SEVENTH EDITION

Integrating Educational Technology into Teaching

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11

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Teaching and Learning with Technology in Mathematics and Science

Learning Outcomes

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

1. Identify implications for technology integration of each current issue that mathematics teachers face. (ISTE Standards•T 4, 5)
2. Select technology integration strategies that can meet various needs for instruction in mathematics curricula. (ISTE Standards•T 2, 5)
3. Identify implications for technology integration of each current issue that science teachers face. (ISTE Standards•T 4, 5)
4. Select technology integration strategies that can meet various needs for instruction in science curricula. (ISTE Standards•T 2, 5)
5. Design a strategy for how to build teacher knowledge and skills in technology integration for mathematics or science instruction. (ISTE Standards•T 5)

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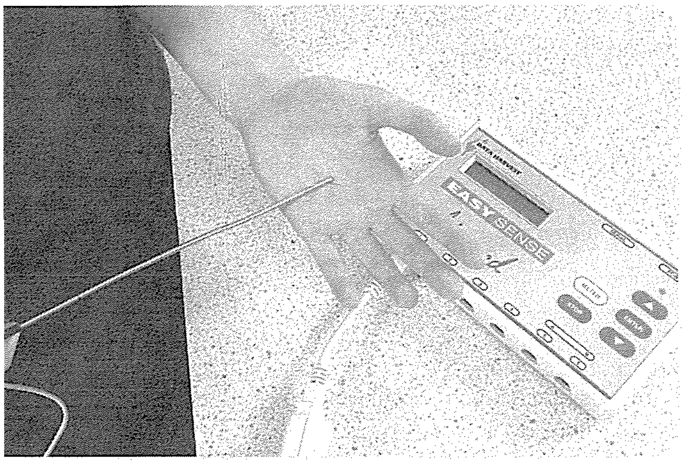
TECHNOLOGY INTEGRATION IN ACTION
HOT AND COLD DATA

GRADE LEVELS: 7-9 • **CONTENT AREA/TOPIC:** Physical science, mathematics • **LENGTH OF TIME:** Three weeks

PHASE 1 ANALYSIS OF LEARNING AND TEACHING NEEDS



Trevor Clifford/Pearson Education

Step 1: Determine relative advantage.

Ms. Belt and Mr. Alter, the physical science teacher and mathematics teacher, respectively, at Pinnacle Middle School, were excited about the new calculator-based laboratories (CBLs) that had just arrived. As they learned about how CBLs can "grab" temperature data and display it in graphs and spreadsheets, they realized that activities with CBLs provide a natural link between science and mathematics studies. Having students use CBLs would be an ideal way to give them hands-on insights into the relationship between these two important skill areas. They also agreed that CBL activities would address the ongoing challenge of making abstract science and math concepts more concrete and visual. Having students collect and analyze their own data, they felt, would give students authentic, hands-on application of these concepts. They decided that a unit on heating and cooling experiments would be a good first activity. Students could take temperature measurements with the CBL probes and then use mathematical procedures to graph and analyze the resulting data.

Step 2: Review required skills and resources.

Both teachers had a good bit of experience with various technologies and knew they would not have trouble learning how to use the new CBL resources. Each had also experimented with small-group collaborative projects in their classrooms, though they knew that a collaboration across classrooms would involve more time for planning and coordination.

PHASE 2 PLANNING FOR INTEGRATION

Step 3: Decide on objectives and assessments.

The teachers decided they would assess student progress in four areas: CBL performance tasks, conducting scientific experiments, interpreting data from experiments, and completing and reporting on scientific experiments. They decided on the following outcomes and objectives they hoped students would achieve and outlined assessment methods to measure students' performance on them:

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.

Outcome: Completing and reporting on scientific experiments, with teacher assistance.
Objective: All students will demonstrate they can work in collaborative groups to complete the steps in an assigned experiment and write individual summaries of their findings 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 collaborative group PowerPoint presentation; a rubric to assess the quality of individually written summaries.

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: Completing and reporting on scientific experiments, without teacher assistance.
Objective: All students will demonstrate they can replicate and interpret data from a CBL experiment by working in pairs to complete the required tasks without assistance.
Assessment: A checklist with points assigned for each step done correctly; a rubric to assess the quality of written summaries.

Step 4: Design integration strategies.

The teachers decided to team-teach the unit to emphasize important links between the two content areas. Working together, they designed the following sequence of activities:

Week 1: Introduce unit activities and CBLs, and provide hands-on practice. Introduce the unit with a Consumer Reports–type scenario. Makers of camp stoves each claim their 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 up their findings for the "Consumer Reports" (CR) 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 grab 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 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 and provides additional instruction as needed. Each small collaborative group is assigned a heating/cooling experiment. For example, have them heat bolts of various sizes and add them to beakers of water. Ask, for example: Does water temperature in a beaker increase more when two smaller metal bolts are added or when one large bolt is added? Each group completes its assigned experiment, answers the question, writes up its findings, and presents the findings to the class by inserting spreadsheet and graphed data into a PowerPoint 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 use the CBLs to heat water to boiling. They collaboratively conduct the step-by-step procedures for hands-on experiments, write up their findings, present them to the whole class, hold a whole-class discussion to interpret results, and write up a summary for credit. 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.

Step 5: Prepare instructional environment.

The teachers prepared the classroom by setting up beakers, hot plates, and CBLs. They got a local sporting goods store to loan them three different camp stoves for the experiments. They tested each of the CBLs and made sure they 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 get to them quickly.

PHASE 3 POST-INSTRUCTION ANALYSIS AND REVISIONS

Step 6: Analyze results.

At the end of the unit, the teachers reviewed students' products and discussed how the unit had worked. Mr. Alter and Ms. Belt 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 on the scientific experiments; they asked the teachers to give them information on careers in science and mathematics.

Step 7: Make revisions.

The teachers concluded that this kind of multidisciplinary 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.

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.

CHAPTER 11 BIG IDEAS OVERVIEW

Before you begin reading the rest of this chapter, listen to the Chapter 11 Big Ideas Overview. It will give you a two-minute audio overview of main concepts to look for and help prepare you to work through information and exercises to achieve this chapter's outcomes.

ISSUES AND CHALLENGES IN MATHEMATICS INSTRUCTION

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

Accountability for Standards in Mathematics

Mathematics and technology have a unique relationship as highlighted in the National Council of Teachers of Mathematics *Technology Principle* in the *Principles and Standards for School Mathematics (2000)* document emphasizes the essential role of technology in teaching and learning mathematics. "The existence, versatility, and power of technology make it possible and necessary to reexamine what mathematics students should learn as well as how they can best learn it" (from the Executive Summary of NCTM Standards). The Association of Mathematics Teacher Educators (AMTE) in their position statement on technology added 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. This section highlights current issues and challenges in mathematics education that shape technology integration strategies for these areas.

Currently, the Common Core State Standards for Mathematics (CCSS-M, National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) are redirecting the curriculum description for what students should know and be able to do in mathematics. In accordance with this move, NCTM noted 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. (from NCTM's position statement *Supporting the Common Core State Standards for Mathematics*). The CCSS-M standards begin with eight Mathematical Practices (MP) for all grades K–12, describing what mathematically proficient students are able to do:

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

Focusing on these recommendations for student engagement in mathematical practices, teachers are challenged 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 (MP2); constructing viable arguments (MP3) in defense of their spreadsheet designs; accurately displaying the mathematics of the problem (MP1) as they make use of the structure in the spreadsheet design (MP7) that uses repeated reasoning (MP8); and ultimately defending their use of the spreadsheet as an appropriate tool for solving the problems (MP5) as they model the ideas using mathematics (MP4).

The CCSS-M serves as a primary resource and guide for those making decisions that affect the mathematics education of students. The standards add to the 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 11.1.

NCTM states that when the CCS 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 their *Principles and Standards* document (2000) for prekindergarten through grade 12. Their content standards are described in five categories from which most of the domains/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 11.2.

TABLE 11.1 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

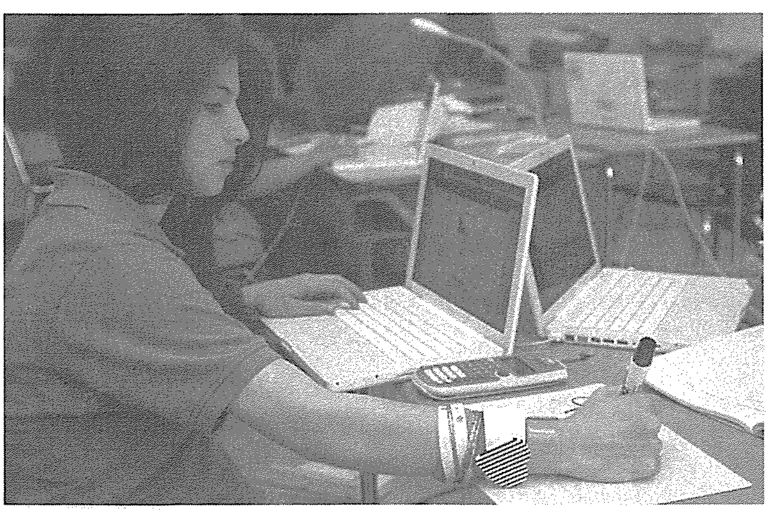
TABLE 11.2 Linking the NCTM Process Standards with the CCSS-M Mathematical Practices

NCTM Process Standards	Linked with CCSS-M Mathematical Practices
Problem Solving	MP1. Make sense of problems and persevere in solving them.
Reasoning and Proof	MP2. Reason abstractly and quantitatively. MP3. Construct viable arguments and critique the reasoning of others. MP7. Look for and make use of structure. MP8. Look for and express regularity in repeated reasoning.
Communication	MP3. Construct viable arguments and critique the reasoning of others. MP6. Attend to precision.
Connections	MP7. Look for and make use of structure.
Representations	MP4. Model with mathematics. MP5. Use appropriate tools strategically.

Challenges in Implementing the Common Core State Standards for School Mathematics

The mathematics education community has actively supported the implementation of the NCTM *Principles and Standards* since 2000, effectively influencing the majority of the current textbooks. Yet, critics have challenged the current curriculum is a mile wide and an inch deep; that is, it is broad in scope of topics but demands minimal performance in any one topic. Critics say this results in lower math performance of U.S. students on internationally benchmarked assessments. The CCSS-M hopes to provide a more focused and coherent set of mathematics standards that results in improving mathematics achievement of all students. Helping teachers change their teaching styles to meet this vision is not an easy task since the standards seek a fundamental shift in 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 more concrete the abstract world of mathematics. Technologies can also serve as a catalyst to move teachers toward an instructional style that is more student-centered, active, and relevant to the world in which they live. The challenge for teachers is to determine:



▲ Digital technologies with advanced computational, graphical, and symbolic capabilities have changed how mathematicians are able to think and do mathematics. Pearson Education

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.

Hot Topic Debate
Do Calculators Mean the End of Memorizing Math Facts?

Take a position for or against (based either on your own position or one assigned to you) on the following controversial statement. Discuss it in class or on an online discussion board, blog, or wiki, as assigned by your instructor. When the discussion is complete, write a summary of the main pros and cons that you and your classmates have stated, and put the summary document in your Teacher Portfolio.

A curricular "war" has long raged between those who believe that students must be taught to memorize certain basic math skills and those who feel that the focus should be on deeper conceptual mathematical knowledge and insights. Epitomizing this struggle is the debate over the role of calculators in the classroom. With the onset of the CCSS-M, the arguments continue. Crary and Wilson (2013) say that the math wars are really battles over a progressive reform agenda in math education. Does the ready availability of calculators in classrooms mean that children no longer need to spend time memorizing math facts, the mathematical algorithms, and multiplication tables? What evidence can you cite that helps define an appropriate role for calculators with young children?

Directed versus Social-Constructivist Teaching Strategies: Ongoing "Math Wars"

In Sparks's 2010 article reporting results of studies of early math curricula, she 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 them 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 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. 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. See the Hot Topic Debate feature for one of the "battles" in these "math wars."

▲ The debate over the role of calculators is one reflection of the curricular "war" over whether students should memorize certain basic math or focus on deeper conceptual mathematical knowledge and insights. (Photo courtesy W. Wiencke)

TECHNOLOGY LEARNING CHECK

Complete TLC 11.1 to review what you have learned from this section about issues that affect how technology may be integrated into mathematics education.

TECHNOLOGY INTEGRATION STRATEGIES FOR MATHEMATICS INSTRUCTION

Technology resources have made possible a variety of teaching and learning strategies to help address the Common Core State Standards in Mathematics. This section describes those strategies, and Table 11.3 summarizes them and gives examples of some of the technology resources that make them possible.

TABLE 11.3 Summary of Technology Integration Strategies for Mathematics

Technology Integration Strategies	Benefits	Sample Resources and Activities
Bridging the gap between abstract and concrete with virtual manipulatives	• Helps make abstract mathematics concepts more concrete to young students • Offers flexible environments that allow students to explore complex concepts • Provides concrete representations of abstract concepts	• National Library of Virtual Manipulatives—a database of Java applets and interactive, hands-on activities for K–12 mathematics
Allowing representation of mathematical principles	• Allows a visual depiction of abstract math concepts • Gives students environments to explore conjectures and make discoveries about geometry concepts	• Geometer's Sketchpad from Keypress, Inc.—an interactive geometry software program that uses Euclidean tools for exploring geometry, algebra, and other K–12 mathematics • Maple software from Maplesoft—a computer algebra system with capabilities for symbolic computation in secondary and higher levels of mathematics. • Derive from Texas Instruments—a computer algebra system for symbolic and numeric mathematics.
Supporting mathematical problem solving	• 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	• Geometer's Sketchpad from Keypress Inc.—an interactive geometry software program that uses Euclidean tools for exploring geometry, algebra, and other K–12 mathematics • Vernier data collection systems—provides active hands-on science through a combination of multiple probeware sensors and data loggers for gathering real-time data for experiments and graphical analysis. • Texas Instruments graphing calculators and TI-NspireCAS from Texas Instruments—handheld devices providing algebraic manipulation capabilities for mathematical explorations in middle and secondary classes.
Implementing data-driven curricula	• Provides easy access to many data sets • Provides real data and statistics to support investigations • Helps students develop skills in data analysis • Allows students to explore and present data in graphical form	• Fathom from Keypress—dynamic data and statistical software package for secondary and higher-level mathematics • Spreadsheets such as Microsoft Excel—data analysis tool for supporting algebraic reasoning and thinking in K–12 mathematics • Data from the U.S. Census • SPSS statistical software from IBM—data analysis statistical package for college level and above.
Supporting math-related communications	• Allows easy contact with math experts for help on math problems • Promotes social interaction and discussion of math topics • Allows teachers to connect with each other and exchange ideas	• Math Forum at Drexel: Ask Dr. Math—an Internet resource for K–12 mathematics where students submit questions to be answered by mathematics experts • Student-developed websites
Motivating skill building and practice	• Provides motivating practice in foundation skills required for higher-level learning • Provides guided instruction in a structured learning environment	• Carnegie's Cognitive Tutor software—relies on an artificial intelligence model for diagnosing student's mastery of mathematics ideas • Waterford's Early Learning Series—a comprehensive computer-based preK-12 curriculum • PLATO's Achieve Now program—computer-based curriculum for elementary and middle school • Leapfrog's Didj—a handheld gaming system for teaching skills in a range of subjects, such as language arts, spelling, math and math facts

TABLE 11.3 Summary of Technology Integration Strategies for Mathematics (continued)

Technology Integration Strategies	Benefits	Sample Resources and Activities
Other mathematics resource websites for teachers	• Offers sources of information, lesson plans on mathematics topics	• National Council of Teachers of Mathematics • Math Forum at Drexel—Internet Math Library • Texas Instruments Resources for Educators • Math World from Wolkfram—a Web-based glossary of mathematical terms • PBS Mathline contains lesson plans with video for grades preK–2

Bridging the Gap Between Abstract and Concrete with Virtual Manipulatives

Physical manipulatives are real objects such as blocks, Cuisenaire rods, and coins. They are a mainstay of the elementary school classroom because they help students bridge the conceptual distance between concrete and abstract mathematical concepts. **Virtual manipulatives** are replicas of real manipulatives that are accessed via the Internet and can be manipulated through a keyboard or other input device. According to Li and Ma (2010), research has found that virtual manipulatives have a positive impact on both attitudes toward mathematics and student achievement. 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. While many of these virtual tools are mentioned most often for lessons at the elementary level, Lee and Chen (2010) also report that virtual manipulatives can improve high school students' attitudes toward mathematics. These simulated activities are popular because they offer more flexibility than activities using actual objects in the way teachers can use them to illustrate concepts.

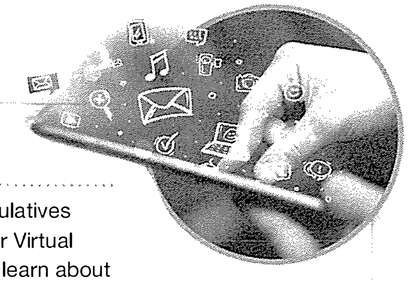
Sarama and Clements (2009) say that virtual manipulatives may actually be better than physical ones for young children who are learning to connect concrete and abstract number concepts. They characterize virtual manipulatives as more "manageable, flexible, extensible, and 'clean' (i.e., free of potentially distracting features)" (p. 147). To support this assertion, they describe "affordances" or unique characteristics that virtual manipulatives have for supporting learning, along with research that supports each one.

Rosen and Hoffman (2009) illustrate how real and virtual manipulatives can be used to enhance mathematics learning at the elementary level. 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. Utah State University maintains a library of virtual manipulatives for all grade levels that are tied to each of the mathematics standards' content strands. For examples of virtual manipulatives, see the websites listed in Table 11.3. Also see Technology Integration Example 11.1 for a lesson that uses these tools.

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. Technology has greatly enriched the way the abstractions of mathematics 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 two- or three-dimensional graphs), or numerical (using tables of numbers or spreadsheets). For each

TECHNOLOGY INTEGRATION



Example 11.1

TITLE: Virtual Manipulatives Help Teach Platonic Solids

CONTENT AREA/TOPIC: Mathematics, geometry

GRADE LEVELS: Middle school

ISTE STANDARDS•S: Standard 1—Creativity and Innovation; Standard 2—Communication and Collaboration; Standard 3—Research and Information Fluency; Standard 6—Technology Operations and Concepts

CCSS: CCSS.MATH.PRACTICE.MP5, CCSS.MATH.CONTENT.6.G.A.4, CCSS.MATH.CONTENT.7.G.A.3

MATHEMATICAL PRACTICES: Make sense of problems (MP1); construct viable arguments (MP3); model with mathematics (MP4); use appropriate tools strategically (MP5); look for and express regularity in repeated reasoning (MP8).

DESCRIPTION: Use 3D manipulatives 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 attributes of the five solids as they view them. For each form, let students use the virtual tools to rotate the form and color each of the planes. Have them count the edges, vertices, and faces. Then have them use Euler's formula to confirm it holds for each solid. Follow up with student construction of other solids using clay or paper. Ask inquiry questions such as, "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 one another?"

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

FIGURE 11.1 TI-Nspire Graphing Calculator

Source: Image used with permission of Texas Instruments Inc.

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) says that students have a hard time visualizing three-dimensional solids; however, by using physical models in conjunction with appropriate software, they can develop the required spatial sense.

Graphing calculators are advanced calculators that can graph equations as well as perform calculation functions involved in higher-level math and science problems (see a sample graphing calculator in Figure 11.1). 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 calculators: (1) collecting or generating raw data, (2) examining multiple cases, (3) providing immediate feedback, and (4) showing graphical and numerical displays. Without technology, it is difficult, if not impossible, for students to move from the symbolic realm of $f(x)=x2-3$ to the equivalent graphical rendering on an x-y coordinate to its accompanying numerical representation.

A number of materials are designed to help students with special needs with calculations and other tasks involved in representing math concepts. See the Adapting for Special Needs feature to see some recommendations for selecting these.

In addition to calculators, many computer-based programs such as Derive (Chartwell-Yorke Ltd.) and TI Interactive! (Texas Instruments) provide learning environments across various mathematical realms. **Interactive or dynamic geometry software** refers to programs that allow users to create and manipulate geometric constructions. They provide students with an environment in which to make discoveries and conjectures related to geometry concepts and objects. Here abstract ideas can be played out on a computer screen, making concepts more real and providing a doorway into mathematical reasoning and proof. Internet 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.

Geometer's Sketchpad is among the most popular of these geometry programs (Graf, 2010; Muller, 2010; Obara, 2010b). Graf (2010) recommends using real manipulatives first, followed by Geometer's Sketchpad. Obara (2010b) recommends both this tool and Maple computer algebra

Adapting for Special Needs

Problem-Solving Aids, Simulations, and Games for Mathematics and Science

Some students with learning disabilities become discouraged in mathematics when they make mistakes in basic calculations involved in solving problems. In these cases, they lose sight of the overall purpose of inquiry and problem solving, and their experience with these subjects suffers. The tools described below 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 (at the Google website)—Complete calculations quickly and easily right within the browser.
- Web Math (at the Discovery Education website)—Enter a problem and view the step-by-step procedure for how the answer is derived.
- Wolfram Alpha (at the Wolfram Alpha website)—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.

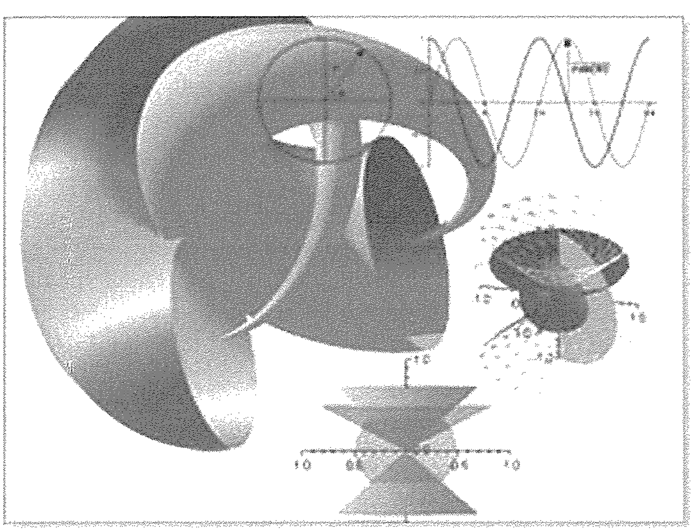
Marino, Tsurusaki, and Basham (2011) say that "appropriate technology-enhanced curricular materials, such as simulation and gaming software, can help students with disabilities (SD) be successful in science. These products engage students in the learning process and are fun and easy to use" (p. 70). They recommend websites like the following that provide interactive, highly motivating science activities. They allow students to repeat experiments quickly and efficiently and help students manipulate complex data.

- Filament Games (at the Filament Games website)—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.
- Explore Learning's Gizmos (at the Explorelearning website)—This website offers over 450 highly interactive simulations for students in grades 3–12.

—Contributed by Dave Edyburn

system (CAS) software. Maple is a multipurpose **computer algebra system (CAS)**. A CAS can be either software or devices with software that help carry out complex numeric calculations involved in higher-level math problems. Maple has its own built-in programming language that is similar to Pascal and allows flexibility to design other algebra applications. See an example product from Maple in Figure 11.2.

FIGURE 11.2 Product of Maple Algebra Software



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

Software capable of depicting solid or three-dimensional 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. Bucher and Edwards (2011) and Garber and Picking (2010) recommend the free GeoGebra dynamic geometry software (shown with other free programs in the Open Source Options feature) for this purpose.

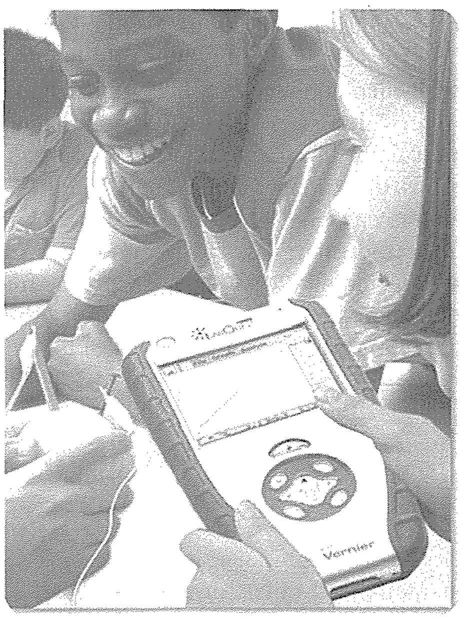
Supporting Mathematical Problem Solving

NCTM defines problem solving as "engaging in a task for which the solution method is not known in advance." In order to find a solution, students must draw on their knowledge, and through this process, they will often develop new mathematical understandings. The NCTM standards indicate that solving problems is both a goal of learning mathematics and provides methods for meeting out the goal. Regardless of

OPEN SOURCE OPTIONS for Mathematics and Science Classrooms

TYPES	FREE SOURCES
Free library of virtual manipulatives	National Library of Virtual Manipulatives: nlvm.usu.edu/en/nav/vlibrary.html Manipula Math with Java: ies-math.com/math/java/
Free online software	GeoGebra geometry software: geogebra.org Graph mathematical graphing software: padowan.dk/graph Mathomatic computer algebra system: mathomatic.org/ Listing of free statistical software: freestatistics.altervista.org/en/stat.php
Free science tutorials and games	Sheppard Software: sheppardsoftware.com/science.htm
Free videos and books	YouTube science videos, for example: "Eureka! #Episode 20, Measuring Temperature" and "Eureka! #Episode 21, Temperature vs. Heat" National Academy Press (NAP): nap.edu

FIGURE 11.3 Sample Vernier LabQuest Probeware System



Source: Photo courtesy of Vernier Software & Technology.

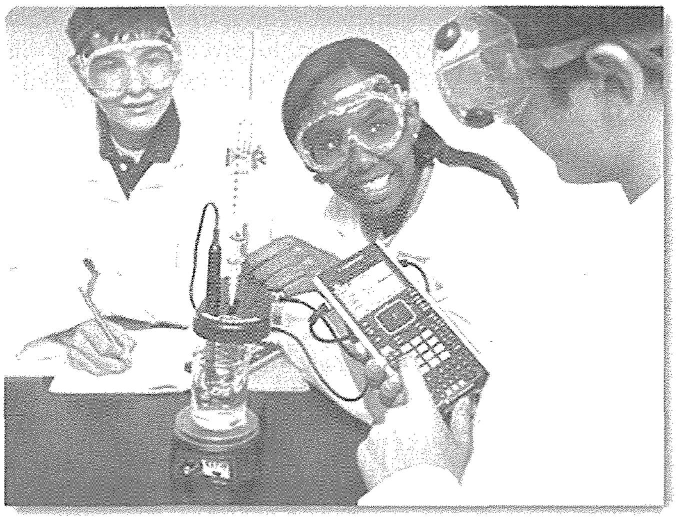
how many mathematical facts, skills, or procedures students learn, the true value of mathematics is realized only when they can apply their knowledge to solve problems. Technology, by its definition, is a tool for solving problems. To prepare mathematically powerful citizens for the future, learning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

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 CAS or graphing calculators, students can graph functions accurately, explore mathematical models of real-life phenomena, and explore symbolic representations and patterns. **Calculator-based laboratories (CBLs**, a.k.a. **probeware**) provide a means to link either calculators or computers to scientific data–gathering instruments, such as thermometers or pH meters, which allow students to gather data and then analyze it. Probes are also available for handheld devices. Texas Instruments and Vernier Inc. are companies that produce many of these tools and they often collaborate on products for both companies to market. See Figures 11.3 and 11.4 for examples of their products.

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.

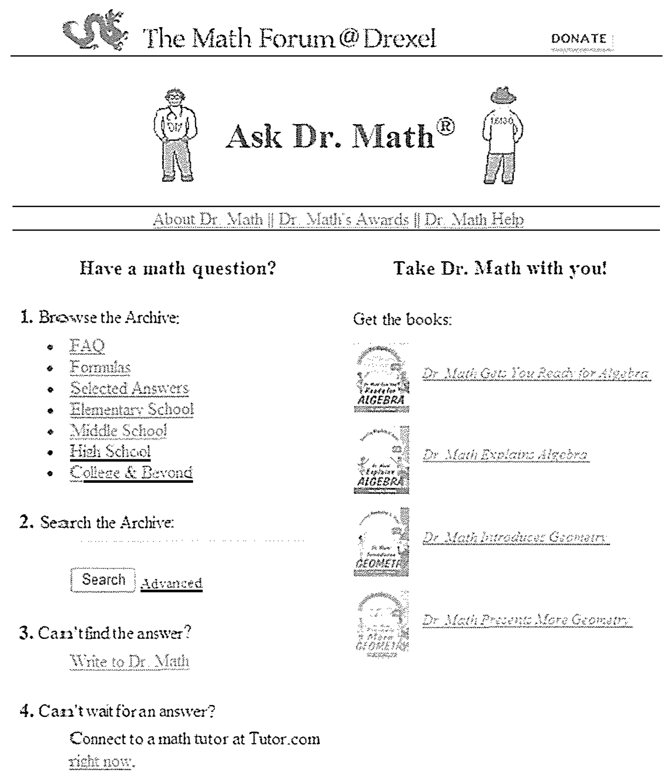
Finally, spreadsheets have long been considered a powerful means of supporting problem-solving activities. Niess, van Zee, and Gillow-Wiles (2010–2011) say that spreadsheets provide tools for problem solving that relies on both "science and mathematics concepts and processes for accurate analysis" (p. 42).

FIGURE 11.4 Texas Instruments TI-Nspire Handheld Data Collection System



Source: Image used with permission of Texas Instruments Inc.

FIGURE 11.5 The Math Forum @ Drexel's Ask Dr. Math



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Implementing Data-Driven Curricula

The importance of statistical inference and probability has already had an impact in U.S. schools. Technology provides an ideal means of developing student knowledge and skill related to data analysis. Fathom is a comprehensive package designed for schools that helps analyze and represent statistical data in a wide range of forms. Edwards and Phelps (2008) describe how Fathom can help students explore common geometry and algebra topics, and Shafer (2010) illustrates its use in teaching hypothesis testing.

Computer spreadsheets 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. Students at later grade levels often use statistical software such as SPSS for this purpose. From sites such as the U.S. Census Bureau, students can download sample data sets to use in their math explorations.

Supporting Math-Related Communications

Expressing numerical ideas in textual form is essential; therefore, students must be able to convert their mathematical thinking into words. 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 11.5).

Student-created websites can be 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 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 Cognitive Tutor, developed by professors at the Carnegie Mellon University. It has been adopted in over 2,600 schools throughout the country (Bhattacharjee, 2009). Brown (2013) reported that a large-scale, randomized study conducted by the Rand Corporation on behalf of the U.S. Department of Education showed that students using the program achieved significantly more than a control group using other curricula.

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 technology resources that can support this practice are listed in Table 11.3.

TECHNOLOGY LEARNING CHECK

Complete TLC 11.2 to review what you have learned from this section about technology integration strategies for mathematics.

ISSUES AND CHALLENGES IN SCIENCE INSTRUCTION

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

Accountability for Standards in Science

The National Science Education Standards (NSES), published in 1996 by the National Research Council (NRC), outlined the content that all students should know and be able to do; it also provided guidelines for assessing student learning in science. Since that time, the NSES provided guidance for science teaching strategies, science teacher professional development, and the support necessary to deliver high-quality science education. The NSES also described the policies to bring coordination, consistency, and coherence to science education programs. Many of the current state standards documents have drawn their content from the *Benchmarks for Science Literacy*, published by the influential American Association for the Advancement of Science (AAAS), and/or the NSES.

As of 2012, the NRC released a new framework for science standards to be designed in its document titled *A Framework for K–12 Science Education: Practices, Crosscutting Concepts and Core Ideas.* Achieve (an education reform organization created in 1996 by group of governors and business leaders) has worked in partnership with the NRC, the National Science Teachers Association (NSTA), and the American Association for the Advancement of Science (AAAS) to create the foundation for the development of the CCSS in Science in the document titled *Next Generation Science Standards for Today's Students and Tomorrow's Workforce*. These K–12 science standards highlight NRC's *Framework* in three dimensions.

These dimensions and the resulting standards are intended for leading toward the Common Core State Science Standards (CCSS-S). A new emphasis in these standards is the recognition of engineering as a result of the STEM initiative that links science, technology, engineering, and mathematics. In these new directions Achieve describes Scientific and Engineering Practices (S&EP) similar in nature to those in the Mathematical Practices.

With these practices in mind, teachers are challenged 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 example, Ms. Bell and Mr. Alter designed a three-week unit around the integration of CBL probeware. They challenged the students to ask questions about the water temperature when two smaller bolts were added versus adding only one larger bolt (S&EP1). They challenged the students to carry out experiments (S&PE3), analyze the results (S&PE4), use spreadsheets for graphing data (S&PE2 and S&PE5), and present their findings to the whole class (S&EP6 and S&EP7)

using a PowerPoint presentation for communicating their results (S&EP8). The crosscutting concepts of the *Framework* include:

- Patterns
- Cause and effect: mechanism and explanation
- Science, proportion, and quantity
- Systems and system models
- Energy and matter: flows, cycles, and conservation
- Structure and function
- Stability and change

Moreover, the four disciplinary core ideas include: physical sciences, life sciences, earth and space sciences, and engineering, technology, and applications of science.

The U. S. Department of Education and the National Science Foundation endorsed the mathematics and science curricula that focused on motivating students through active learning, inquiry, problem solving, cooperative learning, and other instructional methods (NRC, 1996).

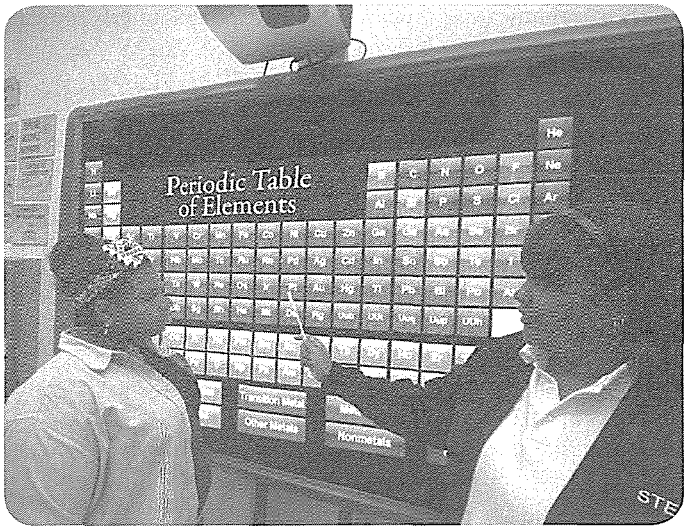
The National Science Education Standards also called for "a vision of science education that will make scientific literacy for all a reality in the 21st century" (NRC, 1996, p. 10). The basis for inquiry-oriented science instruction is developing varied opportunities for students to learn science process skills, such as collecting, sorting, and cataloging; observing, note taking, and sketching; and interviewing, polling, and surveying. In addition, research shows that inquiry-related teaching is effective in developing scientific literacy and the understanding of science processes, vocabulary knowledge, conceptual understanding, critical thinking, positive attitudes toward science, and construction of logico-mathematical knowledge.

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 an inquiry-oriented science instruction. Harris and Rooks (2010) found that these tools allow classrooms to become more inquiry-oriented. Students "engage in real-world investigations and communicate findings" (p. 144) by searching Internet databases and using model-building software and tools to collect data and describe findings. In fact, students are using the same tools as professionals in the field. Owston (2009) also found an important role for technology in science inquiry learning in programs that sought to improve mathematics and science teaching at the high school, middle school, and upper elementary levels: all "emphasized teachers' use of student-centered, inquiry-based approaches in their classrooms that involved all students regardless of ability. All made use of . . . blogs, webcasting, podcasting, and live video sessions" (p. 271).

To integrate technology in the science classroom on a regular basis, one must understand the meaning of technology in the context of science teaching and learning. The NSES explained the difference between science and technology. "The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs. Technology as design is . . . parallel to science as inquiry. . . . The need to answer questions in the natural world drives the development of technological products" (NRC, 1996, p. 24). The parallelism is represented in the recognition that technology results from the design process, much as science results from the inquiry process.

The Narrowing Pipeline of Scientific Talent

Of particular importance throughout the *Framework* is supporting a science, technology, engineering, and mathematics (STEM) curriculum that engages students in the power of the integration of these multiple disciplinary areas. For years now, concern has been growing about America's future ability to compete in science, technology, engineering, and mathematics. Achievement gaps in science are well documented with particular recognition of a continued underrepresentation of female and minority science professionals. When compared with boys, girls' interest in science decreases as they enter middle school. Thus, women continue to be underrepresented in STEM fields. With the declining number of students—especially female and minority students—pursuing studies in the science, technology, engineering, and mathematics fields, America faces a growing crisis in leadership for much-needed STEM initiatives.



The declining number of female and minority students pursuing studies in the math, science, and engineering fields challenges the United States to provide leadership for much-needed STEM initiatives. (Photo by W. Wiencke)

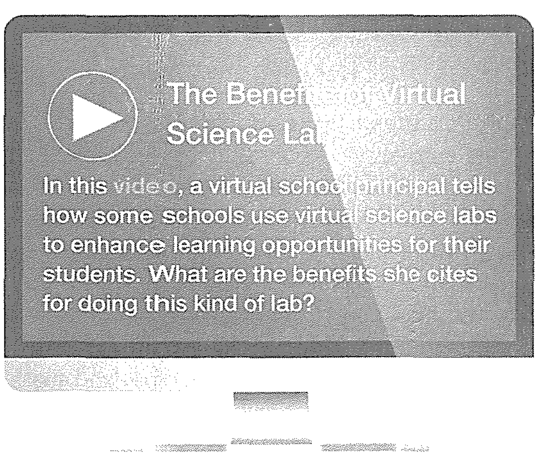
This trend could have serious consequences for the long-term economic and national security of our country. One of the first reports on the issue was presented by EMC Corporation's (2003) *Fueling the Pipeline: Attracting and Educating Math and Science Students*. Since the publication of this seminal report, other organizations—both private and public—have continued to explore the problem. Bayer's Facts of Science Education survey (2010) and the 2011 report by the Committee on Science, Engineering, and Public Policy (COSEPUP) confirm this is an ongoing issue. Providing all students with access to quality education in the STEM disciplines is important to our nation's competitiveness. However, it is challenging to identify the most successful approaches in the STEM disciplines. The reality is that success for all students lies in integrating the four disciplines, rather than segregating them.

Increasing Need for Scientific Literacy

As the science framework emphasizes the importance of students learning 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" (NRC, 2012, p. 26). There is a need for all citizens 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 NRC's *Framework* position (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 scientific inquiry for the primary scientific and engineering 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, since they are typically required to have much less initial preparation in mathematics and science 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 increased professional development (PD). Online PD opportunities increase access for elementary teachers to this important area. For example, the Annenberg Foundation offers a collection of materials that can be used for a distance-education science PD program (see Distance Learning at the Annenberg Foundation website. Moreno and Erdmann (2010) offer BioEd Online and K8 Science, both developed by Baylor College of Medicine (BCM) as online PD to address teachers' needs for "accurate, timely science information and teaching materials" (p. 1589). Finally, in a July 2011 issue of *Science & Children*, the National Science Teachers Association addressed this important need and offered both sources and criteria for effective professional development for elementary teachers. Also see the Adapting for Special Needs feature to see some recommendations for selecting science materials for students with disabilities.



Objections to Virtual Science Labs

When science reform efforts began taking shape in the early 1990s, the American Association for the Advancement of Science called on teachers and schools to engage students in doing science rather than just hearing about it or seeing a demonstration. "Hands-on/minds-on" science became a common term in science reform, synonymous with immersing students in authentic learning experiences. According to Haury and Rillero (1994), Karen Worth, noted science reformer, defined **hands-on/minds-on science** as "engaging in in-depth investigations with objects, materials, phenomena, and ideas and drawing meaning and understanding from those experiences."

Virtual schools, among others, have proposed that simulated labs for activities such as experiments with chemical compounds and animal dissections in biology are very much in keeping with the idea of hands-on learning. They maintain that students can spend more time focusing on the "science" of the activities when danger and sensory unpleasantness are removed. However, the National Science Teachers Association (2007) and the American Chemical Society (2008) take issue with this view, saying that "hands-on" means that students must touch the materials rather than "do" science on a computer. Both organizations have issued position statements arguing against the acceptance of computer simulations as a substitute for real-life laboratory experiences.

At this writing, the College Board requires virtual schools and others who provide distance education courses in biology and chemistry to provide school-lab experiences in order to retain its endorsement as an Advance Placement (AP) course. This policy is under review pending sufficient research comparing learning outcomes from simulated and lab experiences. At this time, research results are inconsistent. For example, 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. But they note that these results contradict results of past studies. Clearly, this is an area in need of further research.

TECHNOLOGY LEARNING CHECK

Complete TLC 11.3 to review what you have learned from this section about issues that affect how technology may be integrated into science education.

TECHNOLOGY INTEGRATION STRATEGIES FOR SCIENCE INSTRUCTION

The Biological Sciences Curriculum Studies (BSCS) 5E instructional model focuses on development of key cognitive 21st-century skills by engaging in scientific inquiry explorations and provides a framework for how technology can enhance science instruction. The models five phases are (Duran, Duran, Haney, & Scheuermann, 2009):

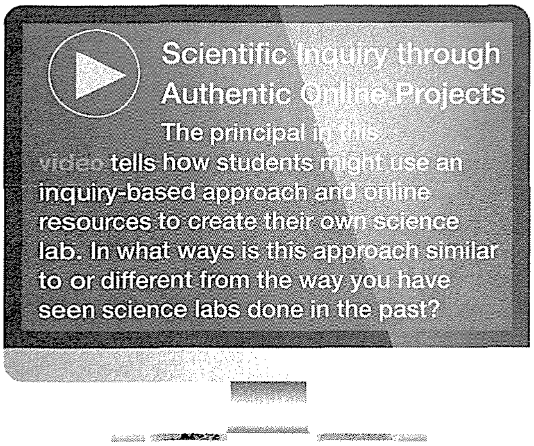
- **Engagement:** Confront students with specific questions for the future inquiry
- **Exploration:** Engage students in experiences where they generate new ideas as they examine and explore the questions
- **Explanation:** Provide teachers with opportunities to directly introduce the topic and for students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

Duran et al. said that "the standards are designed to provide a vision of scientific literacy for all students—regardless of age, race, ethnic background, English-language proficiency, socioeconomic status, disability, or giftedness" (p. 57).

Polly (2011) said technologies are more effective when students engage in higher-order thinking skills. During engagement in technology-rich and learner-centered activities, students analyze and synthesize results from their inquiries in ways that deepen their understandings and helps them make connections among the multiple disciplines. Multiple technology resources support the higher-order thinking engagement that characterizes the emerging science CCSS. Table 11.4 highlights some additional teaching and learning strategies with potential for student engagement in higher-order thinking skills and gives examples of some of the technology resources that make them possible.

TABLE 11.4 Summary of Technology Integration Strategies for Science

Technology Integration Strategies	Benefits	Sample Resources and Activities
Involving students in scientific inquiry through authentic online projects	• Internet projects provide environments that support all phases of an authentic scientific inquiry experience	• Globe Project—GLOBE Program http://globe.gov) • Journey North—global study of wildlife migration and seasonal change • Project FeederWatch at Cornell University—winter-long survey of birds that visit multiple feeders from volunteer locations in North America
Support for specific processes in scientific inquiry	• Helps students locate and obtain information to support inquiry • Makes data collection and analysis more manageable • Makes phenomena easier to visualize and understand • Helps students communicate results of inquiries	• CBLs and spreadsheets—a computer based laboratory for simulating science experiments • The Exploratorium Museum—hands-on museum in San Francisco that provides interactive online exhibits and exhibitions • National Science Digital Library (NSDL) an online resource for science, technology, engineering and mathematics education funded by the National Science Foundation • Digital Library for Earth System Education—an online library resource funded by the National Science Foundation featuring among agricultural, geographical, oceanography and other earth sciences • PhET Independent Simulations at the University of Colorado—provides simulations for physics, biology, chemistry, earth science, and mathematics learning in elementary, middle school, high school and college grade levels • ReciprocalNet: a distributed crystallography network for researchers, students and teachers
Supporting science skills and concept learning	• Allows students to simulate and model various scientific processes • Provides opportunities to engage in problem solving	• Poll Everywhere—a text message polling service that allows students to use their cell phones as "clicker" devices to participate in polls
Engaging students in engineering topics through robotics	• Gives students experience with engineering principles • Gets students thinking about engineering careers	• NASA's Robotics Alliance project (http://robotics.nasa.gov) • International Technology and Engineering Educators Association—a professional association for technology education teachers who teach a curriculum focused on engineering and design
Accessing science information and tools	• Offers sources of information, lesson plans on science topics	• National Academy Press (NAP)—provides publications that address key issues in science • Telescopes that educators and students may use: - Telescopes in Education website - British telescope system with observatories in Hawaii and Australia - National Optical Astronomy Observatory - Bradford robotic telescope in Canary Islands • San Diego Astronomy Association—a non profit educational association focused on furthering astronomy, space and physical science • Night Skies Network—for amateur astronomers to view the nighttime skies
Other science resource websites for teachers	• Offers sources of information, lesson plans on science topics	• National Science Education Standards • National Science Teachers Association (NSTA, http://www.nsta.org • American Association for the Advancement of Science (AAAS) • National Aeronautical and Space Administration (NASA, http://www.nasa.gov) • National Science Education Standards • National Oceanic and Atmospheric Administration (NOAA, http://www.noaa.gov)



Involving Students in Scientific Inquiry Through Authentic Online Projects

Authentic science not only involves having students "do" science, it also includes connecting science to students' 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 5E's 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 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 the results, and getting feedback to help interpret and refine results. Scientists use a variety of technologies in their own work, and these projects use many of the same tools to teach the scientific process. Three such projects are: the Global Learning and Observations to Benefit the Environment (GLOBE) Program, Project FeederWatch, and Journey North.

The GLOBE Program is an excellent example of this kind of all-purpose project. GLOBE is an environmental science project that has 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 state-of-the-art technologies such as temperature **data loggers**, which are devices that record data over time with sensors, and global positioning systems (GPS), as well as traditional technologies such as a weather shelter and a U-tube thermometer. They 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 graphical 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.

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

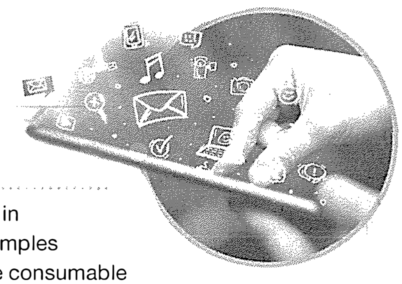
Finally, Journey North projects connect students and scientists in real-life science research. The project identifies itself as the "citizen science" project for children. It engages students in a global study of wildlife migration and seasonal change. K–12 students share their own field observations 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 create can be used to study factors such as climate change, migration, and soil and water conditions. All Journey North projects correlate directly to National Science Education Standards, with an emphasis on science inquiry. The site also offers teachers dozens of lesson plans and activities to use with their students.

Support for 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 can provide support for specific elements of the scientific inquiry process. Some of these are described here. Also see Technology Integration Example 11.2 for an illustration of these principles in action.

Locating information to investigate scientific issues and questions. The Internet 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

TECHNOLOGY INTEGRATION



Example 11.2

TITLE: Think Before You Drink!

CONTENT AREA/TOPIC: Science

GRADE LEVELS: 4–6

ISTE STANDARDS•S: Standard 2—Communication and Collaboration; Standard 3—Research and Information Fluency; Standard 4—Critical Thinking, Problem Solving and Decision Making; Standard 6—Technology Operations and Concepts

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 they are safe to drink. They 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 PowerPoint presentation to the rest of the class. If any water proves to be unsafe or of questionable quality, the students work as a whole class on 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 at http://www.nd.edu/~nismec/vernier.htm.

learning science. For many of the science areas, teachers and students can access information from sources, such as NASA, or museums, such as the Exploratorium (see Figure 11.6).

The National Science Foundation (NSF) has funded the creation of digital libraries for science topics, as well as an online portal to education and research on learning in STEM topics called the National Science Digital Library (NSDL). One of the NSF-funded libraries is the Digital Library for Earth System Education (DLESE). The DLESE is a community of educators, students, and scientists working to improve the teaching of and learning about the earth system 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.

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. The calculator or computer-based laboratory (CBL or probeware) is an ideal tool for middle school through high school science. CBL sensors collect data, and the data can be downloaded into a computer or calculator and then manipulated in a spreadsheet. By archiving data in a spreadsheet, the data can be used at another time or compiled for long-term investigations. 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 where students operate a Geiger counter in Queensland, Australia, to measure how the intensity of radiation changes with distance.

FIGURE 11.6 Exploratorium Website

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

Visualizing data and phenomena. A number of visualization tools exist that 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

FIGURE 11.7 Sheppard Software's Science Website

Source: From Sheppard Software http://www.sheppardsoftware.com. Reprinted by permission.

Technology (PhET) Independent Simulations project at the University of Colorado at Boulder. It offers more than 100 models to teach concepts in physics, chemistry, biology, and calculus; all are free for teachers' and students' use (Quillen, 2011).

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. One such modeling tool for use in physics is ReciprocalNet. It offers a digital collection of molecular structures, as well as software tools for visualizing, interacting with, and rendering printable images of the structures.

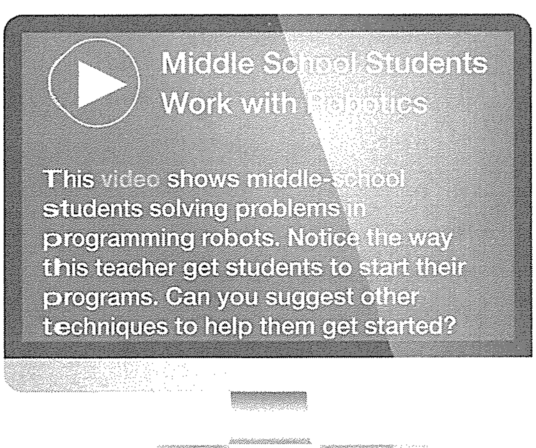
Analyzing data. Analyzing data can be done with a number of existing programs that come standard on computers. Spreadsheets allow data to be entered and analyzed using simple statistics or algorithms supplied by the students. In the GLOBE project, MultiSpec software provides students with the ability 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, scientists write up the results and submit them for publication using standard productivity software (e.g., word processing). Scientists collaborate on scientific problems, and the Internet facilitates the communication process. In addition to graphs and visualizations, scientists use images from digital cameras and other digital instruments to record data and compare and contrast data over time. This is especially useful in land cover investigations and in astronomy. The Internet also provides a medium for communication among scientists. Data can be emailed to researchers around the globe. Classroom teachers can also have 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 Internet.

Supporting Science Skills and Concept Learning

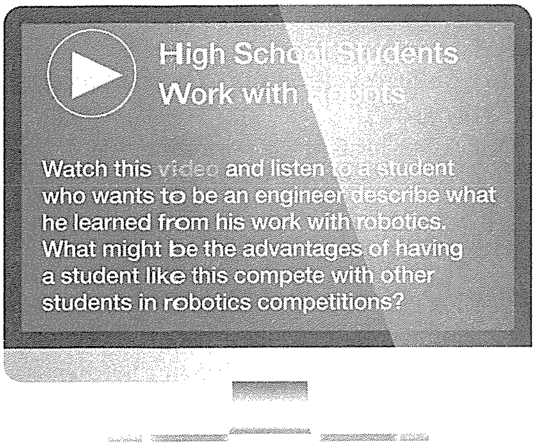
Though hands-on science remains the major science instructional strategy, online science lessons and games can provide motivational ways to supplement this instruction. For example, Sheppard Software has well-designed, free science tutorials and games (see Figure 11.7 for samples of these games, and the Open Source feature for a link to their site). A search for "science games" yields a number of other good activities.

Tremblay (2010) discusses an innovative way to check students' concept learning after a science lesson by turning students' cell phones into student response systems (SRS, a.k.a., clickers). The teacher sets up a set of questions over lesson content in an online survey format on the Poll Everywhere (PE) website. Students respond to the questions by sending a text message from their cell phone to the number provided by the PE service or by going to the PE website using the browser on their phone. As answers come in, the website also updates a graph showing the number of responses to each option.



Engaging Students in Engineering Topics through Robotics

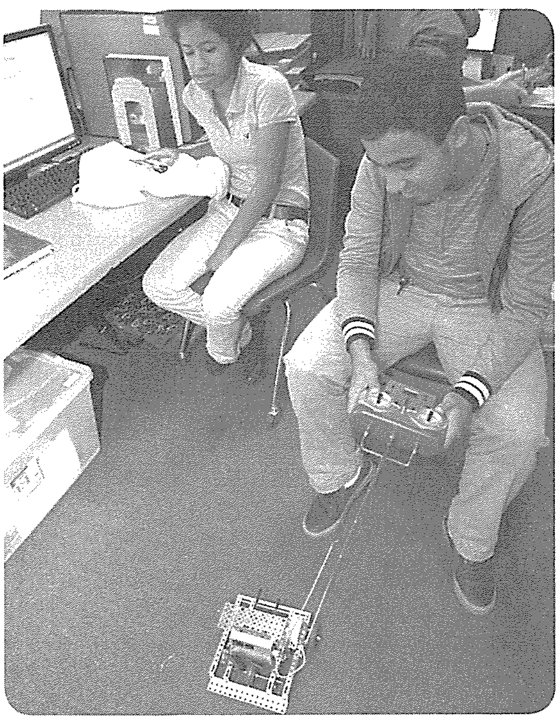
Technology and engineering topics are often called "the missing T and E" in STEM education. One wry observer said that in STEM, the "T is lowercase and the E is silent." In fact, the lack of emphasis on these important areas was



the driving force behind the International Technology Education Association (ITEA) changing its name to the International Technology and Engineering Educators Association in 2010.

The ITEEA has information and publications at its website on how to combine and emphasize these topics. One of these ways is through robotics curriculum, which has 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, but even a three-hour experience modeled on the same camp had great effect on improved attitudes toward science and technology and made kids excited about learning more.

Robotics camps and competitions sponsored by companies, universities, and professional organizations are plentiful; an Internet search under "robotics competitions" lists events at every grade level and region of the country. Many schools sponsor students to prepare products to enter in robotics competitions as a part of their science curriculum. The focus of competitions varies: some set a common problem for all participants and ask for innovative design solutions (e.g., build an electric car), while others set general goals and ask participants to come up with their own innovative products. The number of these contests speaks to their perceived impact on generating student interest in STEM content. NASA provides information on these contests as well as a collection of robotics information and materials at its website.



▲ Robotics projects like this helps supply the "missing E" in STEM education (Photo courtesy of W. Wiencke)

Accessing Science Information and Tools

The Internet has opened up a world of tools and materials for use by teachers and students. One example of the opportunities provided by these unique tools is the ability for teachers and students to get time to use a remote online telescope to carry out various investigations. A few of the remote telescopes are given in Table 11.4.

The Internet is also an unlimited source of data for classroom experiments and investigations, camps and competitions, and 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 National Aeronautics and Space Administration (NASA); for the weather, National Oceanic and Atmospheric Administration (NOAA); and for medicine, the National Institute of Health (NIH). Most of these sites provide content targeted for teachers and students. As of June 2011, anyone can download new publications from the National Academy Press (NAP) website free of charge. The NAP has a wide variety of current, useful publications in science and science education. Teachers can also use the Internet for assistance with content knowledge and for professional development opportunities that may not be available locally. They can also exchange ideas and teaching strategies with other teachers in learning communities. See a general list of helpful information sources under Other Science Resource Websites in Table 11.4 and the Top Ten Must-Have Apps for Science and Mathematics.

TECHNOLOGY LEARNING CHECK

Complete TLC 11.4 to review what you have learned from this section about technology integration strategies for science.

TEACHING MATHEMATICS AND SCIENCE TEACHERS TO INTEGRATE TECHNOLOGY

This section gives recommendations for how teachers can prepare to integrate technology effectively into instruction for mathematics and science learning. Because technological advances change the tools and language of scientific methods, teachers of mathematics and science have found that they must reflect those changes in their teaching. Their challenge is keeping pace with the speed at which these changes are occurring and using new technologies to enhance their methods in ways that address the nation's primary concern in this area: to increase the number of students interested in pursuing STEM careers.

Rubric to Measure Teacher Growth in Mathematics and Science Technology Integration

Begin by reviewing the rubric in Figure 11.8 or Figure 11.9 to measure teachers' progress in effectively integrating technology in mathematics and science instruction. Part I of the rubric addresses knowledge of issues and challenges, and Part II addresses mathematics and science technology integration strategies.

Learning the Issues and Applications

The first step in technology integration is to become acquainted with the issues and challenges discussed in this chapter and how they shape teachers' uses and applications of technologies. Then teachers can begin developing capabilities to address instructional standards and curriculum goals. The following is a suggested sequence of learning activities.

- **Issues and challenges in mathematics and science instruction.** After reviewing the information in this chapter, go to the website of the science and mathematics professional organizations: the National Council of Teachers of Mathematics (NCTM), and the National Science Teachers Association (NSTA); review the standards at both sites. See professional development resources the sites offer, and decide on which can help you gain insight into the issues and challenges outlined in this chapter. Discuss and reflect on the two questions under the Collaborate, Discuss, Reflect feature at the end of the chapter. Complete Part I of the rubric in Figure 11.8 or Figure 11.9 before you begin this sequence and again at various points in your progress.
- **Mathematics and science technology integration strategies.** After reviewing the information in this chapter, review examples of the technologies suggested in the Open Source Options feature and the websites and projects described under each section, and do the lesson evaluation and lesson development activities outlined in the Technology Integration Workshop at the end of this chapter. Reflect on how you will plan for implementing these strategies in your own classroom using the TIP model. Complete Part I of the rubric in Figure 11.8 or Figure 11.9 before you begin this sequence and again at various points in your progress.

TECHNOLOGY LEARNING CHECK

Complete TLC 11.5 to review what you have learned from this section about how mathematics and science teachers can develop their knowledge and skills in technology integration.

FIGURE 11.8 Rubric to Measure Teacher Growth in Mathematics Technology Integration

Part I: Teacher Knowledge of Mathematics Issues and Challenges			
	Basic knowledge (1–2 points)	**Intermediate knowledge (3–4 points)**	**Advanced knowledge (4–5 points)**
Accountability for standards in mathematics	I can articulate the nature of the issue.	I can both articulate the nature of the issue and some of the possible ways to address it.	I can articulate my own plan for addressing the issue in my own teaching.
Challenges in implementing the common core state standards for school mathematics	I can articulate the nature of the issue.	I can both articulate the nature of the issue and some of the possible ways to address it.	I can articulate my own plan for addressing the issue in my own teaching.
Directed vs. Social-Constructivist teaching strategies: ongoing "math wars"	I can articulate the nature of the issue.	I can both articulate the nature of the issue and some of the possible ways to address it.	I can articulate my own plan for addressing the issue in my own teaching.
Part II: Teachers' Technology Integration Strategies for Mathematics Instruction			
	Basic knowledge (1–2 points)	**Intermediate knowledge (3–4 points)**	**Advanced knowledge (4–5 points)**
Bridging the gap between abstract and concrete with virtual manipulatives	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Allowing representation of mathematical principles	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Supporting mathematical problem solving	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Implementing data-driven curricula	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Supporting math-related communications	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Motivating skill building and practice	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Total points	________________ **of 45 possible points**		

FIGURE 11.9 Rubric to Measure Teacher Growth in Science Technology Integration

Part I: Teacher Knowledge of Science Issues and Challenges			
	Basic knowledge (1–2 points)	**Intermediate knowledge (3–4 points)**	**Advanced knowledge (4–5 points)**
Accountability for standards in science	I can articulate the nature of the issue.	I can both articulate the nature of the issue and some of the possible ways to address it.	I can articulate my own plan for addressing the issue in my own teaching.
The narrowing pipeline of scientific talent	I can articulate the nature of the issue.	I can both articulate the nature of the issue and some of the possible ways to address it.	I can articulate my own plan for addressing the issue in my own teaching.
Increasing need for scientific literacy	I can articulate the nature of the issue.	I can both articulate the nature of the issue and some of the possible ways to address it.	I can articulate my own plan for addressing the issue in my own teaching.
Difficulties in teaching K–8 science	I can articulate the nature of the issue.	I can both articulate the nature of the issue and some of the possible ways to address it.	I can articulate my own plan for addressing the issue in my own teaching.
Objections to virtual science labs	I can articulate the nature of the issue.	I can both articulate the nature of the issue and some of the possible ways to address it.	I can articulate my own plan for addressing the issue in my own teaching.
Part II: Teachers' Technology Integration Strategies for Science Instruction			
	Basic knowledge (1–2 points)	**Intermediate knowledge (3–4 points)**	**Advanced knowledge (4–5 points)**
Involving students in scientific inquiry through authentic online projects	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Support for specific processes in scientific inquiry	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Supporting science skills and concept learning	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Engaging students in engineering topics through robotics	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Accessing science information and tools	I can describe the strategies and identify technologies to carry them out.	I have designed at least 1–2 activities based on these strategies to enhance my teaching and my students' learning.	I have designed plans for how I will integrate these strategies throughout my curriculum to enhance my teaching and my students' learning.
Total points	________ **of 50 possible points**		

COLLABORATE, DISCUSS, REFLECT

Monkey Business/Fotolia

The following questions may be used either for in-class, small-group discussions or may be used to initiate discussions in blogs or online discussion boards:

1. As noted in this chapter, the "math wars" continue between those who believe math should be explicit and teacher-directed and those who advocate a more social-constructivist approach. How do technology integration strategies differ between these two positions? Are there ways to combine them that address the recommendations of both sides?

2. As noted in this chapter, the National Science Teachers Association (NSTA) and the American Chemical Society (ACS) have taken the position that "hands-on" means that students must physically touch the materials rather than "do" science on a computer. Both organizations have issued position statements arguing against using computer simulations as a substitute for in-person, in-school laboratory experiences. Can you cite evidence that some science skills cannot be learned from a virtual lab experience? If so, what are they?

3. In the U.S. government's 2010 report, *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5*, the authors make the case that the country is not making the necessary investments in science and technology to remain globally competitive. Go to the National Academies Press website and download and read a free copy of the report. What role does educational technology play in their recommendations to address this need?

Chapter 11 Summary

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

1. **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").

2. **Technology Integration Strategies for Mathematics Instruction.** Integration strategies include:
   - Bridging the gap between abstract and 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

3. **Issues and Challenges in Science Instruction.** Issues include accountability for standards in science, the narrowing pipeline of scientific talent, increasing need for scientific literacy, difficulties in teaching K–8 science, and objections to virtual science labs.

4. **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 projects
   - Support for specific processes in scientific inquiry, including: locating information to investigate scientific issues and questions, collecting data, visualizing data and phenomena, analyzing data, and communicating results
   - Supporting science skills and concept learning
   - Engaging students in engineering topics through robotics
   - Accessing science information and tools

5. **Teaching Mathematics and Science Teachers to Integrate Technology.** Teachers can begin by consulting the rubrics provided in this chapter to measure their own growth in mathematics and science technology integration. After that, they may review issues and challenges in mathematics and science instruction and use chapter resources to learn technology integration strategies they can use to address the issues and challenges.

TECHNOLOGY INTEGRATION WORKSHOP

1. APPLY WHAT YOU LEARNED

To apply the concepts and skills you've read about throughout this chapter, go to the Chapter 11 Technology Application Activity.

2. TECHNOLOGY INTEGRATION LESSON PLANNING: PART 1—EVALUATING AND CREATING LESSON PLANS

Complete the following exercise using the sample lesson plans found on any lesson planning site that you find on the Internet.

a. Locate lesson ideas—Identify three lesson plans that focus on any of the tools or strategies you learned about in this chapter. For example:
- Using virtual manipulatives
- Mathematical problem solving
- Online scientific inquiry
- Engaging students in engineering topics through robotics

b. Evaluate the lessons—Use the Technology Lesson Plan Evaluation Checklist to evaluate each of the lessons you found.

c. Create your own lesson—After you have reviewed and evaluated some sample lessons, create one of your own using a lesson plan format of your choice (or one your instructor gives you). Be sure the lesson focuses on one of the technologies or strategies discussed in this chapter.

3. TECHNOLOGY INTEGRATION LESSON PLANNING: PART 2—IMPLEMENTING THE TIP MODEL

Review how to implement the TIP model in your classroom by doing the following activities with the lesson you created in the Technology Integration Lesson Planning exercise above.

a. Describe the Phase 1—Planning activities you would do to use this lesson in your classroom:
- What is the relative advantage of using the technology(ies) in this lesson?
- Do you have resources and skills you need to carry it out?

b. Describe the Phase 2—Implementation activities you would do to use this lesson in your classroom:
- What are the objectives of the lesson plan?
- How will you assess your students' accomplishment of the objectives?
- What integration strategies are used in this lesson plan?
- How would you prepare the learning environment?

c. Describe the Phase 3—Evaluation/Revision activities you would do to use this lesson in your classroom: What strategies and/or instruments would you use to evaluate the success of this lesson in your classroom in order to determine revision needs?

d. Add lesson descriptors—Create descriptors for your new lesson (e.g., grade level, content and topic areas, technologies used, ISTE standards, 21st Century Learning standards).

e. Save your new lesson—Save your lesson plan with all its descriptors and TIP model notes.

4. FOR YOUR TEACHING PORTFOLIO

Add the following to your Teaching Portfolio:
- Reflections on Hot Topic Debate.
- Summary notes from the Collaborate, Discuss, Reflect activity.
- Lesson plan evaluations, lesson plans, and products you created above.
- Your *Apply What You Learned* Product from Activity 1.