP4. Analyzing and interpreting data
- S&EP5. Using mathematics and computational thinking
- S&EP6. Constructing explanations (for science) and designing solutions (for engineering)
- S&EP7. Engaging in argument from evidence
- S&EP8. Obtaining, evaluating, and communicating information

The disciplinary core ideas (DCI) of the *Framework* and NGSS for physical sciences include:

- PS1. Matter and its interactions
- PS2. Motion and stability: Forces and interactions
- PS3. Energy
- PS4. Waves and their applications in technologies for information transfer

The disciplinary core ideas (DCI) of the *Framework* and NGSS for life sciences include:

- LS1. From molecules to organisms: Structures and processes
- LS2. Ecosystems: Interactions, energy, and dynamics
- LS3. Heredity: Inheritance and variation of traits
- LS4. Biological evolution: Unity and diversity

The disciplinary core ideas (DCI) of the *Framework* and NGSS for earth and space sciences include:

- ESS1. Earth's place in the universe
- ESS2. Earth's systems
- ESS3. Earth and human activity

The disciplinary core ideas (DCI) of the *Framework* and NGSS for engineering, technology, and applications of science include:

ETS1. Engineering design

ETS2. Links among engineering, technology, science, and society

The crosscutting concepts (CC) of the *Framework* and NGSS include:

1. Patterns
2. Cause and effect: Mechanism and explanation
3. Science, proportion, and quantity
4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
6. Structure and function
7. Stability and change

These learning goals challenge teachers to design their science lessons around at least one if not more of these practices as students explore and learn scientific and/or engineering ideas. For example, in the Hot and Cold Data Technology Integration in Action scenario, Ms. Belt and Mr. Alter designed a three-week unit around the integration of **calculator-based laboratories (CBL)** probeware. The entire unit addressed the disciplinary core idea ETS2 by considering that science and engineering are naturally linked. They challenged the students to ask questions about the water temperature when two small bolts were added versus adding only one larger bolt (S&EP1). They challenged the students to carry out experiments (S&EP3), analyze the results (S&EP4), use spreadsheets for graphing data (S&EP2 and S&EP5), and present their findings to the whole class (S&EP6 and S&EP7) using a digital presentation for communicating their results (S&EP8). The Hot and Cold Data example focuses on mathematics and science, as well as motivating students through active learning, inquiry, problem solving, cooperative learning, and other instructional methods.

To integrate technology in the science classroom on a regular basis, teachers must understand the meaning of technology in the context of science and engineering teaching and learning. According to the NRC's *Framework* (National Research Council [NRC, 2012]), the difference between science and engineering/technology is that the purpose of science is to understand the natural world, whereas the purpose of engineering/technology is to modify the world to meet human needs. Technologies are products of engineering design processes just as scientific discoveries are products of scientific inquiry and argumentation. Therefore, this broad view of the definition of technology makes thinking about the learning objectives related to technologies imperative. If the learning objectives are related to the science and the use of technologies enhance that science objective, the lesson should use a tool/application integration approach to teaching. On the other hand, if the development or redesign of the technology through the use of the engineering design process is part of the learning objective (in tandem with the science content), a content integration approach should be used.

Video Example 12.2 Next Generation Science Standards

This video describes the importance of the *Next Generation Science Standards* (NGSS Lead States, 2013).

<https://youtu.be/MqOhLg7gfYQ>

An Increasing Need for Scientific and Engineering Literacy

The *Framework* and *NGSS* emphasize the importance of having students learn about science and engineering through integration of the knowledge of scientific explanations (i.e., content knowledge) and the practices needed to engage in scientific inquiry and engineering design. All citizens need to be scientifically literate in order to make informed decisions that affect our country's future. More than ever before, America's economic and environmental progress depends on the character and quality of the science education that the nation's schools provide. The *Framework* (NRC, 2012) emphasizes the need for students to directly experience scientific practices for themselves in order to fully appreciate the nature of scientific knowledge. Thus, the *Framework* recommends inquiry-based learning for primary scientific and engineering practices. The next section highlights technology for science practices.

Difficulties in Teaching K–8 Science

Science is a rapidly changing area, and teachers are constantly challenged to keep up with new developments in science content, tools, and methods. Elementary education teachers face an even greater challenge because they typically must teach all of the subjects that do not have dedicated teachers (i.e., reading, writing, mathematics, science, and social studies). Because they are licensed to teach all of these areas, elementary education teachers usually have much less initial preparation in science and mathematics content than secondary science teachers. As a result, teaching science for understanding at an early level becomes difficult due to teachers' lack of deep understanding of the discipline. One way to assist teachers in science is through

Box 12.1: Adapting for Special Needs

Adapting for Special Needs when Teaching Science and Mathematics

Some students with learning disabilities become discouraged in mathematics when they make mistakes in basic calculations involved in solving problems. In these cases, these students lose sight of the overall purpose of inquiry and problem solving, and their experience with these subjects suffers. The tools described here offer support that can be provided to an individual student or, better yet, provided to the entire class to support their problem-solving efforts as they pursue big ideas.

- Google Calculator—Complete calculations quickly and easily right within the browser
- Web Math—Enter a problem and view the step-by-step procedure for how the answer is derived
- Wolfram Alpha—A knowledge engine that not only computes simple and complex calculations but also contains links to related problem sets as might be found in a search engine

Appropriate technology materials, such as simulations and gaming software, have functions to help students with disabilities to be more successful in mathematics and science (Marino, Tsurusaki, & Basham, 2011). The following websites provide interactive, highly motivating mathematics and science activities.

- Filament Games—With support from the Institute of Education Sciences (IES) in the U.S. Department of Education, this group is developing a series of middle school life science games informed by current evidence-based educational practices and the Universal Design for Learning framework. These materials are especially intended to meet the needs of students with learning disabilities and other reading difficulties.
- ExploreLearning Gizmos—This website offers over 400 highly interactive simulations aligned to standards for students in grades 3–12.
- Brainquake—Mobile and web games to improve students number sense, disposition to mathematics, mathematics readiness, and mathematical proficiency (in particular, check out Wuzzit™ Trouble).
- DragonBox—Mobile game apps that allow students to play with digital manipulatives to deeply understand mathematical concepts through active play at their own pace.
- DreamBox Learning—Mathematics software solution that adapts to the individual learner, provides access and equity for English Language Learners, and personalizes instruction along the continuum of intervention to enrichment.

—Contributed by Dave Edyburn with additional content provided by Aran Glancy

increased professional development (PD). Online PD opportunities increase access for elementary teachers in this important area. For example, the Annenberg Learner website offers a collection of materials, such as video professional learning in self-paced or facilitated coursework for optional graduate credit, lesson plans, and interactives, that can be used in elementary science programs. BioEd Online and K8 Science, both developed by Baylor College of Medicine, offer online PD for teachers to access contemporary science materials for teaching. The National Science Teachers Association addressed this important need and has been offering many webinars for teachers to learn content and pedagogy. Also see the Adapting for Special Needs feature to see some recommendations for selecting science materials for students with disabilities.



Check Your Understanding 12.2

Technology Integration Strategies for Science Instruction

Multiple technology resources support the higher order thinking engagement that characterizes the science practices present in the NGSS. Technologies are more effective when students engage in higher order thinking skills (Polly, 2011). In order to foster these higher order thinking skills within science, the Biological Sciences Curriculum Studies (BSCS) research group has developed the 5E instructional model, which focuses on development of key cognitive 21st-century skills by engaging in scientific inquiry explorations and providing a framework for ways that technology can enhance science instruction. The model's five phases are (Duran, Duran, Haney, & Scheuermann, 2009):

- **Engagement**—Confront students with specific questions for the future inquiry.
- **Exploration**—Engage students in experiences in which they generate new ideas as they examine and explore the questions.
- **Explanation**—Provide teachers with opportunities to directly introduce the topic and for students to explain their understandings.
- **Elaboration**—Offer students opportunities to develop deeper understandings and apply the ideas to additional activities.
- **Evaluation**—Encourage students to assess their understandings and provide teachers opportunities to evaluate student progress.

During engagement in technology-rich and learner-centered activities, students explore, analyze, explain, and synthesize results from their inquiries in ways that deepen their understanding and help them make connections among the multiple disciplines. This section introduces several teaching and learning strategies with potential for alignment with the 5E instructional model to support higher-order thinking skills and gives examples of some of the technology resources that make them possible.

Involving Students in Scientific Inquiry through Authentic Online Citizen Science Projects

Authentic science not only involves having students “do” science, it also includes connecting science to their lives and life experiences. Involving students in active scientific investigations can improve their attitude toward science as well as their understanding of scientific concepts. The BSCS’s 5E instructional model supports the design of units that involve these scientific investigations. Some online projects are available that can

engage students by making them partners in scientific investigations. These **citizen science** projects give them experience with all aspects of the scientific approach: asking new and novel questions, setting up researchable hypotheses, collecting and analyzing data, communicating results, and receiving feedback to help interpret and refine results that map to the NGSS science practices. Scientists use a variety of technologies in their own work, and these citizen science projects use many of the same tools to teach the scientific process. Three such projects are described here.

GLOBAL LEARNING AND OBSERVATIONS TO BENEFIT THE ENVIRONMENT (GLOBE) PROGRAM The GLOBE Program is an environmental science project in which students investigate the weather, land cover, soil, and hydrology and record their observations at the GLOBE site. In effect, they become collaborators in a real scientific investigation. First, they take ground observations using technologies such as temperature **data loggers**, which are devices that record data over time with sensors, and **global positioning systems (GPS)**, a satellite-based, geographic location technology, as well as traditional technologies such as weather shelters and U-tube thermometers. Students record their data in a notebook and enter it into a database at the GLOBE site. Then they manipulate data with online graphing and visualization tools. The data can also be displayed in a graphic form, allowing students to look for patterns over time. To complete the process, students write up their results and post them to the GLOBE Student Research website. In the write-up, students report on their research questions, discuss their procedures, communicate their results using graphs and charts, and make conclusions. Once posted on the website, the report is peer reviewed by GLOBE participants.

PROJECT FEEDERWATCH Another program that involves students in real scientific investigations is Project FeederWatch from Cornell University, which provides teachers a bird identification key and instructions for stocking a bird feeder, gathering related data, and submitting the information to the site. This project provides numerous opportunities for using spreadsheet data and carrying out geographic information system analyses.

JOURNEY NORTH Journey North identifies itself as a citizen science project to connect children and scientists in real-life science research. The project engages students in a global study of wildlife migration and seasonal change. K–12 students share their own field observations with classmates across North America. They track the coming of spring through the migration patterns of monarch butterflies, robins, hummingbirds, whooping cranes, gray whales, bald eagles, and other birds and mammals; the budding of plants; changing sunlight; and other natural events. The database they help to create can be used to study factors such as climate change, migration, and soil and water conditions. The site also offers teachers dozens of lesson plans and activities to use with their students.

Involving Students in Scientific Inquiry through Virtual Experiences

Scientific inquiry can also be supported through a range of virtual experiences, including labs, simulations, 3-D models, and virtual reality, to provide a simulated online laboratory, field experiences, or content representations for students.

Video Example 12.3: You Can Work for NASA Today

This video explains how participating in GLOBE situates students as contributors to the National Aeronautics and Space Administration (NASA).

<https://youtu.be/QbEHu2ruQqQ>

VIRTUAL LABS Science laboratories are expensive for schools, and some are not able to afford the equipment or the materials needed for all students to conduct their own labs. Virtual labs provide students an opportunity to actively conduct a lab but in an online environment. This provides a low-cost opportunity to enhance students' learning of the science concepts. Virtual environments provide some advantages beyond physical environments because they can:

- Isolate scientific phenomena that are confounded in the physical environment
- Allow students to “see” unobservable phenomena
- Slow down time in an experiment
- Allow students to conduct multiple experiments quickly
- Provide adaptable guidance to students as they work

Application Exercise 12.1 The Value of Virtual Labs

Recent research suggests that virtual labs have at least the same or better learning gains as physical labs, and students have good attitudes toward virtual labs (Burkett & Smith, 2016). In their study comparing learning from simulated and in-person frog dissection, Akpan and Strayer (2010) found that the simulation group had higher achievement gains and better attitudes than the group that did a conventional dissection. In a two-year study on using physical and virtual labs in second-year chemistry, Pyatt and Sims (2012) found that students had similar content gains regardless of participation in virtual or physical labs. Students preferred good inquiry-based experiences whether virtual or physical. Research examining gesture-based systems (using a Kinect video game input sensor) for virtual laboratories in chemistry found that students learned key hand movements needed to conduct the same scientific investigation in a real lab (Jagodziński & Wolski, 2014). In another virtual lab developed for fifth grade students to learn about electric circuits, researchers discovered that students completing the lab virtually or physically both gained conceptual knowledge growth, but the virtual lab learners showed significantly higher conceptual gains (Tekbiyik & Ercan, 2015). de Jong, Linn, and Zacharia's (2013) review of the literature on physical versus virtual science labs suggests that both labs can meet the goals for investigation in science courses and both allow students to work on the practices of science (i.e., use tools, collect data, model data, etc.).

Virtual labs provide teachers and schools many possibilities to teach science to students that privilege hands-on, inquiry-based science. The use of virtual labs can be used alone or in combination with physical labs. Paying attention to the learning objectives set for students and weighing the advantages and disadvantages of each type of laboratory experience can help guide the implementation of virtual laboratories. The Global Online Science Labs for Inquiry Learning at School (Go-Lab) has a repository of online labs. Vfrog simulates the procedures to dissect a virtual frog.

VIRTUAL SIMULATIONS A **simulation** is a computerized model of real or theoretical systems designed to teach how the system works. Simulations are fully described in Chapter 5 as a function of instructional software, and most are available online. As instructional software, simulations contain sequenced content designed for learning. Learners using software simulations usually must choose tasks to do and the order in which to do them in order to explore how changing input variables impact outcomes within the simulated system. The simulations can represent physical things or processes, can slow down or speed up events that are difficult to understand in real-time, can teach procedures or sequences of steps, and can be situational problem-solving tasks. Following are some scientific simulations:

- **BeeSmart**—Simulates honeybees' hive-finding behavior, which represents a complex systems concept in which students can observe, hypothesize, and verify conjectures. This model uses the free software NetLogo, and there are hundreds of scientific and social science models in the NetLogo Models Library (Wilensky, n.d.).
- **SimAnimals**—A forest simulation in which users try to make animals and plants flourish, a process that represents years.
- **PhET Independent Simulations (University of Colorado)**—Provides simulations for physics, biology, chemistry, earth science, and mathematics learning in elementary, middle school, and high school

THREE-DIMENSIONAL (3-D) VIRTUAL MODELS 3-D models are made possible with sophisticated software that creates three-dimensional replicas of objects or locations. **Virtual manipulatives (VM)**, or replicas of real manipulatives that are accessed via the web (Li & Ma, 2010), are one of the most popular types of 3-D models. The National Center for Virtual Manipulatives at Utah State University has a large collection of these tools to support science and math topics, along with instructions for teachers on how to use them. Wang, Kenzie, McGuire, and Pan (2010) find that virtual manipulatives support inquiry learning. The Web-based Inquiry Science Environment (WISE) incorporates both virtual simulations and 3-D models into their instructional and learning resources.

VIRTUAL REALITY A multi-user virtual environment (MUVE) allows users' avatars to meet in web-based, 3-D VR environments on a computer screen. Users create an avatar to represent their digital presence; then they explore the digital world to connect and collaborate with others. Educational MUVes include Quest Atlantis where students from various physical locations use their avatars to solve various problems posed in educational scenarios. EcoMUVE is another virtual environment in which students learn about ecosystems. Chen et al. (2016) found that middle school students' interest in science increased with use of EcoMUVE.

Augmented reality (AR) refers to a combined hardware and software platform that creates a computer-generated environment in which a real-life scene is overlaid with information that enhances its uses. The National Science Foundation (NSF) has funded a project, EcoMOBILE, which allows students to examine ecological aspects of a local pond using phones and AR technology. A NASA mobile app, SpaceCraft 3D, uses AR for learners to explore spacecraft, including rockets and robots, that explore our solar system. The Interactive Periodic Table of Elements by POPAR allows students to virtually see which elements react with each other. Anatomy 4D is an app that allows augmented triggers that change gender or skin opacity, and hide some body systems, while showing others.

Supporting Specific Processes in Scientific Inquiry

Teachers do not always have time to commit to long-term projects that encompass the entire scientific process. However, various technologies described here can provide support for specific elements of the scientific inquiry process. See the Technology Integration Example 12.1 for an illustration of these principles in action.

LOCATING CONTENT INFORMATION TO INVESTIGATE SCIENTIFIC ISSUES AND QUESTIONS The web has become an indispensable tool for investigating important scientific questions. Science teachers and students have access to a number of exciting resources for teaching and learning science. For many of the science areas, teachers and students can access information from science-rich sources, such as NASA, and museums, such as the Exploratorium, a hands-on museum in San Francisco that provides interactive online exhibits and exhibitions (see Figure 12.2).

The NSF has funded the creation of digital libraries on science topics, as well an online portal to education and research on learning in science, technology, engineering,

Technology Integration

Example 12.1

TITLE: Think Before You Drink!

CONTENT AREA/TOPIC: Science

GRADE LEVELS: 4–6

ISTE STANDARDS•S: Standard 1—Empowered Learner; Standard 3—Knowledge Constructor; Standard 5—Computational Thinker; Standard 6—Creative Communicator; Standard 7—Global Collaborator

NGSS SCIENTIFIC AND ENGINEERING PRACTICES: Ask questions (S&EP1); plan and carry out investigations (S&EP3); analyze and interpret data (S&EP4); construct explanations (S&EP6); communicate information (S&EP8).

DESCRIPTION: Students work in small groups to gather water samples from various locations that have consumable drinking water and make predictions about whether the samples are safe to drink. Students use probeware to gather data on various aspects of water quality and enter the data into a spreadsheet for analysis. Each group presents results in a presentation (using a choice of tools such as presentation software) to the rest of the class. If any water proves to be unsafe or of questionable quality, the students work as a whole class to write a letter to the business or city about what needs to be changed to improve the water quality.

SOURCE: Based on a concept in the Vernier lesson plan by Erin Van Lue, Lesley Drinkwine, and Mark Alexander. <http://www3.nd.edu/~nismec/vernier.htm>.

and mathematics education topics. One of the NSF-funded libraries is the Digital Library for Earth System Education (DLESE). It is a community of educators, students, and scientists working to improve teaching of and learning about the earth system, including agriculture, geography, oceanography, and other earth sciences at all levels. DLESE provides access to a number of collections of educational and scientific resources. Digital libraries provide a starting point for the investigation of scientific questions. Teachers can review strategies for searching for online content in Chapter 6.

COLLECTING DATA Data collection and archiving are important parts of the scientific inquiry process. Science bases its conclusions on data, and a number of tools are available for students' data collection and archiving that make data collection and analysis more manageable. As discussed in the opening Hot and Cold Data, the calculator or computer-based laboratory (CBL or probeware) is an ideal tool for middle school through high school science because it provides active hands-on science through a combination of multiple probeware sensors and data loggers for gathering real-time

Figure 12.2 Exploratorium Website

SOURCE: © Exploratorium, www.exploratorium.edu. Reprinted by permission.



data for experiments and graphical analysis. CBL sensors collect data, and the data that can be downloaded to a computer or calculator and then manipulated in a spreadsheet, such as Microsoft Excel or Google Sheets. Archiving spreadsheet data can be used at another time or compiled for long-term investigations. Vernier probes and data analysis systems are commonly used in science classrooms. Using today's tools, students do not even have to be in the same location as the data being collected. They can collect data from remote sensors or from webcams set up to observe phenomena. Quillen (2011) describes one such activity in which students operate a Geiger counter in Queensland, Australia, to measure how the intensity of radiation changes with distance.

VISUALIZING DATA AND PHENOMENA A number of visualization tools allow students to see representations of data and phenomena that may be difficult to observe directly. These include simulations that help students see illustrations of macroscopic phenomena (e.g., phases of the moon or butterfly metamorphoses), which usually occur too slowly to observe processes, and microscopic or other phenomena that would otherwise be difficult or impossible to observe (e.g., molecular structure or parts of cells). In the past, students have learned from images or sped-up videos of some of these phenomena. Computer simulations differ from illustrations or videos in that students can manipulate elements in them and see the result. One resource for simulations is the Physics Education Technology (PhET) Independent Simulations.

Modeling tools make it possible to rotate and examine structures from multiple viewpoints to help students understand them. These tools also emulate the way scientists work in real environments. For example, meteorologists regularly show computer-generated visualizations on television to help explain weather phenomena. City planners use GIS modeling to plot population growth. Students can use data and analysis tools, such as Microsoft Excel, Google Sheets, and Tableau, to create graphical representations of data, such as timelines, charts, and graphs to visualize mathematical concepts or engage in inquiry tasks. Students build an understanding of the persuasive power of information or pattern discovery in data.

ANALYZING DATA Analyzing data can be done with a number of existing programs that come standard on computers. Spreadsheets allow data to be entered and analyzed using simple statistics or algorithms supplied by students. In the GLOBE project, MultiSpec software provides students with the ability to identify land cover types on a LandSat image. GIS software allows students to analyze factors in an image by removing or adding attributes and looking for connections among attributes.

COMMUNICATING RESULTS Once data are analyzed, student scientists write up the results and submit them for peer and teacher review using productivity tools for writing and representing data. In addition to graphs and visualizations, student scientists can use images from digital cameras and other digital instruments to record and compare and contrast data over time. The web also provides a medium for communication among students who are collaborating in groups or across classrooms. Data can be shared between and among students around the globe with cloud computing. Classroom teachers can also have professional scientists interact with students in their classroom via email, blogs, or by participating in **webcasts**, which are live video broadcasts of an event sent over the web. See Table 12.1 for the Top Ten Must-Have Technologies for STEM, many of which support scientific inquiry.

Supporting Science Skills and Concept Learning

Although hands-on science remains the major science instructional strategy, digitally-enhanced textbooks are becoming more available. Schaffhauser (2016) found that educators appreciated Discovery Education's high level of interactive supports, such as streaming media, and Delta Education's Full Option Science System (FOSS) for its NGSS-aligned, project-based instructional approach with digital resources for teachers and students.

Table 12.1 Top Ten Must-Have Technologies for STEM Instruction

Technology	Description
Desmos	Desmos is a free online or iPad graphing calculator. Students can save their graphs, equations, tables, and pictures on it. The tool is available in over 20 languages.
EcoLearn	EcoLearn is an educational research group at Harvard that offers a suite of immersive technologies to support learning about the environment (ecoMUVE, ecoMOBILE, ecoXPT, and ecoMOD). These technologies are virtual environments that are appropriate for students in grades 6–12.
GeoGebra	GeoGebra is a dynamic, interactive, online mathematics software package for learning in STEM that is appropriate for upper elementary through high school students. GeoGebra includes a dynamic 2-D and 3-D geometry environment with a spreadsheet, a computer algebra system including statistics and calculus tools, and scripting.
G Suite	The free G Suite collaboration tools allow for multiple user collaborations. These have most of the functionality needed in K–12 education and are easy to use.
Notability	Notability is an iOS/OSX app that allows students to take multimedia notes and perform PDF annotations. Notability enables students to take notes with handwriting by their finger or a stylus, type notes, highlight texts, import PDFs and other images, audio record notes, link audio recordings to written notes, share documents, and sync notes to Dropbox, Google Drive, or Box.
Scratch 2/Scratch Jr.	Scratch 2 (web-based) and Scratch Jr. (iPad or Android app) are tools that allow students of all ages to learn to code. It is a block-based computer programming language that allows students to develop and share interactive stories, animations, and games.
Tinkercad	Tinkercad is a free, 3-D modeling computer-aided design (CAD) software program appropriate for educators and hobbyists. Tinkercad allows for translation of designs to be actualized through 3-D printing. It is a fun and fairly intuitive program for students to make their design ideas come to life.
TinkerPlots	TinkerPlots is an interactive data visualization and modeling tool for students in upper elementary grades through high school. TinkerPlots is an appropriate tool for any subject in which data need to be analyzed. It allows students to create colorful visual representations that allow for patterns in the data to emerge.
Vernier Interfaces and Probeware	Vernier interface and probeware sets provide students active hands-on science, engineering, and mathematics learning through a combination of multiple probeware sensors and data loggers for gathering real-time data for experiments and graphical analysis. These are appropriate for students in upper elementary grades through high school.
WISE: Web-based Inquiry Science Environment	The WISE: Web-based Inquiry Science Environment is a digital learning platform that allows students to observe, analyze, conduct experiments, and reflect on their learning as they work within the WISE projects. Projects are mostly written for middle school students, but a few of them are appropriate for high school. WISE includes the student learning environment as well as many course management tools and assessments from which teachers can choose.

Tremblay (2010) discussed an innovative way to check students' concept learning after a science lesson by using **student response systems (SRS)** (i.e., **clickers**). The teacher poses content questions in an online survey format using a dedicated SRS technology or online survey. Students' responses populate a graph, revealing their understandings.

Accessing Live or Archived Scientific Information

The web has opened up a world of tools and materials for teachers and students to use. One example of the opportunities provided by these unique tools is the ability for teachers and students to use a remote online telescope to carry out various investigations, using resources such as:

- **Skynet University (University of North Carolina)**—Get space images. (Requires completion of a course prior to access.)
- **Slooh: Space for Everyone**—Watch live telescope feeds from around the world.
- **Observing with NASA**—Examine target images of space objects and set parameters for an image to be taken. Images are sent within 48 hours.

The web is also an unlimited source of data for classroom experiments, investigations, camps, and competitions and of up-to-date science information. Science knowledge changes faster than most school libraries can keep up. For the latest information on space, students can access NASA; for the weather, National Oceanic and Atmospheric Administration (NOAA); and for medicine, the National Institutes of Health (NIH). Most of these sites provide content targeted for teachers and students. The National

Video Example 12.4 Importing Animal Photos for Presentations on Endangered Species

In this video, an elementary school teacher appreciates the fact that her students can access and use real photographs of endangered species in their learning and presentations.



Academy Press (NAP) has a wide variety of current, useful publications in science and science education.

Teacher Growth in Technology Integration Strategies for Science

In the future, teachers should be able to expand and strengthen their capabilities to understand emerging scientific issues, generate possible solutions, and address technology integration in science. Review the rubric in Table 12.2, which measures a teacher's progress in integrating technology in science.

Teachers should become involved in science professional organizations, such as the National Science Teachers Association (NSTA) and the American Association for the Advancement of Science (AAAS). Teachers should follow policy developments, such as changes in NGSS. These resources, along with science organizations like NASA and NOAA offer teaching resources, advocacy ideas, professional development, and collaboration opportunities. Teachers can also use the web for assistance seeking content knowledge and for professional learning opportunities that may not be available locally. Exchanging ideas and teaching strategies with other teachers in learning communities such as in Twitter can be beneficial. The following Twitter hashtags may be useful:

- #stem
- #science or #scichat
- #pbl or #pblchat
- #inquiryed
- #physics
- #geology
- #anatomy
- #ecosystems
- #genetics
- #chemistry
- #biology

Table 12.2 Rubric to Measure Teacher Growth in Technology Integration for Science

Part I: Teachers' Knowledge of Science Issues and Challenges			
	Basic Knowledge (1–2 points)	Intermediate Knowledge (3–4 points)	Advanced Knowledge (5–6 points)
	I can articulate the nature of the issue/challenge.	I can both articulate the nature of the issue/challenge and identify some of the possible ways to address it.	I can articulate and implement my own plan for addressing the issues/challenges in my own teaching.
Accountability for standards in science	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Increased need for scientific and engineering literacy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Difficulties in teaching K–8 science	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Part II: Teachers' Technology Integration Strategies for Science			
	Basic Knowledge(1–2 points)	Intermediate Knowledge (3–4 points)	Advanced Knowledge (5–6 points)
	I can describe the strategies and identify technologies to carry them out.	I have designed at least two activities based on these strategies to enhance my teaching and my students' learning.	I have designed and implemented my own plan for integrating these strategies throughout my curriculum to enhance my teaching and my students' learning.
Involving students in scientific inquiry through authentic online citizen science projects	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Involving students in scientific inquiry through virtual experiences	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Supporting specific processes in scientific inquiry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Supporting science skills and concept learning	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Accessing live or archived scientific information	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Teacher growth in integration strategies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Total Points	of 54 possible points		

Application Exercise 12.2 Technology Integration Strategies for Science**Check Your Understanding 12.3**

Issues and Challenges in Engineering Instruction

Because the *Framework for K–12 Science Education* (National Research Council [NRC], 2012) calls to add engineering design into science education at a level that is as prominent as scientific inquiry, there has been a push to include engineering in the K–12 curriculum. Issues that affect technology integration with engineering are highlighted in this section.

The Relationship between Engineering and Technology

Engineering at its core is a way of approaching the purposeful development and refinement of relevant technologies for a task. In contrast to science, which is the study of the natural world, engineering is concerned with the human-designed world. Technologies are the end result of an engineering design process. This means that if a focal area under study is not part of the natural world (i.e., it would not be here if humans were not on the Earth), it falls under the definition of a technology. This book is primarily focused on educational technology integration in the classroom, but technology from an engineering standpoint does not need to have electricity or a computer chip. Pencils, eye glasses, houses, airplanes, hammers, and mobile phones are all technologies and are the results of human-powered, engineering design processes. The processes that engineers use to work on these technologies is called *engineering design*.

Engineering integrates much information from many different disciplinary areas. Engineering has many diverse facets that students need to understand if they are to have a comprehensive engineering education in their K–12 experience. Engineering design is the heart of the discipline of engineering, but many other aspects of engineering are needed to understand the ways in which engineers work. Moore, Glancy, et al. (2014) developed a working definition of engineering specifically aimed at engineering in K–12 schools. The facets of engineering that contribute to a well-rounded view of engineering include the following:

- **Complete processes of design**—Students must participate in complete processes of engineering design, including problem scoping and solution generation. Problem scoping is the process of understanding the landscape of the problem at hand and includes the following: define the problem and learn about the problem stages. Solution generation is the process of making evidence-based decisions to developing a solution to the problem. This includes the following: plan for the stages of a solution, implement a solution, test a solution, and evaluate a solution.
- **Problem scoping**
 - **Define the problem**—Which includes answering such questions as:
 - What is the problem?
 - What are the criteria (requirements) and constraints (limits)?
 - Who is the client (who has hired you to do the work)?
 - Who is the end user (who will use the end product or process)?
 - **Learn about the problem (or problem background)**—This includes learning about the knowledge and tools that will help solve the problem. This process should include considerations such as what has been done to solve similar problems, what materials are possibilities for this solution, and what other information is needed. It is also necessary to think about how the designer will measure the effectiveness of the solution and how to measure improvement over multiple iterations of a solution.
- **Solution generation**
 - **Plan for a solution**—This involves developing many ideas (called *ideation*) for solutions that have the potential to solve the problem and then making carefully executed decisions on which solution to try or whether to combine ideas into a new idea. This includes communicating the design as it stands to (1) clearly communicate the idea(s) using notebooks, blueprints, schematics, cost sheets, storyboards, etc., (2) include measurements, materials, colors, how things fit together, and the order in which things should be done, and (3) meet the criteria and constraints as best as possible. In this stage, engineers consider trade-offs carefully.
 - **Implement a solution**—This stage includes the use of the design plans to create a prototype (a testable model) or a process (a series of steps or actions that must

be followed in order to reach the goal). In this process, engineers consider risk and how to optimize the solution by again considering trade-offs. The solutions created are technologies.

- **Test a solution**—This includes using fair tests to learn about the performance of the prototypes, processes, or final designs.
- **Evaluate a solution**—This involves using the test results to make decisions about the solution, and iteration is often necessary. Evaluations ask:
 - Does it solve the problem criteria and stay within the constraints?
 - Are there new things that need to be learned in order to better solve the problem?
 - Should other ideas be tried that were previously brainstormed or develop new ideas to achieve a better solution?
- **Apply science, engineering, and mathematics knowledge**—The practice of engineering requires the application of science, mathematics, and engineering knowledge. Engineering education at the K–12 level should emphasize this interdisciplinary nature.
- **Engineering thinking**—Students must learn to be independent and reflective thinkers capable of seeking out new knowledge and learning from failure when problems arise. Engineering requires other ways of thinking beyond design called *engineering habits of mind*, which includes systems thinking, creativity, optimism, perseverance, and innovation.
- **Conceptions of engineers and engineering**—K–12 students not only need to participate in engineering processes, but also to understand what engineering is and what an engineer does.
- **Engineering tools, techniques, and processes**—Students studying engineering need to become familiar with and proficient in the processes, techniques, skills, and tools that engineers use in their work. Examples of these include processes such as manufacturing and production; techniques such as DNA isolation; skills such as using Excel, creating flowcharts, and drawing schematics; and tools such as hammers, rulers, calipers, calculators, CAD software.
- **Issues, solutions, and impacts**—To solve complex and multidisciplinary problems, students need to be able to understand the impact of their solutions on current issues and vice versa.
- **Ethics**—Students should consider ethical situations inherent in the practice of engineering.
- **Teamwork**—Students should develop abilities to participate as a contributing engineering team member.
- **Communication**—Communication is the ability of a student to effectively take in information and to relay understandings to others in an engineering context.

These indicators of a quality K–12 engineering education can guide how teachers, curriculum developers, and policy makers think about and plan for engineering in the classroom.

Accountability for Teaching Engineering

Engineering in K–12 is relatively new to school curriculum, and at this point, there are some questions as to where engineering ought to reside. NGSS suggests that engineering should be part of the science education curricula; other entities promote engineering within the technology education curricula. It is easy to support both of these views. Engineering is a great integrator and provides a way to allow students to anchor their science and mathematics learning within a context and challenge that will make the content useful. Yet the science teachers implementing engineering to teach science

content are responsible only for teaching engineering design, and mathematics teachers using engineering have no responsibility to teach engineering at all. On the other hand, technology teachers tend to follow the Standards for Technological Literacy (STL) produced from the International Technology and Engineering Education Association (ITEEA), which provide a comprehensive learning of technology and technological impacts. This includes more areas of engineering than the other STEM standards including engineering design and how technologies are developed and manufactured. It is good for students to see engineering in all of these settings and in different formats in order to have a well-rounded view of the discipline of engineering.

Engineering appears in some meaningful way in all of the most commonly used STEM standards. The NGSS standards include engineering both as performance expectations (for middle school) and as learning goals (for all students within the science and engineering practices). Engineering included in these standards is focused only on engineering design; the NGSS Appendix I states that this focus on engineering design was a purposeful decision and that engineering design is what is necessary for a scientifically literate citizen (NGSS Lead States, 2013). The STL's view of engineering and what should be taught is more comprehensive. However, the emphasis on understanding technologies is more at the forefront than the engineering in these standards. The STL comprehensively address several of the facets of engineering for K–12 put forth by Moore, Glancy, et al. (2014) including the *complete process of design; engineering tools, techniques, and processes; and issues, solutions, and impacts*. Other facets that are alluded to in the STL but not directly within the standards include *applying science, engineering, and mathematics knowledge; engineering thinking; teamwork; and communication*, which means that educators can but are not required to use these ideas about engineering. The STL address *ethics* as it relates to technology use, not the process for which it was developed (i.e., the engineering decisions needed). The STL do not directly address *conceptions of engineers and engineering*. The Common Core State Standards for Mathematics (CCSS-M) have no explicit requirements for engineering. However, the Standards for Mathematical Practice within the CCSS-M include references to engineering, such as the Model with Mathematics standard, which discusses an example in which students might use geometry ideas to solve a design problem. Design shows up in the content standards too, when referencing modeling within that content. Even with all three standards highlighting engineering in some meaningful way, none focuses on what it means *to be an engineer* or what it means *to engineer*.

Through all three areas, students have the opportunity to have a comprehensive engineering education in their K–12 schooling. All students must take mathematics and science and, therefore, should be exposed at the very minimum to engineering design. Many states also require students to take at least some technology education, which has a more well-rounded take on engineering as a discipline. The engineering design ideas highlighted in the NGSS and alluded to in the CCSS-M are not enough to provide students with the technological literacy needed in today's world. Technology education standards provide the missing pieces to the story of engineering, but the typical practice of focusing on the tools of engineering rather than the processes of engineering means students may still be missing out. Teachers have the ability to help bridge these gaps if they take a comprehensive view of STEM integration as a means to help students learn engineering principles.

Difficulties in Teaching K–12 Engineering

There are many difficulties in teaching engineering in the K–12. First, mathematics, science, and technology teachers have some responsibility to help students understand some facets of engineering, but there is no one discipline that ensures that students have a comprehensive understanding of engineering. This means that students will get parts of their engineering education from different areas. Therefore, administrators

and lead teachers need to attend to the engineering learning objectives of students in their schools across curricular boundaries to ensure that students achieve engineering understanding.

Another difficulty in teaching engineering is that most K–12 teachers have not been comprehensively exposed to engineering in their own preparation. This means they need to participate in continuing education for professional learning in this area.

Because there are no comprehensive stand-alone engineering standards, engineering must necessarily be integrated into other subjects. Yet, because engineering can serve as the connector to all of the other subjects, this allows for teachers to use engineering as a pedagogy to teach their core content whether it be mathematics, science, or technology. However, this also means that, in order to make engineering an enduring understanding, teachers must give engineering the same treatment as the content area they teach—at least for some amount of time in the year. As the standards for each of the areas are already fairly packed, teachers may let the engineering ideas fall away in order to focus on the other content. STEM integration is a good pedagogical strategy to overcome this issue.



Check Your Understanding 12.4

Technology Integration Strategies in Engineering Instruction

Engineering in the classroom is likely to integrate science, mathematics, and technology; consequently, many applicable educational technology tools are shared across the disciplines. For example, all data analysis tools in science and mathematics are potentially relevant in engineering settings. This section introduces the educational technology integration strategies and examples that are unique to engineering with the potential for student engagement in high-level engineering processes. Educational technology integration in the engineering-focused lesson or classroom should always map to the focal learning objectives.

Developing Technical Communication of Engineering Thinking and Design

Engineers communicate their ideas and designs to themselves, each other, their clients, and the end users through notebooks, sketches, diagrams, schematics, client reports, presentations, and explicit demonstrations. The field of engineering places high importance on verbal communication, and poor communication skills are often a barrier to success in engineering (Riemer, 2007).

Thus, students must use notebooks to systematically make observations, collect data, record analysis results, capture their thinking, and document design trials and decisions for design challenges (Hill, 2006). Digital note-taking tools, such as Notability and Evernote, are ideal for engineering notebooks in which students can type notes, write and draw with a stylus, insert photos or screenshots, and work with imported PDF scans. Within their notebooks, students can plan processes with flow chart or mind-mapping tools, such as Cmap or ClickCharts. Students also represent their design ideas that could include 2-D and 3-D models. **Computer-aided design (CAD)** software applications, such as Tinkercad and SketchUp, support the development of these types of representations. Having students work in 2-D and 3-D modeling and CAD software supports the development of student spatial thinking and reasoning abilities (National

Research Council, 2006; Onyancha, Derov, & Kinsey, 2009). Other communication tools, such as word processors (e.g., Word, Pages, Google Docs), presentation software (e.g., PowerPoint, Keynote, Prezi, Google Slides), video development software (e.g., iMovie, Camtasia), assist students in communicating their designs.

The benefits of students' engineering communication activities include:

- Providing opportunities to communicate engineering ideas in technical and non-technical ways
- Engaging in the work processes of engineers
- Supporting the use of multiple representations to communicate engineering ideas
- Helping to understand the need for language literacy in STEM careers

Engaging Students in Engineering Thinking through Makerspaces

There is a movement in the United States to incorporate **makerspaces**, or informal workshop environments, into K–12 schools or classrooms. Makerspaces provide a space and some tools with which students design, create, and engage in self-expression by making things. Martin (2015) suggests makerspaces should include:

- Access to technologies such as 3-D printers, laser cutters, programmable robots, single-board microcontrollers, sewing machines, tools for prototyping electric circuits, and hand tools, but also can include found objects such as cardboard, tape, and Styrofoam
- Goals based on the needs and interests of the community it serves
- A maker mindset, which means a commitment to playfulness, growth, failing as a positive, and collaboration

Makerspaces provide students with the ability to engage in problem solving and design thinking without the constraints of a typical classroom project. With appropriate scaffolding from the teacher, makerspaces can encourage STEM integration through real-world contexts and problems (Hira, Joslyn, & Hynes, 2014). Makerspaces allow students to pursue their own design ideas by giving them opportunities to explore them without being constrained by someone else's requirements and by encouraging higher-order thinking in a choice-based environment. Because students can explore solutions to problems of their own choosing, explorations within makerspaces may bolster interest in engineering and, thus, potentially broaden students' pathways to enter engineering fields (Jordan & Lande, 2013).

Engaging Students in Engineering through Programming, Robotics, and Simulations

Many digital technological tools engage students in engineering thinking. Programming, computing, and **computational thinking** are gaining traction in K–12 education, and they fit naturally within the engineering domain, by offering students experience with computing and engineering and encouraging students to think about engineering careers.

Students can engage with coding apps and web resources such as Scratch 2, Scratch Jr., and Code.org, as well as robotic toys that require programming, such as Code & Go Robot Mouse, Dash and Dot, and Ozobot. Curricular resources for robotics are available (e.g., NASA's Robotics Alliance and LEGO Engineering), which have become an increasingly popular strategy for engaging students in problem solving and getting them interested in engineering principles and careers. Nugent, Barker, Grandgenett, and Adamchuk (2010) found that an intensive 40-hour robotics, GPS, GIS camp had great impact on students' learning of science content, and even a three-hour experience

Technology Integration

Example 12.2

TITLE: Designing a Mouse Challenge

CONTENT AREA/TOPIC: Engineering/Computational Thinking

GRADE LEVELS: 1-4

ISTE STANDARDS•S: Standard 1—Empowered Learner; Standard 4—Innovative Designer; Standard 5—Computational Thinker; Standard 6—Creative Communicator; Standard 7—Global Collaborator

NGSS SCIENTIFIC AND ENGINEERING PRACTICES: Ask questions (S&EP1); plan and carry out investigations (S&EP3); analyze and interpret data (S&EP4); construct explanations (S&EP6); communicate information (S&EP8).

CCSS-M MATHEMATICAL PRACTICES: Make sense of problems and persevere in solving them (SMP1); Model with mathematics (SMP4)

STL STANDARDS: Engineering design (STL9); The role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving (STL10); Apply the design process (STL11)

DESCRIPTION: Students work in pairs to understand the game, develop precoding understandings, and design a new game for other students. The Code & Go Robot Mouse Activity Set has multiple representations and translations among the representations of coding for the learner. The representations embedded in the game are the game board and pieces (concrete manipulative representations), the programming cards (flowchart representation), the map of the board (pictorial representation), the buttons on the mouse to push to program it (programming representation), and students talking about their planned code (pseudocode). First, have students play the Robot Mouse game as it was designed to be played. Next, set up stations that have the students go from one representation to another. For example, have students look at a set up game board and then draw the map that would represent that board (concrete manipulative to pictorial representation translation). Finally, have students design new mouse challenges for other students in the class by developing a map that has the board set up and the goal for the mouse pictured.

SOURCE: Based on the Code & Go Robot Mouse Activity Set from Learning Resources (<https://www.learningresources.com/product/learning+essentials--8482--stem+robot+mouse+coding+activity+set.do>) and new ways to engage students with the activity developed by Tamara Moore.

modeled on the same camp had improved students' attitudes toward science and technology and made them excited about learning more. Finally, students can engage in simulations and virtual worlds that encourage engineering design and engineering thinking. One such simulation software, Energy 3D, has students design netzero energy buildings as CAD-like prototypes and allows for testing and analysis within the software package. The Technology Integration Example 12.2 calls on teams of students to play a game, code, and design a new game with the Code & Go Robot Mouse.

Supporting Students in Learning to Work on Engineering Teams

An important aspect of K–12 engineering education is developing a student's ability to participate as a contributing team member. This includes providing scaffolding to allow students to take on different roles within the team. Benefits that emerge from effective teamwork include giving students ways to truly work together in a manner that they can see each other's work as they work on a different aspect of a project and simulating how engineers collaborate in the real world.

Teams of two to four students should work together toward a common goal. This may also include aspects of cooperative learning that focus on collaborative work as students build effective teamwork and interpersonal skills necessary for it (Smith, Shepard, Johnson, & Johnson, 2005). Good collaboration includes individual accountability. The following tools allow for all members of a team to be working together at the same time:

Video Example 12.5 High School Students Work with Robots

In this video, a high school student talks about what he learned and experienced from his collaborative work on a team to build a robot.



- G Suite tools (e.g., Google Docs, Google Sheets, Google Slides)
- Cloud storage applications (e.g., Google Drive, Dropbox)
- Group messaging software and apps (e.g., GroupMe, Bonfyre)

Application Exercise 12.3 Technology Integration Strategies for Engineering

Teacher Growth in Technology Integration Strategies for Engineering

In the future, teachers should expand and strengthen their capabilities to understand emerging issues, generate possible solutions, and address technology integration in engineering. Review the rubric in Table 12.3, which measures a teacher's progress in integrating technology in engineering.

In addition to resources from this chapter, teachers should become involved in engineering professional organizations, such as the ITEEA, a professional association for technology education teachers who teach a curriculum focused on engineering and design. Teachers should follow policy developments, such as changes in the standards—NGSS, STL, and CCSS-M—which may position engineering differently in the content areas.

LinkEngineering.org offers teaching resources, advocacy ideas, professional development, and collaboration opportunities within the LinkEngineering.org community and was created in collaboration with major organizations such as the National Academy of Engineering, Achieve, American Society for Engineering Education (ASEE), ITEEA, and NSTA. TeachEngineering offers classroom-tested engineering curricular aligned with ITEEA, NGSS, and CCSSM standards. Commercially-based websites also offer engineering or STEM integration curricula and/or kits including the following:

- Engineering is Elementary
- STEM in Action

Table 12.3 Rubric to Measure Teacher Growth in Technology Integration for Engineering

Part I: Teachers' Knowledge of Engineering Issues and Challenges			
	Basic Knowledge (1–2 points)	Intermediate Knowledge (3–4 points)	Advanced Knowledge (5–6 points)
	I can articulate the nature of the issue/challenge.	I can both articulate the nature of the issue/challenge and identify some of the possible ways to address it.	I can articulate and implement my own plan for addressing the issues/challenges in my own teaching.
The relationship between engineering and technology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Accountability for teaching engineering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Difficulties in teaching K–12 engineering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Part II: Teachers' Technology Integration Strategies for Engineering			
	Basic Knowledge (1–2 points)	Intermediate Knowledge (3–4 points)	Advanced Knowledge (5–6 points)
	I can describe the strategies and identify technologies to carry them out.	I have designed at least two activities based on these strategies to enhance my teaching and my students' learning.	I have designed and implemented my own plan for integrating these strategies throughout my curriculum to enhance my teaching and my students' learning.
Developing technical communication of engineering thinking and design	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Engaging students in engineering thinking through makerspaces	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Engaging students in engineering through programming, robotics, and simulations	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Supporting students in learning to work on engineering teams	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Teacher growth in integration strategies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Total Points	of 48 possible points		

- KidWind
- Engineering by Design
- Project Lead The Way

The following project-based websites also offer engineering or STEM integration curricula:

- PictureSTEM
- STEMTeachingKits
- EngrTEAMS
- EngineerYourWorld

Teachers can also use the web for assistance when seeking content knowledge and for professional learning opportunities that may not be available locally. Exchanging ideas and teaching strategies with other teachers in learning communities such as in Twitter can be beneficial. The following Twitter hashtags may be useful:

- #engineer or #EngineeringEducation
- #design
- #computerscience or #programming #code #coding
- #robotics or #robots

**Check Your Understanding 12.5**

Issues and Challenges in Mathematics Instruction

Issues that impact technology integration in mathematics are similar to those in science. The appropriate role for technology in helping to meet educational standards for mathematics is the focus of this section.

Accountability for Standards in Mathematics

Mathematics and technology have a unique relationship as highlighted in the Common Core State Standards for Mathematics (CCSS-M) (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), which emphasize the essential role of technology in learning mathematics through the Standard of Mathematical Practice 5—Use Appropriate Tools Strategically. This requires educators to reconsider what and how mathematics can be taught and learned. In its position statement on technology, the Association of Mathematics Teacher Educators (2015) stated that students have to be better prepared to use technology efficiently and fluently, both so they can learn mathematics better and apply what they learn in the workplace. Thus, it is not surprising that efforts to reform teaching and learning in mathematics has been at the center of the national standards movement. Technology provides many opportunities to build students' conceptual knowledge of mathematics as well as to connect their learning to problems found in our world.

The CCSS-M (National Governors Association, 2010) redirect the curriculum description for what students should know and be able to do in mathematics. In accordance with this move, the NCTM noted in a position statement (National Council of Teachers of Mathematics, 2013) that the Common Core State Standards provide a foundation to develop mathematics curricula, instruction, and assessments that strengthen understanding, reasoning, and skill fluency and ultimately better prepare students for college and careers. The CCSS-M standards begin with eight Standards for Mathematical Practice (SMP) for all grades K–12 describing what mathematically proficient students are able to do:

- SMP1. Make sense of problems and persevere in solving them
- SMP2. Reason abstractly and quantitatively
- SMP3. Construct viable arguments and critique the reasoning of others
- SMP4. Model with mathematics
- SMP5. Use appropriate tools strategically
- SMP6. Attend to precision
- SMP7. Look for and make use of structure
- SMP8. Look for and express regularity in repeated reasoning

Focusing on these recommendations for student engagement in mathematical practices challenges teachers to redesign their mathematics lessons around at least one if not more of these practices as students explore and learn mathematical ideas. For example, when students design a spreadsheet for solving a mathematics problem, they are engaged in the following: reasoning abstractly as they enter formulas (SMP2), constructing viable arguments (SMP3) in defense of their spreadsheet designs,

Table 12.4 Domains and Conceptual Categories for CCSS-M

Domain/Conceptual Category	K	1	2	3	4	5	6	7	8	High School
Counting and Cardinality	X									
Operations and Algebraic Thinking	X	X	X	X	X	X				
Number and Operations in Base Ten	X	X	X	X	X	X				
Number and Operations—Fractions				X	X	X				
Ratios and Proportional Relationships							X	X		
Measurement and Data	X	X	X	X	X	X				
The Number System							X	X	X	
Expressions and Equations							X	X	X	
Number and Quantity										X
Algebra										X
Functions									X	X
Modeling										X
Geometry	X	X	X	X	X	X	X	X	X	X
Statistics and Probability							X	X		X

accurately displaying the mathematics of the problem (SMP1) as they use the structure in the spreadsheet design (SMP7) that uses repeated reasoning (SMP8), and ultimately defending their use of the spreadsheet as an appropriate tool for solving the problems (SMP5) as they model the ideas using mathematics (SMP4).

The CCSS-M serve as a primary resource and guide for those making decisions that affect the mathematics education of students. The standards add to mathematical practices by describing the mathematics content that students should understand in their study at each grade level, kindergarten through high school. The standards are organized in multiple domains for each grade level through grade 8. High school standards are then organized in conceptual categories providing a comprehensive view for high school mathematics. The content domains and conceptual categories are described in Table 12.4.

NCTM states that when the CCSS-M are properly implemented, they will both support students' access to mathematics skills and enhance their learning of them. The ultimate goal is to be able to apply mathematical concepts in both their workplace and everyday activities. NCTM's support continues to direct educators' attention to its *Principles and Standards* document (2000) for prekindergarten through grade 12. Its content standards are described in five categories from which most of the domains and conceptual categories of the CCSS-M have been drawn:

1. Numbers and operations
2. Algebra
3. Geometry
4. Measurement
5. Data analysis

NCTM also recommends five process standards that are reasonably linked with the Common Core Mathematical Practices as shown in Table 12.5.

Table 12.5 Linking the NCTM Process Standards with the CCSS-M Mathematical Practices

NCTM Process Standards	Linked with CCSS-M Mathematical Practices
Problem Solving	SMP1. Make sense of problems and persevere in solving them.
Reasoning and Proof	SMP2. Reason abstractly and quantitatively. SMP3. Construct viable arguments and critique the reasoning of others. SMP7. Look for and make use of structure. SMP8. Look for and express regularity in repeated reasoning.
Communication	SMP3. Construct viable arguments and critique the reasoning of others. SMP6. Attend to precision.
Connections	SMP7. Look for and make use of structure.
Representations	SMP4. Model with mathematics. SMP5. Use appropriate tools strategically.

SOURCE: Reprinted by permission from *Standard Principles for School Mathematics*. Copyright © 2000 by The National Council for Teachers of Mathematics/NCTM. All rights reserved.

Challenges in Implementing the Common Core State Standards for School Mathematics

The mathematics education community has actively supported the implementation of the NCTM's *Principles and Standards* since 2000, effectively influencing the content in current textbooks. Yet critics have challenged that the current curriculum is broad in scope of topics but demands minimal performance in any one topic. Critics say that this results in lower mathematics performance of U.S. students on internationally benchmarked assessments. The CCSS-M provide a more focused and coherent set of mathematics standards that improve mathematics achievement of all students. Helping teachers change their pedagogy to meet this vision is not an easy task because the standards seek to fundamentally shift the way many teachers have learned mathematics and have been taught to teach.

Digital technologies with advanced computational, graphical, and symbolic capabilities have changed how mathematicians are able to think and do mathematics. The question is whether this change has shifted how students should learn and do mathematics. These technologies provide students with the opportunity to visualize and make the abstract world of mathematics more concrete. Technologies can also serve as catalysts to move teachers toward instruction that is more student-centered, active, and relevant to the world in which they live. The challenge for teachers is to determine the following:

1. Which technologies are best for developing student thinking?
2. How should these technologies serve as mathematics learning tools?
3. When in the course of the mathematics content development should these technologies be incorporated?

One way to accomplish these goals is to use technology applications that can be extended for long periods of time across topics to engage students in meaningful problems and projects rather than providing a variety of applications with no internal coherence.

Directed versus Social-Constructivist Teaching Strategies

In her article reporting the results of studies of early mathematics curricula, Sparks (2010) observed that the "math wars" battling traditional versus reform-based mathematics curriculum and instruction remain unresolved. Do students learn mathematics best from explicit, teacher-directed explanations followed by individual practice? Do they

learn best when they are engaged in student-centered learning where they construct the conceptual ideas through hands-on activities that help students build their personal understandings as in the constructivist approach? Or do they learn best when they are involved in group work and discussions with other students using a more social-constructivist approach? In support of the question on constructivism, Cobb and Yackel (1996) describe the social and constructivist ideas as being reflexive rather than in conflict, thus influencing the movement toward a social-constructivist approach. Their research has influenced the discussions on learning mathematics with the recognition that the social context in which the students are learning impacts their personal understandings. Furthermore, the CCSS-M supports a constructivist way of teaching mathematics. This is seen particularly in the Standards for Mathematical Practice. These socio-constructivist practices help students not only develop a deeper conceptual understanding of mathematics but also participate in experiences that are a part of their lives after school (Boaler, 2001). Technologies are available to support many of these methods, but the approach teachers use to teach math definitely determines the kind of integration strategies they would consider appropriate.



Check Your Understanding 12.6

Shared Writing 12.1 The Role of Calculators in Directed and Socio-Constructivist Mathematics Pedagogy

Technology Integration Strategies for Mathematics Instruction

Technology resources have made possible a variety of teaching and learning strategies to help address the CCSS-M and the NCTM *Principles and Standards*. This section describes those strategies and gives examples of some of the technology resources that make them possible.

Bridging the Gap between Abstract and Concrete with Virtual Manipulatives

Physical manipulatives are real objects such as blocks, Cuisenaire rods, and coins. They are mainstays of the mathematics classroom because they help students bridge the conceptual distance between concrete and abstract mathematical concepts. VMs are replicas of real manipulatives that are accessed via the web and can be manipulated through a keyboard, mouse, handheld touchscreen device, interactive whiteboard, and sometimes in augmented or virtual reality. Benefits for learners include:

- Helping make abstract mathematics concepts more concrete to young students.
- Offering flexible environments that allow students to explore complex concepts.
- Providing concrete representations of abstract concepts.

Most of the research suggests that virtual manipulatives provide similar learning gains to physical manipulatives (Bryan, 2014), and some research suggests that they are better for students (Moyer-Packenham & Westenskow, 2013). Research has

found that virtual manipulatives have a positive impact on both attitudes toward mathematics and student achievement (Burris, 2013; Lee & Chen, 2015; Li & Ma, 2010). For example, Burris (2013) compared third graders' mathematical thinking using virtual versus concrete base-10 blocks to learn place-value concepts. The study found that the students were able to manipulate the virtual blocks in much the same way as the concrete blocks but that the virtual models were advantageous for students in generating nonstandard numbers connected with addition and subtraction. Niess (2012) describes advantages of virtual algebra tiles with sliders for changing the lengths of the tiles when modeling variable lengths. Thus, the virtual manipulatives provide a clearer vision of the variable ideas than that provided with the handheld blocks.

Recent research (Root, Browder, Saunders, Lo, Ya-yu, & Copeland, 2017; Satsangi & Bouck, 2015; Satsangi, Bouck, Taber-Doughty, Bofferding, & Roberts, 2016) indicates that virtual manipulatives are practical and accessible for mathematics learning for students with learning disabilities. For example, Satsangi et al. (2016) alternatively used virtual and concrete manipulatives for algebra in over thirty intervention sessions. These secondary students achieved 90% accuracy at the time with both virtual and concrete VMs, although two students achieved higher learning outcomes using the concrete manipulatives.

In a meta-analysis of research studies, Moyer-Packenham and Westenskow (2013) identified five affordances of virtual manipulatives for mathematics learning, including:

- Focused constraint—VMs focus and constrain student attention on mathematical objects and processes.
- Creative variation—VMs encourage creativity and increase the variety of students' solutions.
- Simultaneous linking—VMs simultaneously link representations with each other and with students' actions.
- Efficient precision—VMs contain precise representations allowing accurate and efficient use.
- Motivation—VMs motivate students to persist at mathematical tasks. (p. 35)

These affordances were replicated in a more recent study (Tucker, Moyer-Packenham, Westenskow, & Jordan, 2016) that examined thirty-three second graders' interactions with virtual mathematics manipulatives via touchscreen tablets. Yet, they discovered that the child's ability and context for learning impacts VM's affordances, so teachers should be sensitive the VM's design and the possibility for interventional scaffolding by the teacher.

Examples of virtual manipulatives include:

- National Library of Virtual Manipulatives (Utah State University)—A library of Java applets and interactive, hands-on activities for K-12 mathematics tied to each of the mathematics standards' content standards
- Apps for handheld touchscreen devices, such as virtual Geoboards, Virtual tangrams, Virtual base blocks, Virtual number racks

Augmented reality apps for mathematics available on tablets or phones include:

- Geometry 101 (Zientia)—Allows students to manipulate features of geometric structures such as area, prism, and platonic solids
- Lunch Rush (PBS)—Teaches students addition and subtraction
- CyberChase Shape Quest! (PBS)—Assists elementary students in learning geometry, spatial reasoning, and problem solving

See Technology Integration Example 12.3 for a lesson that uses VM tools.

Video Example 12.6 Using Interactive Games to Learn to Solve Equations

In this video, a STEM principal describes a tablet game application his school adopted, which assists students learning to solve algebraic equations.



Allowing Representation of Mathematical Principles

Mathematics is an abstract subject. Our understanding of mathematical ideas and concepts is closely tied to how we represent the abstractions of mathematics. To some, the concept of “five” is literally five objects (apples, pennies, and so on); to others, it is the numeral 5; to the ancient Romans, it was represented by the numeral V; yet to others, it is a place on the number line. Technology has greatly enriched the way the abstractions of mathematics

Technology Integration

Example 12.3

TITLE: Virtual Manipulatives Help Teach Platonic Solids

CONTENT AREA/TOPIC: Mathematics, geometry

GRADE LEVELS: Middle school

ISTE STANDARDS•S: Standard 1—Empowered Learner; Standard 3—Knowledge Constructor; Standard 4—Innovative Designer; Standard 5—Computational Thinker; Standard 6—Creative Communicator

CCSS – MATHEMATICAL CONTENT: CCSS.MATH.CONTENT.6.G.A.4, CCSS.MATH.CONTENT.7.G.A.3

CCSS – MATHEMATICAL PRACTICES: Make sense of problems (SMP1); construct viable arguments (SMP3); model with mathematics (SMP4); use appropriate tools strategically (SMP5); look for and express regularity in repeated reasoning (SMP8).

DESCRIPTION: Use 3-D manipulatives available online at the National Center for Virtual Manipulatives to help students learn about the five Platonic solids. Introduce or reinforce the terms *vertices*, *edges*, and *faces* and review Euler’s formula. Encourage students to describe the attributes of the five solids as they view them. Let students use the virtual tools for each form to rotate it and color each of the planes. Have students count the edges, vertices, and faces. Then have them use Euler’s formula to confirm that it holds for each solid. Follow up with student construction of other solids using clay or paper. Ask inquiry questions such as these: “What is the minimum number of colors required if no two faces of the same color can share an edge? Which of the Platonic solids have faces that could reasonably be considered opposite to one another?” Have students draw the resulting 2-D shape obtained by running planes through the 3-D solids at different angles after playing with the “Platonic Solids—Slicing” virtual manipulative.

SOURCE: Based on a concept from instructor information at the National Library of Virtual Manipulatives. <http://nlvm.usu.edu>

can be represented, and today students must learn mathematics using several representations: symbolic (with numerals, variables, equations, and so on), verbal (with words such as “What percent increase is needed to reach \$32,000?”), graphical (using 2- or 3-D graphs), and numerical (using tables of numbers or spreadsheets). For each of these representations, technology resources have been developed to allow learners to explore mathematics within that representation—and to explore the interaction among representations. For example, Obara (2010a) reports that students have a hard time visualizing 3-D solids; however, by using physical models in conjunction with appropriate software, students can develop the required spatial sense. Using technologies to represent mathematical principles allows a visual depiction of abstract math concepts and gives students environments to explore conjectures and make discoveries about geometry concepts.

GRAPHING UTILITIES Graphing utilities can graph equations as well as perform calculation functions involved in higher-level math and science problems (see an online graphing utility and a sample graphing calculator in Figure 12.3). Research has shown that these tools can improve students’ understanding of functions and graphs as well as the interconnections among the symbolic, graphical, and numerical representations of problems. Browning and Garza-Kling (2010) review four different ways to use graphing utilities:

1. Collecting or generating raw data
2. Examining multiple cases
3. Providing immediate feedback
4. Showing graphical and numerical displays

It is difficult for students to move from the symbolic realm of $f(x) = x^2 - 3$ to the equivalent graphical rendering on an x - y coordinate to its accompanying numerical representation. There are several free graphing utilities online (e.g., Desmos), which have the following advantages over a handheld graphing calculator:

- Better display (color and resolution)
- User-friendly interface
- Free to the user
- Multi-platform access to the software, including online iPad/iPhone apps and Android apps

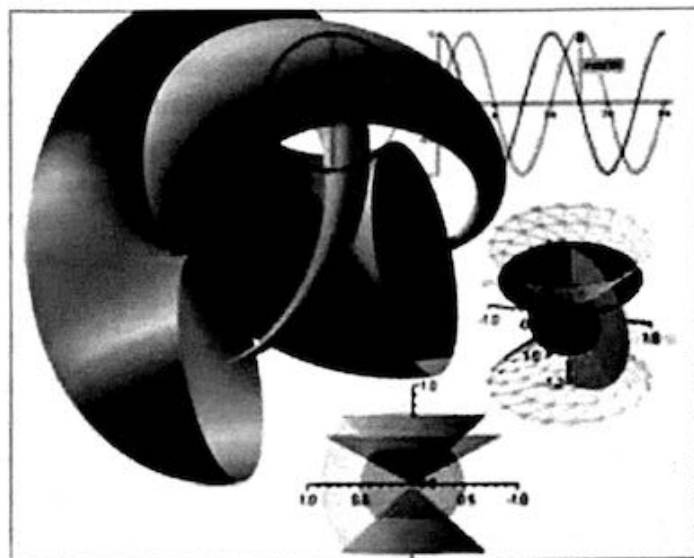
Figure 12.3 Graphing Utilities: Desmos and TI-Nspire Graphing Calculator

SOURCE: Screenshot used with permission of Desmos, Inc; Image used with permission of Texas Instruments Inc.



Figure 12.4 Maple Algebra Software

SOURCE: *Maple* is a trademark of Waterloo Maple Inc. Reprinted by permission.



A number of materials are designed to help students with special needs with calculations and other tasks involved in representing math concepts. See Adapting for Special Needs feature earlier in this chapter.

COMPUTER-BASED SOFTWARE Interactive or dynamic geometry software refers to programs that allow users to create and manipulate geometric constructions. Geometer's Sketchpad and GeoGebra are among the most popular of these geometry programs (Contreras, 2015; Dogan & İçel, 2011; Gergelitsová & Holan, 2016; Lee & Boyadzhiev, 2016; Romero Albaladejo, del Mar García, & Codina, 2015; Stupel & Ben-Chaim, 2014). TI InterActive! (Texas Instruments) is an integrated learning environment that emulates the functions of the graphing calculator with increased functionality. Software capable of depicting solid or 3-D objects on a screen provides learners with a way to visualize objects that are difficult to imagine. Understanding the nature and properties of transformations and symmetry has become increasingly important and can be found in nearly all state mathematics standards. These software programs provide students with an environment in which to make discoveries and conjectures related to geometry concepts and objects. Abstract ideas can be played out on a computer screen, making concepts more real and providing a doorway into mathematical reasoning and proof. Web resources also can help students make connections between abstract geometry and real objects in the world around them. Instead of memorizing geometric facts or concepts, students can explore proofs and arrive at conclusions on their own. Graf (2010) recommends using real manipulatives first followed by a dynamic geometry software program.

For algebra, Obara (2010b) also recommends the multipurpose Maple **computer algebra system (CAS)** software. A CAS can be either software or devices with software that help carry out complex numeric calculations involved in higher-level mathematics problems. Maple has its own built-in programming language that is similar to Pascal and allows the flexibility to design other algebra applications. See an example product from Maple in Figure 12.4. TI-Nspire (Chartwell-Yorke Ltd.) is another CAS that integrated the Derive software into its technology offering.

Supporting Mathematical Problem Solving

NCTM defines problem solving as “engaging in a task for which the solution method is not known in advance.” To find a solution, students must draw on their knowledge, and through this process, they often develop new mathematical understandings. The NCTM standards indicate that solving problems is both a goal of learning mathematics and

Video Example 12.7 Geometer's Sketchpad for Learning Mathematics

In this video, Mr. Patterson explains how Geometer's Sketchpad allows students to express their mathematical learning in ways that answer why and how, ultimately going beyond rote lecture and quiz pedagogy.



the method for meeting the goal. Regardless of how many mathematical facts, skills, or procedures students learn, the true value of mathematics is realized only when they can apply their knowledge to solve problems. Technology, by its definition, is a tool for solving problems. To prepare mathematically powerful citizens for the future, learning to solve problems using mathematics and appropriate technological tools is essential to education at all levels. In doing so, it:

- Helps students gather data to use in problem solving
- Provides rich, motivating, problem-solving environments
- Gives students opportunities to apply mathematical knowledge and skills in authentic contexts

As students acquire number sense, they can begin to make generalizations that lead them to concepts in algebra. Technology tools provide students with a variety of means for exploring the critical concept of functions. Using the CAS, interactive geometry software, and graphing calculators described in the last section, students can graph functions accurately, explore mathematical models of real-life phenomena, and explore symbolic representations and patterns. A **calculator-based lab (CBL)** or **probeware** provide a means to link either calculators or computers to scientific data-gathering instruments, such as thermometers and pH meters, which allow students to gather data and then analyze it. Probes are also available for handheld devices. Texas Instruments and Vernier Inc. produce many of these tools, and often collaborate on products for both companies to market. See Figure 12.5.

Although data collection devices are available for purchase, Sory, Willard, and Kim (2010) describe a lesson in which students create their own low-cost digital thermometers and use a graphing calculator to calibrate them. Doe (2009) points out that handheld devices like mobile phones make technologies such as probeware an even more versatile tool for problem-solving lessons.

Finally, the use of spreadsheets has long been considered a powerful means of supporting problem-solving activities. Niess, van Zee, and Gillow-Wiles (2010–2011)

Figure 12.5 Sample Vernier LabQuest Probeware System

SOURCE: Photo courtesy of Vernier Software & Technology.



indicate that spreadsheets provide tools for problem solving that relies on both “science and mathematics concepts and processes for accurate analysis” (p. 42).

Implementing Data-Driven Curricula

The importance of statistical inference and probability has already had an impact on U.S. schools. Technology provides an ideal means for developing student knowledge and skill related to data analysis. Some of the advantages that technology provides include:

- Easy access to many data sets
- Access to real data and statistics to support investigations
- Opportunities for students to develop skills in data analysis
- Opportunities to explore and present data in graphical form

Fathom is a comprehensive package designed for schools to help analyze and represent statistical data in a wide range of forms for secondary and higher level mathematics. Edwards and Phelps (2008) described how Fathom can help students explore common geometry and algebra topics, and Shafer (2010) illustrated its use in teaching hypothesis testing. TinkerPlots is another dynamic statistical software. It was originally built on the platform of Fathom, but is much more user-friendly and is very powerful for students from upper elementary schools to university. Watson and Donne (2009) found that Tinkerplots provides a medium for middle school students to develop their statistical thinking and understanding. Garfield, delMas, and Zieffler (2012) conducted a three-month teaching experiment in an introductory college-level statistic course that used TinkerPlots for all modeling and analysis in the course and found that it promoted true statistical thinking rather than a statistics by recipe approach that most students adopt.

Computer spreadsheets, such as Excel, Numbers, or Google Sheets, also provide environments in which children can explore number concepts, operations, and patterns with data they obtain from various sources. Students can work with basic operations, explore “what-if” problems, and build a foundation for algebraic thinking. As noted by Niess et al. (2010–2011), spreadsheet features permit modeling situations and

analyzing the impact of changes. Presentation of tables and charts to display variables offers “dynamic environments that afford opportunities to engage in algebraic reasoning even in elementary grades” (p. 52). Spreadsheets can facilitate activities such as planning a fund-raising activity or analyzing data from students’ counts of colors in a bag of M&Ms or other candies; both are much-used strategies for helping to build students’ number sense. Plot.ly is an online database and visualization tool, which facilitates expressing data results in graphical form. Students at higher grade levels can use dedicated statistical software such as MiniTab and SPSS. Many data sets on a variety of topics are available online. For example, data on the U.S. population can be found on the Census Bureau’s website; data on sports, politics, and society can be found at FiveThirtyEight’s github website; and sites such as the Internet Movie Database (IMBD) often make their data available for download.

Supporting Mathematics-Related Communications

Expressing numerical ideas in textual form is essential. Students must be able to convert their mathematical thinking into words. Technology can help students achieve success by allowing them to interact with experts on topics that they are struggling with or with others who can be of assistance. The web can also provide tools that can help students find guidance on specific mathematical concepts.

Projects such as those found at the Math Forum @ Drexel’s Problems of the Week allow teachers to pose problems that their students must solve and then communicate about. Ask Dr. Math (also on the Math Forum) lets students contact math experts who can answer a question (see Figure 12.6).

Student-created websites can provide a valuable form of communication for student projects. Using computers and calculators in small-group settings also promotes social interaction and discourse. Teachers often find that grouping students in pairs

Figure 12.6 The Math Forum @ Drexel’s Ask Dr. Math

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enhances learning, augmenting communication from teacher-to-student or computer-to-student to a richer student-to-student-to-computer type of communication.

Motivating Skill Building and Practice

Computer-based tutoring systems for mathematics have been available for some time. One such product is Carnegie Learning, which integrates Cognitive Tutor, developed by professors at Carnegie Mellon University. Although the current emphasis in mathematics instruction is on learning higher-order mathematics skills, students often need more resources to support the practice of basic skills. These skills provide an important foundation on which they can build more advanced skills. Some other technology resources that support this practice include:

- IXL Math—Practice questions that include a range of question types, real-world contexts, and gamified challenges
- Renaissance Learning Accelerated Math—Software for mathematical practice that was distinguished by educators for its “math practice adventures” (Schaffhauser, 2016)
- DreamBox Learning—An adaptive, online mathematics program for K–8
- Assessment and Learning in Knowledge Spaces (ALEKS)—Web-based, artificially intelligent assessment and learning system
- Waterford’s Early Learning Series—A comprehensive computer-based pre-K–12 curriculum
- Khan Academy—Online self-paced practice, instruction, and management of learning

Application Exercise 12.4 Technology Integration Strategies for Mathematics

Teacher Growth in Technology Integration Strategies for Mathematics

In the future, teachers should expand and strengthen their capabilities to understand emerging issues, generate possible solutions, and address technology integration in mathematics. Review the rubric in Table 12.6, which measures a teacher’s progress in integrating technology in mathematics.

In addition to resources from this chapter, teachers should become involved in mathematics professional organizations, such as NCTM. Teachers should also follow policy developments, such as changes in the NCTM and CCSS-M standards.

Teachers can also use the web for assistance in seeking content knowledge and professional learning opportunities that may not be available locally. A range of web resources and online communities facilitate sharing ideas between mathematics educators such as:

- Activity Builder by Desmos—An online platform for developing interactive lessons or modules using the Desmos calculator and other tools designed by Desmos
- GeoGebraTube—An online repository where teachers can upload and share interactive GeoGebra Applets
- Youcubed—Teacher resources including lesson plans and materials as well as videos

Table 12.6 Rubric to Measure Teacher Growth in Technology Integration for Mathematics

Part I: Teachers' Knowledge of Mathematics Issues and Challenges			
	Basic Knowledge (1–2 points)	Intermediate Knowledge (3–4 points)	Advanced Knowledge (5–6 points)
	I can articulate the nature of the issue/challenge.	I can both articulate the nature of the issue/challenge and identify some of the possible ways to address it.	I can articulate and implement my own plan for addressing the issues/challenges in my own teaching.
Accountability for standards in mathematics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Challenges in implementing the Common Core State Standards for school mathematics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Directed versus social-constructivist teaching strategies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Part II: Teachers' Technology Integration Strategies for Mathematics			
	Basic Knowledge (1–2 points)	Intermediate Knowledge (3–4 points)	Advanced Knowledge (5–6 points)
	I can describe the strategies and identify technologies to carry them out.	I have designed at least two activities based on these strategies to enhance my teaching and my students' learning.	I have designed and implemented my own plan for integrating these strategies throughout my curriculum to enhance my teaching and my students' learning.
Bridging the gap between abstract and concrete with virtual manipulatives	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Allowing representation of mathematical principles	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Supporting mathematical problem solving	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Implementing data-driven curricula	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Supporting math-related communication	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Motivating skill building and practice	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Teacher growth in integration strategies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Total Points	_____ of 60 possible points		

- Blog “dy/dan”—Blog of Dan Meyer, former mathematics teacher and current Chief Academic Officer of Desmos, provides many lesson ideas and pedagogical strategies for helping students engage meaningfully with mathematics
- YouTube videos of Ted Talks on mathematics education—Videos worth watching include those by Jo Boaler’s TEDxStanford and Dan Meyer’s TEDxNYED

Exchanging ideas and teaching strategies with other teachers in Twitter is also valuable. The following Twitter hashtags can be useful:

- #math or #mathchat
- #MTBoS (mathematics educators who regularly share ideas and materials)



Check Your Understanding 12.7

Chapter 12 Summary

The following is a summary of the main points covered in this chapter.

1. **Introduction to STEM and STEM Integration**—Optimally, the STEM disciplines are integrated. The three types of STEM integration are: STEM content integration, STEM context integration, and STEM application/tool integration.
2. **Issues and Challenges in Science Instruction**—Issues include accountability for standards in science, the increasing need for scientific and engineering literacy, and difficulties in teaching K–8 science.
3. **Technology Integration Strategies for Science Instruction**—Integration strategies are based on the BSCS 5e framework (engagement, exploration, explanation, elaboration, and evaluation) and include:
 - Involving students in scientific inquiry through authentic online citizen science projects
 - Involving students in scientific inquiry through virtual experiences
 - Supporting specific processes in scientific inquiry including locating content information to investigate scientific issues and questions, collecting data, visualizing data and phenomena, analyzing data, and communicating results
 - Supporting science skills and concept learning
 - Accessing live or archived scientific information
 - Developing teacher growth in integration strategies for science
4. **Issues and Challenges in Engineering Instruction**—Issues include the relationship between engineering and technology, accountability for teaching engineering, and difficulties in teaching K–12 engineering.

5. **Technology Integration Strategies for Engineering Instruction**—Integration strategies unique to engineering instruction include:

- Developing technical communication of engineering thinking and design
- Engaging students in engineering thinking through makerspaces
- Engaging students in engineering through programming, robotics, and simulations
- Supporting students in learning to work on engineering teams
- Developing teacher growth in integration strategies for engineering

6. **Issues and Challenges in Mathematics Instruction**—These issues include accountability for standards in mathematics, challenges in implementing the common core state standards for school mathematics, and directed versus social-constructivist teaching strategies (the ongoing “math wars”).

7. **Technology Integration Strategies for Mathematics Instruction**—Integration strategies include:

- Bridging the gap between the abstract and the concrete with virtual manipulatives
- Allowing representation of mathematical principles
- Supporting mathematical problem solving
- Implementing data-driven curricula
- Supporting math-related communications
- Motivating skill building and practice
- Developing teacher growth in technology integration strategies for mathematics

Technology Integration Workshop

1. Apply What You Learned

In this chapter, you learned about teaching and learning with technology in STEM education. Now apply your understanding of these concepts by completing the following activities:

- Reread Ms. Belt’s and Mr. Alter’s lesson *Hot and Cold Data* at the beginning of this chapter. Pay close attention to Step 3 of their TTIPP when they identify the technological possibilities for their problem of practice: integrating science, math, and engineering with hands-on learning that makes abstract concepts

concrete. Using your knowledge about technology integration strategies for STEM education introduced in this chapter, generate at least one new technological possibility for targeting Ms. Belt and Mr. Alter’s problem of practice.

- Review how Ms. Belt and Mr. Alter RATified their lesson in Step 5 of their TTIPP as represented in Figure 12.1. Use the RAT Matrix to analyze the role(s) and relative advantage that your new technological possibilities (identified in the last step) would play in the lesson. You must reflect on the roles your identified technological possibilities play as replacement,

amplification, and/or transformation of instruction, student learning, and/or curriculum. Do you feel your proposed technology would provide relative advantage?

2. Technology Integration Lesson Planning: Evaluating Lesson Plans

Complete the following exercise using the Technology Integration Examples 12.1–12.3, any lesson plan you find on the web, or one provided by your instructor.

- a. Locate lesson ideas—Identify three lesson plans that focus on any of the technologies you learned about in this chapter, for example:
 - Scientific inquiry in online citizen science projects
 - Scientific inquiry through virtual experiences
 - Access of live or archived scientific information
 - Technical communication of engineering thinking and design
 - Engagement of students in engineering topics through robotics or computer programming
 - Support of students exploring design and making in makerspaces
 - Use of virtual manipulatives
 - Representation of mathematical principles visually
 - Software that supports mathematical problem solving
- b. Evaluate the lessons—Use the Technology Lesson Plan Evaluation Checklist and the RAT Matrix to evaluate each of the lessons you found. Based on the evaluation and your RATification of the lessons, would you adopt these lessons in the future? Why or why not?

3. Technology Integration Lesson Planning: Creating Lesson Plans With The TTIPP Model

Review how to implement the TTIPP Model (see Figure 2.6) for technology integration planning and use Ms. Belt and

Mr. Alter's lesson *Hot and Cold Data* in this chapter as a model. Create your own technology-supported lesson that uses STEM technologies to support learning by students by completing the following activities:

- a. Describe Phase 1—Analysis of Learning and Teaching Assets and Needs:
 - What is the problem of practice or main content topic in your lesson?
 - What are the technology resources that your students, their families, you, and your school could bring as assets to the lesson?
 - What are the technological possibilities for helping to solve or help the identified problem of practice? Identify the technology(ies) you will integrate into the lesson to ensure that you have the skills and resources you need to solve the problem.
- b. Describe Phase 2—Design of the Integration Framework:
 - What are the objectives of the lesson plan?
 - How will you assess your students' accomplishment of the objectives?
 - What integration strategies will you use in this lesson plan?
 - What is the relative advantage of using the technology(ies) in this lesson?
 - How would you prepare the learning environment?
- c. Describe Phase 3—Post-Instruction Analysis and Revisions:
 - What strategies and/or instruments would you use to evaluate the success of this lesson in your classroom, in order to determine revision needs?
 - Create descriptors for your new lesson (e.g., grade level, content and topic areas, technologies used, ISTE standards, 21st-century learning standards).
 - Save your lesson plan with all its descriptors and TTIPP Model notes and share with your peers, teacher, and others.

When you use your new lesson with students, be sure to assess it using the Technology Impact Checklist.