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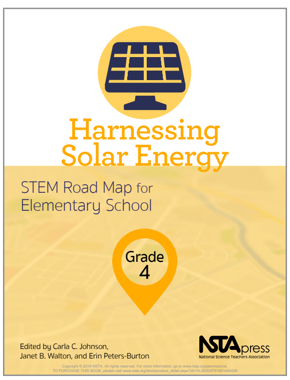

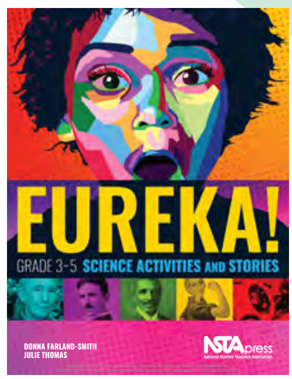

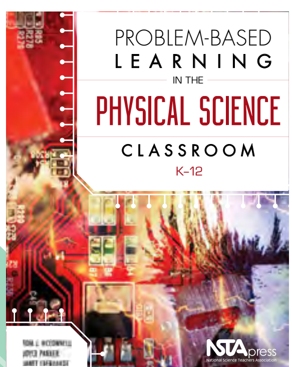

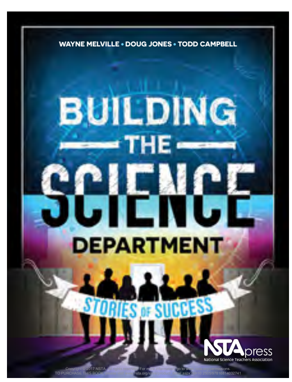

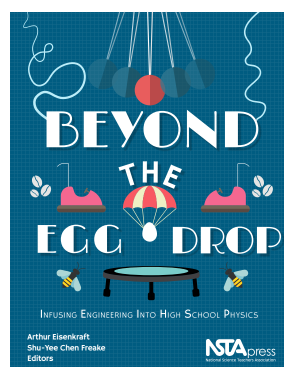

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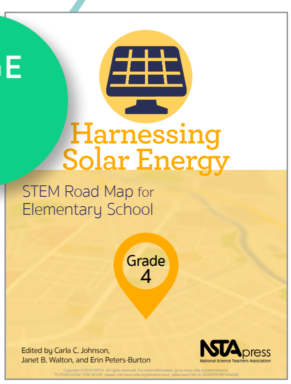

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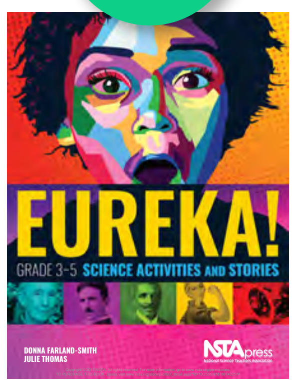

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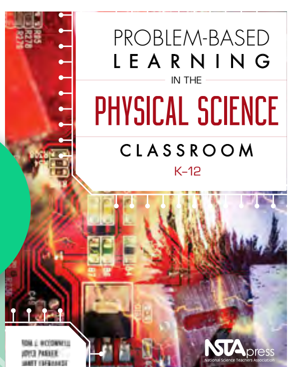

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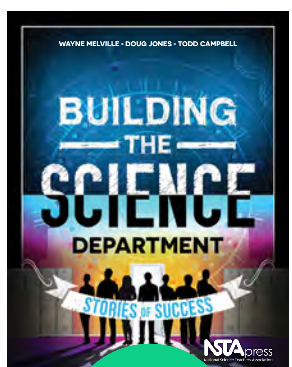

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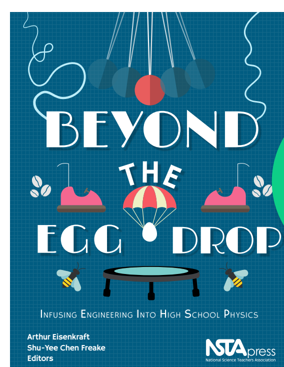

Harnessing Solar Energy

STEM Road Map for Elementary School

Grade 4

Edited by Carla C. Johnson, Janet B. Walton, and Erin Peters-Burton

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HARNESSING SOLAR ENERGY MODULE OVERVIEW

Janet B. Walton, Jessica Carr, Carla C. Johnson, and Erin Peters-Burton

THEME: Innovation and Progress

LEAD DISCIPLINES: Social Studies and Science

MODULE SUMMARY

In this module, students learn about energy and energy sources, with a focus on solar energy. Students explore the science concepts of potential and kinetic energy, solar energy, the greenhouse effect, and salinity. They investigate solar energy's potential as an energy source and limitations associated with its widespread use as a power source. The concept of scarce resources is introduced from a global perspective, centering on the availability of potable water worldwide. As a social studies connection, teams of students each choose one country or region facing water scarcity and research that area to understand its geographic features, climate, and culture. Putting together what they have learned about solar energy, desalination, and the engineering design process (EDP), student teams then design, build, and test passive solar desalination devices in the Water for All Challenge. Each team creates a public service announcement (PSA) highlighting features of its device and the need for such devices around the world, concentrating on the water-scarce country it chose to research. The module culminates with a Water Conservation Expo in which students exhibit their understanding of solar energy, water scarcity, and desalination in the global context (adapted from Capobianco et al. 2015).

ESTABLISHED GOALS AND OBJECTIVES

At the conclusion of this module, students will be able to do the following:

- Provide examples of potential and kinetic energy
- Design a device in which potential energy is transformed into kinetic energy

- Provide evidence that energy can be transferred from place to place by various mediums
- Understand the difference between renewable and nonrenewable resources and describe their sources
- Understand and discuss the advantages and disadvantages of nonrenewable and renewable energy sources
- Understand solar energy's benefits and limitations as an energy source
- Apply their understanding of solar power to create devices that are powered by passive solar energy
- Identify areas of the world where water is a scarce resource
- Identify and discuss causes and effects of water scarcity
- Understand that ocean water is a solution of salt and water and apply this understanding to measuring salinity of various solutions of salt water
- Combine their understanding of solar energy, water scarcity, and desalination to justify a design for a solar desalination device
- Use the EDP to create solutions to problems
- Collaborate with peers to create solutions to problems and design products as assigned
- Understand the role of PSAs in disseminating information about social causes

CHALLENGE OR PROBLEM FOR STUDENTS TO SOLVE: WATER FOR ALL CHALLENGE

Student teams are challenged to use their understanding of solar energy and the EDP to design and build desalination devices powered by passive solar energy. They also create PSAs to highlight the features of their devices and relate their usefulness to water-scarce countries worldwide. Then, students exhibit their devices and present their PSAs in a Water Conservation Expo.

Driving Question: How can we design a solar-powered device that will help people access drinkable water in a country where water is scarce?

CONTENT STANDARDS ADDRESSED IN THIS STEM ROAD MAP MODULE

A full listing with descriptions of the standards this module addresses can be found in the appendix. Listings of the particular standards addressed within lessons are provided in a table for each lesson in Chapter 4.

STEM RESEARCH NOTEBOOK

Each student should maintain a STEM Research Notebook, which will serve as a place for students to organize their work throughout this module (see p. 26 for more general discussion on setup and use of this notebook). All written work in the module should be included in the notebook, including records of students' thoughts and ideas, fictional accounts based on the concepts in the module, and records of student progress through the EDP. The notebooks may be maintained across subject areas, giving students the opportunity to see that although their classes may be separated during the school day, the knowledge they gain is connected.

Each lesson in this module includes student handouts that should be kept in the STEM Research Notebooks after completion, as well as a prompt to which students should respond in their notebooks. Students will have the opportunity to create covers and tables of contents for their STEM Research Notebooks in Lesson 1. You may also wish to have students include the STEM Research Notebook Guidelines student handout on page 26 in their notebooks.

Emphasize to students the importance of organizing all information in a Research Notebook. Explain to them that scientists and other researchers maintain detailed Research Notebooks in their work. These notebooks, which are crucial to researchers' work because they contain critical information and track the researchers' progress, are often considered legal documents for scientists who are pursuing patents or wish to provide proof of their discovery process.

STUDENT HANDOUT

STEM RESEARCH NOTEBOOK GUIDELINES

STEM professionals record their ideas, inventions, experiments, questions, observations, and other work details in notebooks so that they can use these notebooks to help them think about their projects and the problems they are trying to solve. You will each keep a STEM Research Notebook during this module that is like the notebooks that STEM professionals use. In this notebook, you will include all your work and notes about ideas you have. The notebook will help you connect your daily work with the big problem or challenge you are working to solve.

It is important that you organize your notebook entries under the following headings:

1. **Chapter Topic or Title of Problem or Challenge:** You will start a new chapter in your STEM Research Notebook for each new module. This heading is the topic or title of the big problem or challenge that your team is working to solve in this module.
2. **Date and Topic of Lesson Activity for the Day:** Each day, you will begin your daily entry by writing the date and the day's lesson topic at the top of a new page. Write the page number both on the page and in the table of contents.
3. **Information Gathered From Research:** This is information you find from outside resources such as websites or books.
4. **Information Gained From Class or Discussions With Team Members:** This information includes any notes you take in class and notes about things your team discusses. You can include drawings of your ideas here, too.
5. **New Data Collected From Investigations:** This includes data gathered from experiments, investigations, and activities in class.
6. **Documents:** These are handouts and other resources you may receive in class that will help you solve your big problem or challenge. Paste or staple these documents in your STEM Research Notebook for safekeeping and easy access later.
7. **Personal Reflections:** Here, you record your own thoughts and ideas on what you are learning.
8. **Lesson Prompts:** These are questions or statements that your teacher assigns you within each lesson to help you solve your big problem or challenge. You will respond to the prompts in your notebook.
9. **Other Items:** This section includes any other items your teacher gives you or other ideas or questions you may have.

MODULE LAUNCH

To launch the module, introduce students to the idea of scarce resources through the Popcorn for All activity. Students then participate in a class discussion about scarcity that leads to a discussion of energy sources as scarce resources. Next, students watch an age-appropriate video about energy and energy sources. After viewing the video, students create a list of all the sources of energy they noticed in the video, as well as other sources they can think of that were not included.

PREREQUISITE SKILLS FOR THE MODULE

Students enter this module with a wide range of preexisting skills, information, and knowledge. Table 3.1 (p. 28) provides an overview of prerequisite skills and knowledge that students are expected to apply in this module, along with examples of how they apply this knowledge throughout the module. Differentiation strategies are also provided for students who may need additional support in acquiring or applying this knowledge.

Table 3.1. Prerequisite Key Knowledge and Examples of Applications and Differentiation Strategies

Prerequisite Key Knowledge	Application of Knowledge by Students	Differentiation for Students Needing Additional Knowledge
Measurement skills: • Volume • Length • Time	Measurement skills: • Students measure volumes, length, and time using standard units.	Measurement skills: • Provide students with opportunities to practice measuring length and volume using various units and measuring time to the nearest minute. • Provide students with additional content, including textbook support, teacher instruction, and online videos for telling time to the nearest minute.
Map-reading skills	Map-reading skills: • Students use a world map to identify water-scarce countries globally and water-scarce regions within the United States.	Map-reading skills: • Review basic map-reading and geography skills, including continents and oceans. • Have the whole class practice identifying features on a map, such as oceans, islands, and countries.
Inquiry skills: • Ask questions, make logical predictions, plan investigations, and represent data. • Use senses and simple tools to make observations. • Communicate interest in phenomena and plan for simple investigations. • Communicate understanding of simple data using age-appropriate vocabulary.	Inquiry skills: • Select and use appropriate tools and simple equipment to conduct an investigation. • Identify tools needed to investigate specific questions. • Maintain a STEM Research Notebook that includes observations, data, diagrams, and explanations. • Analyze and communicate findings from multiple investigations of similar phenomena to reach a conclusion.	Inquiry skills: • Select model and use appropriate tools and simple equipment to help students conduct an investigation. • Provide samples of a STEM Research Notebook. • Scaffold student efforts to organize data into tables, graphs, drawings, or diagrams by providing step-by-step instructions. • Use classroom discussions to identify specific investigations that could be used to answer a particular question and identify reasons for this choice.
Numbers and operations: • Add and subtract numbers within 1,000. • Multiply and divide whole numbers.	Numbers and operations: • Engage in activities that involve finding sums of numbers within 1,000. • Understand percentages with a focus on division. • Use division to calculate speed.	Numbers and operations: • Review and provide models of adding and subtracting within 1,000 using the standard algorithm. • Review multiplication and division and provide examples.

Table 3.1. (*continued*)

Prerequisite Key Knowledge	Application of Knowledge by Students	Differentiation for Students Needing Additional Knowledge
Reading: • Use information gained from the illustrations and words in a print or digital text to demonstrate understanding of the connection between a series of events, scientific ideas or concepts, or steps in technical procedures in a text.	Reading: • Read informational texts to understand the relationship between geography and water scarcity; environmental effects of various energy sources; and topics associated with solar energy.	Reading: • Provide reading strategies to support comprehension of nonfiction texts, including activating prior knowledge, previewing text by skimming content and scanning images, and rereading.
Writing: • Write informative/explanatory and narrative texts in which students introduce a topic, use facts and definitions to develop points, and provide a concluding statement or section.	Writing: • Write informative/explanatory texts to examine a topic and convey ideas and information clearly. • Write narratives to develop real or imagined experiences or events using effective technique, descriptive details, and clear event sequences.	Writing: • Provide a template for writing informative/explanatory texts to scaffold student writing exercises. • Provide writing organizer handouts to scaffold student work in describing details and clarifying event sequence.
Speaking and listening: • Participate in collaborative conversations using appropriate language and listening skills. • Tell a story or recount an experience with appropriate facts and relevant, descriptive details, speaking audibly in coherent sentences.	Speaking and listening: • Engage in a number of collaborative discussions and presentations in which they need to provide evidence and speak persuasively. • Present factual information to an audience.	Speaking and listening: • Scaffold student understanding of speaking skills by providing examples of appropriate language and presentation, with an emphasis on presentation techniques and language use. • Provide handouts or graphic organizers to support organization of appropriate facts and relevant descriptive details for presentations.

POTENTIAL STEM MISCONCEPTIONS

Students enter the classroom with a wide variety of prior knowledge and ideas, so it is important to be alert to misconceptions, or inappropriate understandings of foundational knowledge. These misconceptions can be classified as one of several types: "preconceived notions," opinions based on popular beliefs or understandings; "nonscientific beliefs," knowledge students have gained about science from sources outside the scientific community; "conceptual misunderstandings," incorrect conceptual models based on incomplete understanding of concepts; "vernacular misconceptions," misunderstandings of words based on their common use versus their scientific use; and "factual misconceptions," incorrect or imprecise knowledge learned in early life that remains unchallenged (NRC 1997, p. 28). Misconceptions must be addressed and dismantled in order for students to reconstruct their knowledge, and therefore teachers should be prepared to take the following steps:

- *Identify students' misconceptions.*
- *Provide a forum for students to confront their misconceptions.*
- *Help students reconstruct and internalize their knowledge, based on scientific models. (NRC 1997, p. 29)*

Keeley and Harrington (2010) recommend using diagnostic tools such as probes and formative assessment to identify and confront student misconceptions and begin the process of reconstructing student knowledge. Keeley and Harrington's *Uncovering Student Ideas in Science* series contains probes targeted toward uncovering student misconceptions in a variety of areas and may be useful resources for addressing student misconceptions in this module.

Some commonly held misconceptions specific to lesson content are provided with each lesson so that you can be alert for student misunderstanding of the science concepts presented and used during this module. The American Association for the Advancement of Science has also identified misconceptions that students frequently hold regarding various science concepts (see the links at *http://assessment.aaas.org/topics*).

SRL PROCESS COMPONENTS

Table 3.2 illustrates some of the activities in the Harnessing Solar Energy module and how they align to the SRL processes before, during, and after learning.

Table 3.2. SRL Process Components

Learning Process Components	Examples From Harnessing Solar Energy Module	Lesson Number and Learning Component
BEFORE LEARNING		
Motivates students	Students participate in an inquiry activity demonstrating resource scarcity and the unequal distribution of resources worldwide.	Lesson 1, Activity/ Exploration
Evokes prior learning	Students share their ideas about the "fairness" of the distribution of natural resources and share ideas about whether and how more equality in the distribution of natural resources should be addressed.	Lesson 1, Activity/ Exploration
DURING LEARNING		
Focuses on important features	Students use solar energy to heat food by creating solar ovens using the engineering design process.	Lesson 3, Activity/ Exploration
Helps students monitor their progress	Students are given the opportunity to improve on their solar oven designs based on the ovens' performance.	Lesson 3, Elaboration/ Application of Knowledge
AFTER LEARNING		
Evaluates learning	Students receive feedback on rubrics for various components of their responses (the device design, a public service announcement, and a presentation) to the Water for All Challenge.	Lesson 5, Assessment
Takes account of what worked and what did not work	Students use prior observations of desalination devices recorded in their STEM Research Notebooks to design their challenge solutions.	Lesson 5, Activity/ Exploration

STRATEGIES FOR DIFFERENTIATING INSTRUCTION WITHIN THIS MODULE

For the purposes of this curriculum module, differentiated instruction is conceptualized as a way to tailor instruction—including process, content, and product—to various student needs in your class. A number of differentiation strategies are integrated into lessons across the module. The problem- and project-based learning approach used in the lessons is designed to address students' multiple intelligences by providing a variety of entry points and methods to investigate the key concepts in the module (for example, investigating solar power from the perspectives of science and social issues via scientific inquiry, literature, journaling, and collaborative design). Differentiation strategies for students needing support in prerequisite knowledge can be found in Table 3.1 (p. 28). You are encouraged to use information gained about student prior knowledge during introductory activities and discussions to inform your instructional differentiation. Strategies incorporated into this lesson include flexible grouping, varied environmental learning contexts, assessments, compacting, and tiered assignments and scaffolding.

Flexible Grouping: Students work collaboratively in a variety of activities throughout this module. Grouping strategies you might employ include student-led grouping, grouping students according to ability level, grouping students randomly, or grouping them so that students in each group have complementary strengths (for instance, one student might be strong in mathematics, another in art, and another in writing). You may also choose to group students based on their prior knowledge about solar energy. Beginning with the Not Enough Water Here activity in Lesson 3, you should group students into the teams with which they will work for the module's culminating challenge, since they start collecting geographically specific information for their final challenge in this activity.

Varied Environmental Learning Contexts: Students have the opportunity to learn in various contexts throughout the module, including alone, in groups, in quiet reading and research-oriented activities, and in active learning through inquiry and design activities. In addition, students learn in a variety of ways, including through doing inquiry activities, journaling, reading fiction and nonfiction texts, watching videos, participating in class discussion, and conducting web-based research.

Assessments: Students are assessed in a variety of ways throughout the module, including individual and collaborative formative and summative assessments. Students have the opportunity to produce work via written text, oral and media presentations, and modeling. You may choose to provide students with additional choices of media for their products (for example, PowerPoint presentations, posters, or student-created websites or blogs).

Compacting: Based on student prior knowledge, you may wish to adjust instructional activities for students who exhibit prior mastery of a learning objective. For instance, if some students exhibit proficiency in working with percentages in mathematics in Lesson 1, you may wish to limit the amount of time they spend practicing these skills and instead have students analyze and compare charts and graphs representing the proportions of energy that are provided by solar power in the United States and globally.

Tiered Assignments and Scaffolding: Based on your awareness of student ability, understanding of concepts, and mastery of skills, you may wish to provide students with variations on activities by adding complexity to assignments or providing more or fewer learning supports for activities throughout the module. For instance, some students may need additional support in identifying key search words and phrases for web-based research or may benefit from cloze sentence handouts to enhance vocabulary understanding. Other students may benefit from expanded reading selections and additional reflective writing or from working with manipulatives and other visual representations of mathematical concepts. You may also work with your school librarian to compile a set of topical resources at a variety of reading levels.

STRATEGIES FOR ENGLISH LANGUAGE LEARNERS

Students who are developing proficiency in English language skills require additional supports to simultaneously learn academic content and the specialized language associated with specific content areas. WIDA has created a framework for providing support to these students and makes available rubrics and guidance on differentiating instructional materials for English language learners (ELLs) (see *www.wida.us/get.aspx?id=7*). In particular, ELL students may benefit from additional sensory supports such as images, physical modeling, and graphic representations of module content, as well as interactive support through collaborative work. This module incorporates a variety of sensory supports and offers ongoing opportunities for ELL students to work collaboratively. The focus on global water access issues affords an opportunity for ELL students to share culturally diverse experiences with water access and quality.

Teachers differentiating instruction for ELL students should carefully consider the needs of these students as they introduce and use academic language in various language domains (listening, speaking, reading, and writing) throughout this module. To adequately differentiate instruction for ELL students, teachers should have an understanding of the proficiency level of each student. The following five overarching preK–5 WIDA learning standards are relevant to this module:

- Standard 1: Social and Instructional language. Focus on social behavior in group work and class discussions, following directions, and information gathering.
- Standard 2: The language of Language Arts. Focus on biographies and autobiographies, informational texts, and main ideas and details.
- Standard 3: The language of Mathematics. Focus on numbers and operations, patterns, number sense, percentages, and measurement.
- Standard 4: The language of Science. Focus on safety practices, energy sources, ecology and conservation, natural resources, and scientific inquiry.
- Standard 5: The language of Social Studies. Focus on resources and products; needs of groups, societies, and cultures; topography; and location of objects and places.

SAFETY CONSIDERATIONS FOR THE ACTIVITIES IN THIS MODULE

This module's science component focuses on solar energy. Students should understand that items left in the sun can become hot and that they should always use appropriate caution when handling items heated by solar power, using potholders or oven mitts. Additionally, students may need to cut through rigid materials such as plastics in this lesson. You may choose to do this cutting if you feel it would be too difficult for students to cut the material with scissors, or instruct them in the safe use of scissors to cut rigid materials. All laboratory occupants must wear safety glasses or goggles during all phases of inquiry activities (setup, hands-on investigation, and takedown). Everyone should also wash their hands with soap and water after completing the activities. For more general safety guidelines, see the section on Safety in STEM in Chapter 2 (p. 18).

DESIRED OUTCOMES AND MONITORING SUCCESS

The desired outcomes for this module are outlined in Table 3.3, along with suggested ways to gather evidence to monitor student success. For more specific details on desired outcomes, see the Established Goals and Objectives section for the module (p. 23) and individual lessons.

Table 3.3. Desired Outcomes and Evidence of Success in Achieving Identified Outcomes

Desired Outcome	Evidence of Success	
	Performance Tasks	Other Measures
Students complete a variety of group projects and individual tasks related to the projects within the module. Completion of these tasks demonstrates student understanding of the concepts and ability to apply these concepts to solving problems.	• Students are assessed on individual work, including handouts and STEM Research Notebook entries, throughout the module. • Students are assessed individually and as groups using project rubrics that focus on content and application of skills related to the academic content.	• Student collaboration is assessed using a collaboration rubric.

ASSESSMENT PLAN OVERVIEW AND MAP

Table 3.4 provides an overview of the major group and individual *product*s and *deliverables*, or things that constitute the assessment for this module. See Table 3.5 (pp. 36–38) for a full assessment map of formative and summative assessments in this module.

Table 3.4. Major Products and Deliverables in Lead Disciplines for Groups and Individuals

Lesson	Major Group Products and Deliverables	Major Individual Products and Deliverables
1	• The Marshmallow Mile marshmallow launcher	• You've Got Potential data sheet • World Water Scarcity Map • The Marshmallow Mile Engineer It! handouts • STEM Research Notebook prompt
2	• Sunsational Energy Poster • Sunsational Energy Presentation • Team choice of water-scarce country	• Energy Beans data sheet • Energy Flows handout • Sunsational Energy graphic organizer • Heat It Up data sheet • Evidence of collaboration (Sunsational Energy collaboration rubric) • STEM Research Notebook prompt
3	• Team report on energy source and contribution to class chart for Powerful Pollution activity • Sun Chefs solar oven • Not Enough Water Here lapbook	• Powerful Pollution graphic organizer • Sun Chefs Engineer It! handouts • Evidence of collaboration (Sun Chefs collaboration rubric) • STEM Research Notebook prompt
4	• Not applicable.	• How Salty Is Salt Water? data sheet handout • Desalination Station handouts • STEM Research Notebook prompts
5	• Desaladora device for Water for All Challenge • Budget for Water for All Challenge • Public service announcement for Water for All Challenge	• Water for All Challenge Engineer It! handouts • Evidence of collaboration (Water for All Challenge collaboration rubric) • STEM Research Notebook prompt

Table 3.5. Assessment Map for Harnessing Solar Energy Module

Lesson	Assessment	Group/ Individual	Formative/ Summative	Lesson Objective Assessed
1	You've Got Potential *data sheet*	Individual	Formative	• Provide examples of potential and kinetic energy. • Demonstrate transformations of potential to kinetic energy.
1	World Water Scarcity *map*	Individual	Formative	• Use understanding of the concept of scarcity to discuss resource scarcity and identify geographic areas with water scarcity. • Use maps to identify areas with water scarcity and understand geographic features of these regions.
1	The Marshmallow Mile *design challenge*	Group	Formative	• Apply understanding of potential and kinetic energy and the EDP to design a device that demonstrates transformations from potential to kinetic energy.
1	The Marshmallow Mile Engineer It! *handouts*	Individual	Formative	• Apply understanding of potential and kinetic energy and the EDP to design a device that demonstrates transformations from potential to kinetic energy.
1	STEM Research Notebook *prompt*	Individual	Formative	• Use understanding of the concept of scarcity to discuss resource scarcity and identify geographic areas with water scarcity.
2	Energy Beans *data sheet*	Individual	Formative	• Understand and discuss the differences between renewable and nonrenewable energy sources.
2	Sunsational Energy *poster and presentation*	Group	Formative	• Understand and discuss the advantages and disadvantages of using solar energy as an energy source to supply human needs.
2	Sunsational Energy *graphic organizer*	Individual		• Understand and discuss the advantages and disadvantages of using solar energy as an energy source to supply human needs.
2	Energy Flows *handout*	Individual	Formative	• Trace the source of the energy in their bodies back to the Sun.
2	Sunsational Energy *collaboration rubric*	Individual	Formative	• Apply collaboration skills to solve a problem.

Table 3.5. *(continued)*

Lesson	Assessment	Group/ Individual	Formative/ Summative	Lesson Objective Assessed
2	STEM Research Notebook *prompt*	Individual	Formative	• Demonstrate an understanding of patterns of energy consumption, identifying renewable and nonrenewable resources students use as they consume energy daily.
3	Powerful Pollution *graphic organizer*	Individual	Formative	• Apply understanding of the greenhouse effect to an understanding of the environmental effects of solar energy and fossil fuels.
3	Sun Chefs *oven design* and Engineer It! *handouts*	Group and individual	Formative	• Apply the EDP and understanding of solar energy to design and build a solar oven.
3	Sun Chefs *collaboration rubric*	Individual	Formative	• Collaborate with peers to solve problems and create products as assigned.
3	Not Enough Water Here *lapbook*	Group	Summative	• Understand the physical and cultural characteristics of a country with water scarcity.
3	STEM Research Notebook *prompt*	Individual	Summative	• Demonstrate an understanding of the physical and cultural characteristics of a country with water scarcity.
4	How Salty Is Salt Water? *data sheet handout*	Individual	Formative	• Understand the concept of salinity. • Measure the salinity of various water samples.
4	Desalination Station *handouts*	Individual	Formative	• Discuss the effects of salinity on the human body. • Discuss various methods of removing salt and other particles from water.
4	STEM Research Notebook *prompts*	Individual	Formative	• Demonstrate a conceptual understanding of the water cycle and observe examples of the water cycle in their daily lives. • Demonstrate an understanding of why solar energy is a better choice than fuel-based energy to power a desalination device.

Table 3.5. (*continued*)

Lesson	Assessment	Group/ Individual	Formative/ Summative	Lesson Objective Assessed
5	Water for All Challenge *design, budget, PSA*	Group	Summative	• Apply understanding of solar energy and desalination techniques to create a desalination device. • Communicate the benefits of a device students designed using persuasive language. • Demonstrate an understanding of a water-scarce country by targeting a PSA to residents of that country.
5	Water for All Challenge Engineer It! *handouts*	Individual	Summative	• Apply understanding of solar energy and desalination techniques to create a desalination device. • Demonstrate understanding of the EDP by applying it to create a solution to a challenge.
5	Water for All Challenge *collaboration rubric*	Individual	Summative	• Successfully collaborate with peers to create a solution to a challenge.
5	STEM Research Notebook *prompt*	Individual	Summative	• Discuss the EDP and its usefulness in solving problems.

MODULE TIMELINE

Tables 3.6–3.10 (pp. 39–40) provide lesson timelines for each week of the module. The timelines are provided for general guidance only and are based on class times of approximately 45 minutes.

Table 3.6. STEM Road Map Module Schedule for Week One

Day 1	Day 2	Day 3	Day 4	Day 5
Lesson 1 *Energetic Interactions* • Launch the module by introducing the concept of scarcity and potential and kinetic energy. • Have students prepare STEM Research Notebooks. • Introduce the Water for All Challenge.	*Lesson 1* *Energetic Interactions* • Students explore potential and kinetic energy in the You've Got Potential activity. • Introduce the EDP and continue exploration of scarcity. • Introduce literature connection.	*Lesson 1* *Energetic Interactions* • Students apply the EDP and their understanding of potential and kinetic energy in the Marshmallow Mile activity.	*Lesson 1* *Energetic Interactions* • Students test and redesign marshmallow launchers and present designs.	*Lesson 2* *Renewable or Not?* • Introduce the concept of renewable and nonrenewable energy sources with the Energy Beans activity.

Table 3.7. STEM Road Map Module Schedule for Week Two

Day 6	Day 7	Day 8	Day 9	Day 10
Lesson 2 *Renewable or Not?* • Introduce the concept of energy transformations in the Energy Flows activity.	*Lesson 2* *Renewable or Not?* • Students research topics related to solar power in the Sunsational Energy activity.	*Lesson 2* *Renewable or Not?* • Students create Sunsational Energy posters.	*Lesson 2* *Renewable or Not?* • Student teams present their Sunsational Energy posters to the class. • Students investigate radiant heat in the Heat It Up activity. • Student teams choose a water-scarce country to investigate.	*Lesson 3* *Energy and Earth* • Introduce the idea that accessing and using energy sources can affect the environment. • Students participate in the Greenpeople Effect activity. • Introduce the Powerful Pollution research activity. • Introduce Not Enough Water Here lapbook project.

Table 3.8. STEM Road Map Module Schedule for Week Three

Day 11	Day 12	Day 13	Day 14	Day 15
Lesson 3 *Energy and Earth* • Students research environmental effects of various energy sources in the Powerful Pollution activity. • Continue work on lapbooks.	*Lesson 3* *Energy and Earth* • Students complete Powerful Pollution activity. • Introduce Sun Chefs solar oven activity. • Continue work on lapbooks.	*Lesson 3* *Energy and Earth* • Students create solar ovens in the Sun Chefs activity. • Continue work on lapbooks.	*Lesson 3* *Energy and Earth* • Students complete Sun Chefs activity. • Students complete lapbooks.	*Lesson 4* *Salty Seas* • Introduce the properties of salt water using discussion and the Floating Away demonstration.

Table 3.9. STEM Road Map Module Schedule for Week Four

Day 16	Day 17	Day 18	Day 19	Day 20
Lesson 4 *Salty Seas* • Students create and use a hydrometer in the How Salty Is Salt Water? activity.	*Lesson 4* *Salty Seas* • Students continue their investigation of salinity and desalination by participating in Desalination Stations.	*Lesson 5* *Water for All Challenge* • Introduce materials for the Water for All Challenge and have students begin planning.	*Lesson 5* *Water for All Challenge* • Students continue work on Water for All Challenge by completing planning and "purchasing" supplies.	*Lesson 5* *Water for All Challenge* • Students continue work on Water for All Challenge by building their devices and leaving them in a sunny spot for at least a day to test them.

Table 3.10. STEM Road Map Module Schedule for Week Five

Day 21	Day 22	Day 23	Day 24	Day 25
Lesson 5 *Water for All Challenge* • Students continue work on Water for All Challenge with testing and redesign. • Students begin to work on their PSAs.	*Lesson 5* *Water for All Challenge* • Students continue work on Water for All Challenge with further testing and redesign. • Students continue work on their PSAs.	*Lesson 5* *Water for All Challenge* • Students continue work on Water for All Challenge by filming PSAs.	*Lesson 5* *Water for All Challenge* • Students complete all work for the Water for All Challenge.	*Lesson 5* *Water for All Challenge* • Students present their devices, PSAs, and lapbooks in a Water Conservation Expo.

RESOURCES

The media specialist can help teachers locate resources for students to view and read about the solar energy and provide technical help with spreadsheets and multimedia production software. Special educators and reading specialists can help find supplemental sources for students needing extra support in reading and writing. Additional resources may be found online. Community resources for this module may include civil engineers, energy company representatives, and local water conservation group representatives.

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Grade 4

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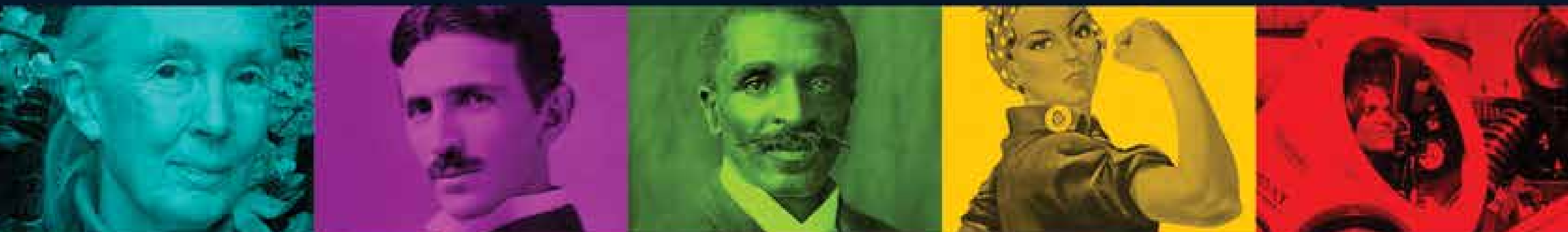

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FOREWORD

Kevin D. Finson

Elementary teachers know the challenges of balancing literacy instruction with high-stakes testing and content area instruction. One way to do this is by incorporating literature relating to the content area into the lessons of that content area. In the case of science, the use of trade books to integrate literacy into science instruction is commonly used as a means of maximizing students' understanding of specific content-related concepts. Some educators, however, have expressed concern that not all books containing science information meet a suitable standard for both science and literature content. Perhaps more troublesome, some studies have demonstrated that science literature books can actually create or increase misconceptions about the content they include (Trundle, Troland, and Pritchard 2008). Should these concerns derail elementary teachers' selection and use of science trade books in their classrooms? Certainly, the answer is *no*. However, these concerns do heighten the need for teachers to have a clear understanding of the quality of science trade book content that appropriately conveys the desired information and concepts. Included with such considerations is the need to make trade book selections with very clear and purposeful rationales, having a definite sense for how a book's content can be used to address specific science messages to students while at the same time providing support for high-quality literacy instruction.

A perusal of many science trade books might quickly reveal that the science content targeted in them can range from concepts (such as lightning, magnets, or volcanoes) to gizmos (such as science equipment and devices) to history (such as science during a specific era) or to other aspects of the discipline. One aspect of science that is sometimes difficult to tease out of trade books is the nature and work of scientists. What are scientists like? What do they do? How do they do it? Who can be a scientist? These are among the questions that arise when a teacher wishes to find a trade book that focuses on scientists. A trade book whose primary focus is on gizmos might mention scientists in passing but is likely going to do a poor job of addressing the actual nature of scientists. In short, it might be difficult for teachers to find high-quality science trade books that focus on the nature and work of scientists. The authors of this book have undertaken the task of helping elementary teachers with this problem. They have carefully identified key elements about the nature and work of scientists that should be considered in trade book selection and then developed and followed a process for assessing trade books to derive a set of books that could best meet the need.

Among those key features about the nature and work of scientists that are included in the authors' selection process are (1) personal stories about scientists' lives (who scientists are), (2) portrayal of science as a human endeavor (what inspires scientists' work), (3) features of the processes scientists use (what we know as the science process skills describing how scientists do what they do), and (4) illustrations of scientists (how they are depicted) within the books. For many elementary teachers, locating personal stories (who scientists are) is likely to be the easiest of these three things to accomplish. Finding the science processes (how scientists do their work) within the pages of these same books might be a little more difficult but still relatively easy. However, finding trade books that clearly identify science as a human endeavor is more difficult but certainly possible in trade books (Segun 1988; Tapscott 2009). Let's look briefly at aspects of these last three elements the authors dealt with in this book.

Science Process Skills

How do scientists actually do science? Shortly after the launching of the satellite *Sputnik* by the Soviet Union on October 4, 1957, this became a key question for American education to answer. It was important because leaders in our nation realized we needed to do a better job of helping future citizens not only understand science but also how to actually do science. Congress provided millions of dollars in funding to various agencies and universities to develop science curricula that could help teachers accomplish this task. The three major elementary curriculum projects that emerged were Elementary Science Study (ESS), Science Curriculum Improvement Study (SCIS), and Science: A Process Approach (SAPA) (Shymansky 1989). Each of these curricula had at its heart the most significant science concepts and science process skills. The process skills were derived from observations and interviews with actual practicing scientists to assess the procedures they followed when doing their work (i.e., process skills). Hence, one of the aspects of the nature of scientists is the process skills scientists choose to use and how they employ them.

The set of science process skills derived varies depending on the source one reads, but all sets include essentially the same process skills. These skills can be categorized as either basic process skills or integrated process skills. The basic science process skills are the foundational skills upon which all other skills are based. The integrated science process skills are those that can be seen as integrated combinations of two or more of the basic science process skills. Although educators often view the basic science process skills as being taught only at the elementary level, many of them need to be revisited during later grades and at higher levels of sophistication. The essentials about the science process skills are described below.

Basic Science Process Skills

Observing

Observing is using the senses (or extensions of them) to gather information about an object or event. An example is watching and describing an ice cube as it melts.

Inferring

Inferring is making a conclusion or interpretation based on observations, whether observed by oneself or others, using reasoning to explain data or information. An example is concluding that the lid of a container filled with water was pushed off the container by the expansion of water as it turned to ice.

Measuring

Measuring is using both standard and nonstandard measures or estimates to describe dimensions of objects or events in quantitative ways. An example is using a metric ruler to measure the length and width of an ice cube in centimeters.

Communicating

Communicating is sharing or transferring ideas through spoken, written, graphic, or pictoral form. An example is using graphs to show the relationship of an ice cube's melting to time exposed to the air.

Using Numbers

Using numbers is applying mathematical rules and/or formulas to calculate quantities or determine relationships. An example is calculating the average time for an ice cube to melt in 25 ml of room-temperature water.

Manipulating Materials

Manipulating materials is handling or treating materials and equipment skillfully and effectively. An example is pouring a liquid from a graduated cylinder into another container when making ice.

Classifying

Classifying is grouping, ordering, or arranging objects, events, or information into groups or categories based on their properties or the criteria specified in some method or system. An example is placing ice crystals in groups based on their shape.

Predicting

Predicting is stating an outcome for a future event or condition one expects to exist based on a pattern of evidence derived from observations and measurements. An example is stating that an ice cube will melt within a specified amount of time.

Developing Vocabulary

Developing vocabulary is using and understanding terminology, specific and unique to uses of words in a discipline, in ways that have meaning. An example is applying working definitions of science concepts in verbal discussions, such as *melting* or *heat exchange* for an ice cube.

Integrated Science Process Skills

Questioning

Questioning is using questions to focus inquiry or to determine prior knowledge and establish purposes or expectations for an investigation. An example is formulating a question about how an ice cube wrapped in newspaper will melt.

Identifying and Controlling Variables

Identifying and controlling variables is identifying and describing the factors that are thought to be constant or changing under differing conditions that can affect the outcome of an experiment, keeping all of them constant except for the one being investigated. An example is identifying the factors that might affect the melting of an ice cube and keeping all of them the same except for the amount of light that shines on the ice cube.

Defining Operationally

Defining operationally is stating how to measure a variable or stating what a phenomenon is according to the actions or operations to be performed on it. An example is stating that an ice cube has "melted" when there is no solid material left in the cup where the ice cube was kept.

Recording Data

Recording data is setting down data in writing or some other permanent form (e.g., taking notes, making lists, and entering in data tables) in an organized manner to facilitate analysis to determine whether patterns or relationships exist in the data. An example is recording data about the mass of the ice remaining in an ice cube compared with the time it has been in a cup on the table.

Formulating Models

Formulating a model is creating a mental or physical model or representation of a process, object, or event. An example is making a three-dimensional model of the molecules in an ice cube.

Hypothesizing

Hypothesizing is stating or constructing a statement that is tentative and testable about what is thought to be the expected outcome of the interaction of two or more variables. An example is stating that if one ice cube is placed in water and another is left in an open container, the one in the water will melt more quickly.

Experimenting

Experimenting is conducting procedural steps to test a hypothesis, including asking appropriate questions, stating the hypothesis, identifying and controlling variables, operationally defining variables, designing a "fair test," and interpreting and then communicating the results. An example is investigating whether hot water or cold water freezes more quickly in a freezer.

Making Decisions

Making decisions is drawing conclusions based on the results of experiments or collections of data, including identifying alternatives and choosing a course of action from among them based on the judgment for the selection with justifiable reasons. An example is identifying alternative ways to store ice cubes to avoid causing some of them to melt within a specific amount of time.

Science as a Human Endeavor

Science as a human endeavor is a significant component of both the American Association for the Advancement of Science (AAAS) *Benchmarks for Science Literacy* (Project 2061) (*AAAS Benchmarks*; 1993), the *National Science Education Standards* (*NSES;* NRC 1996), and *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (*Framework*; NRC 2012), which delineated how science as a human endeavor is evidenced by the following: (1) being people engaged in science and technology for a long time, (2) those who have contributed throughout history to the knowledge base have been both men and women and of various ethnicities—some of whom make careers in the sciences, and (3) science is an ongoing endeavor that does not end. It would seem logical that educators interested in teaching science would therefore look for ways to help students see science as a human endeavor.

A very human aspect of doing science is engaging in scientific inquiry (Akerson and Hanuscin 2005). Scientific inquiry consists of posing questions and then conducting investigations in attempts to find evidence-based answers to them. This is central to the scientific enterprise and necessitates the appropriate development of scientific habits of mind and thinking. Seeing science as a human endeavor helps students develop an image of science going beyond familiar bodies of knowledge, helps them perceive science as something they can engage in successfully, and becomes something to them that is clearly a human endeavor. Abd-El-Khalick, Bell, and Lederman (1998) and Lederman (2007) emphasized that science as a human enterprise is practiced within the context of the culture in which it is situated. Hence, how science and scientists are portrayed in trade books can help contextualize students' views and understanding about science as a human endeavor.

Illustrations of Scientists

Good picture books include colorful images students will want to look at and be able to refer to over and again (House and Rule 2005; Verhallen and Bus 2011; Xiung 2009). Analysis of images differentiates between photographs and other types of illustrations and considers their attributes, qualities, and appropriateness for use with targeted student age groups. The differentiation between photographs and illustrations is an important consideration because students' preferences—and subsequent attentiveness to the images in a book—help them comprehend the content being presented (Fang 1996; Glenberg and Langston 1992).

Included in the extant research regarding the impact of illustrations and images on elementary students were examinations of image attributes of color (bold and bright versus muted and pastels), realistic versus conventionalized presentation, sharp versus rounded lines, line drawings versus drawn images, and drawings or paintings versus photographs. Rationales for considering the importance of such elements encompass improvement of reader comprehension and development of specific language. The overall design of visual features and illustrations typically guides the reader in comprehending and linking elements of stories (Andrews, Scharff, and Moses 2002; Wolfenbarger and Sipe 2007). Appropriate and well-done illustrations help children develop a language of science (beyond simple vocabulary) extending to the language of inquiry: observation, logically derived hypothesizing, question posing, and examination of evidence (Pappas 2006). So, it is important to select trade books that have appropriately designed illustrations of scientists that are constructed in ways students prefer. Students' preferences include such qualities as:

- being realistic and life-like (Rudisill 1952), with life-like realism being more important than color when those aspects are considered separately (King 1967);
- photographs, particularly in color, over drawings and paintings (Rudisill 1952; Simcock and DeLoache 2006);
- being simplified and less complex (French 1952), although they accept more complexity increases with each grade level; and
- being more realistically colored over those either using no color or including colors too bold and not seen in the "real" things represented in the images (Rudisill 1952; Welling 1931). Younger children prefer bright primary colors, while older children tend to prefer softer colors (Andrews, Scharff, and Moses 2002; Stewig 1972). Freeman and Freeman (1933) noted that preschool-age children favored bolder and more life-like colors.

Illustrations in nonfiction picture books play an integral role in how the reader understands the content. They "serve a special comprehension function in that these [visual] elements help readers link information-containing portions of the text" (Donovan and Smolkin 2002, p. 510). Thus, illustrations are an essential component in not only understanding science content but also aiding students' understanding of science as a human endeavor or something they themselves could engage in.

Illustrations can go a long way in influencing students not only with respect to understanding where scientists work and what they do but also with regard to instilling interest and later engagement in actual career choices (Archer et al. 2010; Shope 2006). Children are very likely to formulate much of their perceptions about scientists from what they see in the illustrations in books. This factor can have a number of implications teachers may not readily consider. For example, the perceptions students hold about scientists may relate to their attitudes toward science and scientists (Finson 2003; Fung 2002). Finson (2003) found that students having more negative attitudes toward science tended to have more stereotypical perceptions of scientists, which in turn led to a reduced desire to pursue science as a vocation later in life.

Another component influencing student interest and choice is self-efficacy. O'Brien, Kopala, and Martinez-Pons (1999) linked self-efficacy (with respect to a given field) to the probability of an individual choosing a career in that field. Individuals who perceive themselves as being successful or potentially successful engaging in science are those who will have higher science self-efficacy. From this finding, one could reasonably conclude that individuals holding negative perceptions of science or scientists may be less interested in science and less likely to select science courses or pursue science as a career.

The specifics with respect to the *NSES* (NRC 1996) are as follows:

Standard Statement 1: "The long-term and ongoing practice of science and technology is done by many people" (NRC 1996, p. 141).

- The practice of science must include students' practice and learning. The content of a trade book must be both age- and developmentally appropriate for its intended audience so readers can cognitively connect with what is presented. An example of a book that meets these criteria is *Gregor Mendel: The Friar Who Grew Peas* by Cheryl Bardoe (2006), which tells how Mendel had paired different species of plants to see what offspring (hybrids) would result and then would count the numbers of specific traits that exhibited themselves in each hybrid to determine whether a mathematical pattern would emerge.
- The storytelling aspect of the book is more likely to reflect science as a human endeavor than are presentations of sets of facts. As an example, in *Rachel Carson: Preserving a Sense of Wonder*, Locker and Bruchac (2004) wrote about Carson hearing stories of robin deaths linked to pesticides, leading her to write a story in which the songbirds of the world had disappeared. Carson followed that up with *Silent Spring* in which she explained how every strand within the web of life is connected to the other strands and how the collapse of one endangers all the others.

Standard Statement 2: "Both men and women have made significant contributions to science and technology throughout history" (NRC 1996, p. 141).

- A trade book should include images of both males and females inasmuch as this is historically appropriate. In addition, the images of persons included within a trade book should be as nonstereotypical as possible (Farland 2006a; Farland 2006b).

Standard Statement 3: "By its nature, science will never be finished. Although much has been learned through inquiry about phenomena, objects, and events, there remains ever more to be discovered and learned" (NRC 1996, p. 141).

- Two things need consideration: (1) accuracy of the science information (Rice and Snipes 1997) and (2) attributes of the processes of science as delineated by the *NSES* and National Science Teachers Association documents on scientific literacy (Showalter et al. 1974). An example of a trade book that meets the requisites for accuracy of science information is Dan Yaccarino's (2009) *The Fantastic Undersea Life of Jacques Cousteau*, in which he describes how Cousteau conducted life inventories of sea flora and fauna in books and documentaries and how that inventory information changed over decades of study.

Standard Statement 4: "Many men and women choose science as a vocation and devote their lives to studying it. Many also derive great pleasure from doing so" (NRC 1996, p. 141).

- The story presented in a trade book should illustrate the roles of people engaging in the scientific enterprise. A good example is Jacqueline Briggs Martin's (1998) *Snowflake Bentley,* in which she describes how a farmer became interested in and persisted in photographing snowflakes over many years until he was able to publish a book about them at the age of 66—and even then he continued his work about them.

Conclusion

In writing this book, the authors have been diligent and deliberate in selecting the science trade books that serve as the anchors for each of the chapters. Through careful examination of each of those books, the authors identified the science process skills that were attendant to the work of the person at the focus of each book and then matched those process skills to suggested activities that clearly lead children in their learning of how to apply those essential skills for investigations in science.

Elementary teachers who read and use this book will benefit from the extensive work already completed by the authors. Teachers can be confident that the trade books used as the focus within the chapters are high quality and meet well-established standards for both literacy and science with respect to the nature of scientists. Making use of this book will help teachers save precious time, will help them make science more personable to their students, and will guide them in how to connect the science process skills central to excellent science activities they can select to accompany literature that truly engages students.

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Dedication

This book is dedicated to the best science teacher I know, who teaches at Eastford Elementary School in Connecticut.
—Donna Farland-Smith

This book is dedicated to my most supportive husband, who has helped me brainstorm, craft, and edit these ideas and lessons from the very beginning.
—Julie Thomas

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Donna Farland-Smith has over a decade of experience in the classroom and previously taught science in all grades K–12. She currently serves as an associate professor of science education in The School of Teaching and Learning at The Ohio State University-Mansfield. Her areas of expertise include teacher education, students' perceptions of science and scientists, and encouraging girls to explore science and engineering fields. Along with several book chapters and many articles about science education, Farland-Smith has written and published four books that inspire children to understand and appreciate scientists and their work: *Jungle Jane* (Authentic Perceptions Press, 2002), *It Takes Two: The Story of the Watson and Crick Team* (Authentic Perceptions Press, 2002), and *The Simple Truth About Scientists* (Authentic Perceptions Press, 2002). Farland-Smith received a BA in elementary education, a BA in natural science, an MA in science education, and an EdD in mathematics and science education from the University of Massachusetts-Lowell. In 2017, she published the book *Many Hands, One Vision: 20 Principles That Built a Children's Museum and Revitalized a Downtown Community* (CreateSpace), which tells about her experience in founding The Little Buckeye Children's Museum in Mansfield, Ohio.

Julie Thomas is an experienced elementary classroom teacher and elementary gifted-program coordinator. Now a research professor of science education in the College of Education and Human Sciences at the University of Nebraska-Lincoln, Thomas focuses her efforts on elementary science—for teachers and their students. She has led both state-funded and federally funded projects and has published research about children's science learning and teacher professional development. Thomas's accomplishments include collaborative efforts such as No Duck Left Behind, a partnership with waterfowl biologists to promote wetland education efforts; and Engineering Is Everywhere (E2), a partnership with a materials engineer to develop a time-efficient model for STEM career education. Throughout her teaching career, Thomas has been active in professional associations such as the School Science and Mathematics Association, for which she is a past executive director; the National Science Teachers Association, for which she has authored articles in the journal *Science and Children* and has served on the Awards Committee and Nominations Committee; and the Council for Elementary Children International, for which she is a past president.

3

Developing and Using Models

The practice of developing and using models is very important in science and engineering. This chapter focuses on three scientists who developed and used models for their work—Annie Jump Cannon, who developed a star classification system; George Washington Ferris Jr., who designed the Ferris wheel; and Gregor Mendel, who used the Punnett square to find patterns in inherited traits. Cannon's and Mendel's work improved our understanding of the natural world, and Ferris introduced a new opportunity for public entertainment. The words *imaginative, visionary,* and *patient* well describe the character traits of these scientists and engineers.

Science seeks to understand the way nature works. The *Next Generation Science Standards* (*NGSS*) say that science models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations (NGSS Lead States 2013) in investigating that understanding. The goal of engineering is to develop solutions to problems, so engineering models test possible solutions to a problem and help to explain a system or understand where and under what conditions flaws might develop. Engineering models can also be used to visualize and refine a design, communicate a design's features to others, and explain a new prototype's design performance.

Models can often be the source of misconceptions (see Posner, Strike, Hewson, and Gertzog 1982), especially if students do not also have a direct experience with the "real thing." Models do not correspond exactly to the real world; rather, they provide a visual representation that explains a phenomenon or how something works. They have limitations, and students need opportunities to experience models to realize them. Students in grades 3–5 can learn to identify limitations of models by building and revising simple models and using a variety of models to represent phenomena and design solutions.

Recommended Science Teaching Strategy: Graphic Organizers as Models

We like to teach students about the limitations of models sometime in the fall (or before winter break) because it's something we will reference throughout the rest of the year. All you need is a store-bought plastic model of any part of the human body. If your school lacks models, borrow one from a doctor or nurse for a short time. We have used models of a tongue, skin, and an ear, and they all worked equally well for teaching students about the limitations of models.

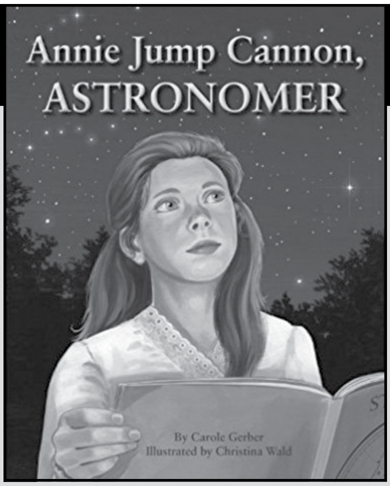
We begin by holding up a body-part model in front of the class and ask students to tell us what it is. When they identify it, we probe for evidence as to why they have identified it as that body part. After students have had time to observe the model, we pass out mirrors and ask students to observe their corresponding body part. Then, we discuss the idea that a model is a representation, and we suggest that not everything about a model is exactly like the thing it represents. Next, we ask the students to provide several of their own observations about what is the same and what is different about the model and the real thing it represents. The point of this lesson is to encourage students, when they encounter a model, to ask themselves, "How is this model like the real thing, and how is it different?"

The first lesson in this chapter includes a foldable model. Foldables are a type of graphic organizer that students manipulate (Zike 2004). They are made primarily of paper and do not require any additional materials. Because using models can become expensive, we like to incorporate foldables throughout the year to reinforce models of all types. In the second lesson, students build a three-dimensional (3-D) model of a Ferris wheel. There is evidence that 3-D models assist students' visualization and cognitive processing of the lesson concepts in diverse science classrooms. For example, Bradley and Farland-Smith (2010) discuss the use of 3-D models to help science students who have a variety of learning disabilities and learning styles. In the third lesson, students build a model to show the random manner in which physical characteristics are passed down from one generation to the next and how siblings and their parents might or might not look alike.

SCIENTISTS AND ENGINEERS ARE

IMAGINATIVE

Learning About Annie Jump Cannon



Imaginative (adj.): creative or having the ability to think of unique ideas

Lesson: Starlight—Light From the Sun

Description

In this lesson, students will learn about how scientist Annie Jump Cannon observed variations in the brightness of stars and explored behaviors of light from the Sun.

Objectives

Students will consider how the character trait of *being imaginative* helped Annie Jump Cannon develop a classification system for stars and explore the nature of reflected light.

- Before starting the lesson, students will make a two-dimensional (2-D) foldable model of their place in the solar system.
- As a class, students will make a model to show the position of Earth and the solar system within the Milky Way galaxy.
- Students will hear the story *Annie Jump Cannon, Astronomer* by Carole Gerber and discuss how it relates to the word *imaginative*.
- Students will explore the behaviors and benefits of luminous and reflected light.
- To conclude the lesson, students will engage in a light-tag activity to further explore the behavior of reflected light.

Learning Outcomes

Students will (1) make a science notebook entry to explain what it means to be imaginative and why being imaginative is an important trait for scientists and engineers and (2) demonstrate their understanding of the behavior and benefits of reflected light.

Connections to the *NGSS* and the Nature of Science, Grades 3–5

Disciplinary Core Ideas

ESS1.A: THE UNIVERSE AND ITS STARS

- The sun is a star that appears larger and brighter than other stars because it is closer. Stars range greatly in their distance from Earth.

PS3.B: CONSERVATION OF ENERGY AND ENERGY TRANSFER

- Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.
- Light also transfers energy from place to place.

PS4.B: ELECTROMAGNETIC RADIATION

- An object can be seen when light reflected from its surface enters the eyes.

Science and Engineering Practices

Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested. Asking questions and defining problems in grades 3–5 builds from grades K–2 experiences and progresses to specifying qualitative relationships.

- Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.
- Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.

Developing and Using Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.

- Develop and/or use models to describe and/or predict phenomena.
- Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.

Crosscutting Concepts

Patterns: Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.

- Similarities and differences in patterns can be used to sort, classify, communicate and analyze simple rates of change for natural phenomena and designed products.
- Patterns can be used as evidence to support an explanation.

Scale, Proportion, and Quantity: In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.

- Natural objects and/or observable phenomena exist from the very small to the immensely large or from very short to very long time periods.
- Standard units are used to measure and describe physical quantities such as weight, time, temperature, and volume.

Nature of Science Connections

SCIENTIFIC INVESTIGATIONS USE A VARIETY OF METHODS

- Science methods are determined by questions.
- Science investigations use a variety of methods, tools, and techniques.

SCIENCE KNOWLEDGE IS BASED ON EMPIRICAL EVIDENCE

- Science findings are based on recognizing patterns.
- Science uses tools and technologies to make accurate measurements and observations.

SCIENCE IS A WAY OF KNOWING

- Science is both a body of knowledge and processes that add new knowledge.

SCIENCE IS A HUMAN ENDEAVOR

- Men and women from all cultures and backgrounds choose careers as scientists and engineers.
- Most scientists and engineers work in teams.
- Creativity and imagination are important to science.

SCIENCE ADDRESSES QUESTIONS ABOUT THE NATURAL AND MATERIAL WORLD

- Science findings are limited to questions that can be answered with empirical evidence.

Source: NGSS Lead States 2013.

Overview

In this lesson, students learn how Annie Jump Cannon invented a model for classifying stars based on the stars' temperatures and shared her classification system with others in her science community. This challenged the way people thought about female astronomers. Through the featured book, students learn that men and women from all backgrounds choose careers as scientists and engineers. The character trait *imaginative* references Cannon's meticulous and creative attempts to organize the starlight behaviors she observed. Students also share ideas about women being scientists. In the hands-on exploration, students explore the nature of reflected light.

Materials

You will need supply of 9 in. × 14 in. or 8.5 in. × 11 in. colored paper in seven colors, enough for one color set for each student; and one copy of the featured book, *Annie Jump Cannon, Astronomer,* by Carole Gerber (ISBN 978-1589809116). Each group of students will need one rock, a cup of water, a piece of aluminum foil, a piece of white paper, and a small plastic bag. Each student will need a set of colored papers prepared ahead by the teacher, a glue stick, his or her science notebook, a flashlight, safety glasses or goggles, and a small acrylic mirror (e.g., 3 in. × 5 in.). *Note:* Acrylic mirrors minimize the safety risks of glass mirrors. Sheets of mirrored acrylic are available online and in most building supply stores and can be cut to any size.

Safety Notes

(1) Personal protective equipment should be worn during the setup, hands-on, and takedown segments of the activity. (2) Immediately wipe up spilled water—it creates a slip-and-fall hazard. (3) Wash hands with soap and water upon completing this activity.

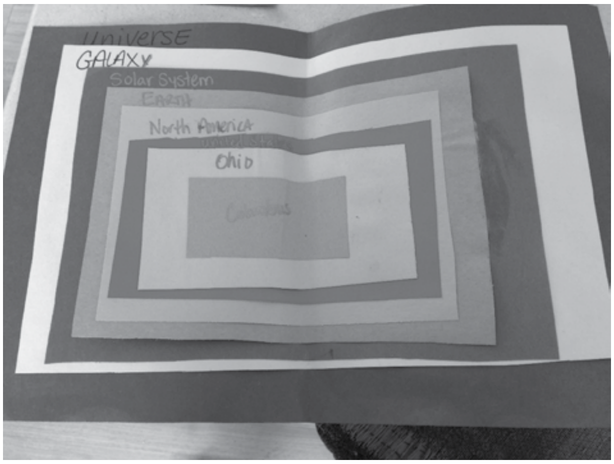
Setting the Context

Engage

Ask students whether they have ever wondered how humans fit in the universe; that is, where we are relative to galaxies, the universe, and the solar system. Ask, "Which is larger, a galaxy, the universe, or a solar system?" Help students build a model of the universe so they appreciate how they actually fit into the big picture.

Figure 3.1

Example of a Student's Stacked-Paper Model of the Universe



This model helps students conceptualize the relative sizes of the various parts of the universe and their location within it. See Zike 2004 for more information.

1. Before class, prepare the colored paper sets for students, planning for all students to create their stacks in the same color sequence. Leave the sheets of the first color of paper whole. For each subsequent color, cut the sheet to be 1 in. shorter and 1 in. narrower than for the previous color.

2. Provide each student with one set of precut colored paper and a glue stick. Have students stack the seven paper sheets by descending size (see Figure 3.1) and glue them in place.

3. Help students label their models. First, have them label the bottommost paper "Universe" (the outermost location in the universe model) and the topmost paper "Home" (the innermost location in the universe model). *Students might instead use the city name and/or street addresses for the innermost label.* Involve students in a conversation about which colors in this model represent the Milky Way galaxy, the solar system, Earth, North America, the United States, and their state. Prompt students with questions about relative size; for example, ask, "If the universe is the biggest, what fits inside it?" It is sometimes easier to begin with the home city and expand outward. You might use the book *My Place in Space* by Robin and Sally Hirst to help your students think about the smaller and larger components of this model.

4. Prompt students to connect their models to the classification of the stars by asking, "Where would the stars be found?" and "How might scientists find out the temperature of a star?" Guide the discussion to the idea that collecting data about space is challenging because stars are far away.

Guided Reading

Inform students that by reading *Annie Jump Cannon, Astronomer,* they will be learning about how stars are classified and about the work of Annie Jump Cannon, a scientist who was especially imaginative. Introduce the book by asking, "Can you describe the person on the front cover? What seems to be happening on the front cover?" Read the story aloud. Encourage students to notice and think about the challenges Cannon faced as a female astronomer. The questions below may be used to guide students' attention to detail as you read. (Page numbers reference unnumbered book pages, beginning with the title page as page 1.)

1. **Pages 3–5:** When she was young, Annie Jump Cannon enjoyed stargazing with her mother. How did Cannon and her mother know what stars they were looking at? *Cannon and her mother climbed onto the roof of their house and matched their view of the night sky to her mother's school star charts. This was how Cannon learned the names of the visible constellations.*

2. **Pages 6–10:** Cannon enrolled in a nearby boys' school after they began admitting girls and graduated at the top of her class. How did Cannon happen to then enroll in Wellesley College? *Annie's father had toured Wellesley on a business trip and was impressed that Wellesley, a women's college, offered the same courses as all-male universities.*

3. **Pages 12–15:** Cannon loved attending Wellesley College, especially the laboratory experiments in her science classes. What challenges did she encounter as a student? *During her sophomore year, Cannon had scarlet fever and developed an ear infection that left her partially deaf. Despite that, she graduated with her class.*

4. **Pages 16–18:** After her mother died, Cannon remembered how much she had enjoyed studying the stars with her mother, so she returned to Wellesley to study astronomy. How did Cannon's astronomy studies set the course for her career? *While at Wellesley, Cannon arranged a way to use the telescope at the Harvard College Observatory.*

5. **Pages 19–21:** The director of Harvard College Observatory hired Cannon to help photograph and classify all the stars in the sky; however, Cannon soon learned that she would not actually be photographing stars. How did astronomers take photographs of the stars? Why did Cannon not photograph stars? *Astronomers used a special system to photograph the stars. They attached prisms to telescopes that separated the light from each star into different wavelengths, similarly to how raindrops separate sunlight into a rainbow. Cannon did not take photographs of the stars because only the male astronomers were allowed to. Women could only be assistants who worked as "human*

Annie Jump Cannon

computers" to examine the photographic plates (spectrographs) to analyze the type of light from each star. Women were paid one-fourth the amount that men were paid.

6. **Pages 24–28:** Cannon had sharp eyes and a good memory and soon became the fastest computer—she could classify three stars per minute. How did she identify a problem with the classification system? *The computers used magnifying glasses to examine the spectrographs. They used the dark lines on the spectrographs to determine what the star was made of and how hot it was and then ranked the stars (named according to letters of the alphabet) on the basis of their spectral characteristics. Cannon noticed, for example, that the O stars (the brightest) were the hottest and the A stars were the third hottest. So, she developed a shorter, more accurate star classification system that organized the classes of stars from hottest to coolest—O, B, A, F, G, K, M. Her system is still used today and is remembered by the mnemonic "Oh Be A Fine Guy/Girl, Kiss Me."*

7. **Pages 26–29:** Introduce a discussion of the importance of Cannon's model for classifying stars in ranked order from hottest to coolest by asking the following questions. How did Cannon become known as "the census taker of the stars"? Why is this system needed, and why is it important to science? How does this science activity of re-creating Cannon's classification system on a model help you think about Cannon's imaginative model for classifying the stars? *This is a complex model, and students are expected to understand only that she saw patterns in both the spectra and the temperatures of stars and that she reorganized the alphabetical lettering system (OBAFGKM) to classify stars from hottest (O) to coolest (M).*

Making Sense

Explore

Begin by holding a discussion about rainbows to help students recall their knowledge of refraction—the bending and separating of light into a spectrum of colors. Although refraction is not the lesson focus, this discussion will help students connect the lesson to Annie Jump Cannon's interest in and research about stars. Initiate the discussion by asking, "When do we see rainbows?" "What are the colors of the rainbow?" and "What causes rainbows?" *Rainbows appear when rain and sunlight interact in a specific manner. When sunlight passes through water droplets, the droplets act like prisms and refract (bend) the various wavelengths of light that make up white light, which we then see as a spectrum of colors—red, orange, yellow, green, blue, indigo, and violet (ROYGBIV). Cannon worked with images collected through telescopes equipped with prisms and recognized that the different classes of stars emitted light composed of particular wavelengths, which could be distinguished by their refraction through the prisms.*

Extend the discussion to students' experience of light from the Sun and other stars. Ask, "What do we know about the light that comes from the Sun, which is one of the largest stars in our galaxy?" Encourage students to share personal experiences and observations of the nature of light from the Sun (e.g., what sunlight feels like on their skin, that sunlight passes through clouds and windows, and that blocking sunlight produces shadows). Then, inform students that they will conduct an exploration of how the Sun's light behaves when it strikes various objects. *This exploration focuses on reflection, the bouncing of light rays off an object, which allows us to see the object. It is organized in two parts and will work best in a darkened classroom with the lights off and the shades drawn.* The steps of the exploration are as follows:

1. Organize students into table groups and provide each group with a rock, a cup of water, a piece of aluminum foil, a piece of white paper, and a small plastic bag. Each student will need a flashlight. Invite students to examine each item and predict what will happen when they shine a flashlight on it. Encourage students to think of the flashlight as the Sun. Guide their thinking

by asking, "What will happen to the light when it hits this object?" "Where will the light go?" and "Will the light rays pass through, be blocked, or be reflected?" Have students record their predictions in their science notebooks; encourage them to create a chart so they can record both their predictions and their test results. Then, allow some time for students to use their flashlights to test their predictions. *Students should find that the opaque objects (rock and paper) will block some light and cast a shadow; the shiny object (aluminum foil) will reflect or redirect some of the light; and the clear objects (water and plastic bag) will allow most or all of the light to pass through. Note that all the objects actually reflect some light, although this will not be obvious to your students. This fine point may become clear in the "Extend" and "Explain" sections that follow.*

2. Have students work in pairs. Provide each pair with a flashlight and a small acrylic mirror. Begin with the guiding question, "What happens when the Sun's light reflects off a mirror?" Prompt students to think of their flashlight as the Sun, and invite them to work together to observe what happens when they shine their flashlight on the mirror. They should easily observe a reflected light beam if they lay the flashlight on the table and shine it into a mirror held perpendicular to the table so that some of the light spills onto the table. Once they recognize the line of reflected light, ask, "How can you change the line of reflected light?" Challenge students to record their data by creating three diagrams in their science notebooks. Each diagram should include an arrow to show the direction of the reflected (outgoing) light. *Students may need to adjust the angle of the mirror and the distance between the flashlight and the mirror. Once students have completed their three diagrams, ask, "What pattern do you see?" Students should be able to explain that light reflecting from the mirrors travels in a straight line and that the angle of reflection changes when the position of the mirror changes.*

Explain

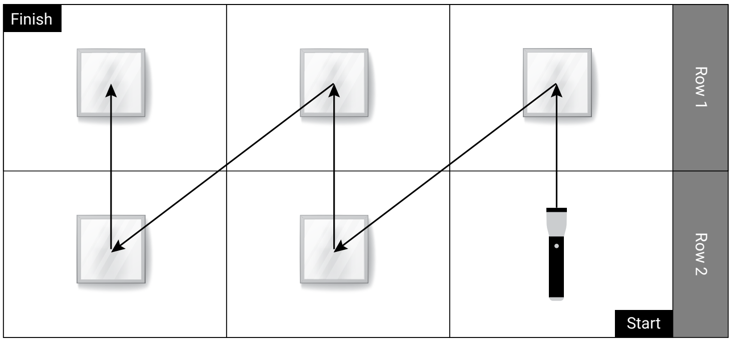
Encourage students to summarize their understanding of the different ways the Sun's light (modeled by the flashlight) behaved when it struck opaque, shiny, and clear objects and the relationship between the angle of the mirror and the line of reflection. *Note: There is a rule for mirror reflections—that the angle of the incidence equals the angle of the reflection—but this is not the point in this lesson. Rather, this lesson introduces the concept of a definite line of light that reflects from the mirror.*

Extend

Organize a light-tag activity. Darken the classroom (turn the lights off and draw the shades) and seat students in two facing rows. Each pair of facing rows is a group. Give a flashlight to a student seated at the end of a row and give small acrylic mirrors to the other students. The goal is for the group members with mirrors to adjust

Figure 3.2

One Way to Organize Students in Rows for Light Tag



them so that the light from the flashlight reflects off each mirror in turn until the light reaches the last person in the group (see Figure 3.2). Then, ask each group to explain what they learned about how to position the mirrors.

Evaluate

Summative evaluation of this lesson will include assessment of students' understanding of (1) what it means to be imaginative and how scientists and engineers might benefit from the character trait of being imaginative and (2) the behavior of light when it hits an object and the benefits of reflected light.

CHARACTER TRAIT

Encourage students to answer the following questions:

1. If Annie Jump Cannon had not designed the starlight classification system, do you think someone else would have? *Although others might eventually have thought of these ideas, Cannon was imaginative and saw a relationship between the heat of the stars and the light being emitted.*
2. Why is being imaginative an important attribute for scientists to have and how was Cannon imaginative? *Imaginative people are clever and often see things that others overlook. In Cannon's case, she perceived the relationship between a star's spectra and its temperature (i.e., she recognized that hotter stars are bluer and cooler stars are redder). From that, she developed a shorter, more accurate system for classifying stars than any astronomer before or since her time.*
3. Brainstorm with a partner about a time when you were (or wished you were) imaginative and/or to think of someone else you consider to be imaginative, such as a family member or neighbor.

CONTENT

You will want to assess students' understanding about how the Sun's light behaves when it strikes opaque, shiny, and clear objects and how light is reflected in a mirror. Table 3.1 is a rubric you might use to evaluate their science notebook entries.

Table 3.1

Rubric for Assessing Student Science Notebook Entries for Starlight—Light From the Sun

Content	Not Yet	Beginning	Developing	Secure
Opaque Objects	Student did not include information about the rock and paper blocking some light and casting a shadow.	Student included some information about the rock and paper blocking some light and casting a shadow.	Student included much information about the rock and paper blocking some light and casting a shadow.	Student included much information about the rock and paper blocking some light and casting a shadow and a clear explanation for that phenomenon.
Shiny Objects	Student did not include information about the aluminum foil reflecting or redirecting some light.	Student included some information about the aluminum foil reflecting or redirecting some light.	Student included much information about the aluminum foil reflecting or redirecting some light.	Student included much information about the aluminum foil reflecting or redirecting some light and a clear explanation for that phenomenon.
Clear Objects	Student did not include information about the water and plastic bag allowing the light to pass through them.	Student included some information about the water and plastic bag allowing the light to pass through them.	Student included much information about the water and plastic bag allowing the light to pass through them.	Student included much information about the water and plastic bag allowing the light to pass through them and a clear explanation for that phenomenon.
Mirror	Student did not produce three diagrams with an arrow showing the direction of the reflected (outgoing) light.	Student produced three diagrams but they did not all have an arrow showing the direction of the reflected (outgoing) light.	Student produced three diagrams and all had an arrow showing the direction of the reflected (outgoing) light.	Has three diagrams that include an arrow to show the direction of the reflected (outgoing) light. Highlights the relationship between the angle of incidence and the angle of reflection.

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Argument-Driven Inquiry in EARTH AND SPACE SCIENCE

LAB INVESTIGATIONS for GRADES 6–10

Victor Sampson, Ashley Murphy,
Kemper Lipscomb, and Todd L. Hutner

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PREFACE

A Framework for K–12 Science Education (NRC 2012; henceforth referred to as the *Framework*) and the *Next Generation Science Standards* (NGSS Lead States 2013; henceforth referred to as the *NGSS*) call for a different way of thinking about why we teach science and what we expect students to know by the time they graduate high school. As to why we teach science, these documents emphasize that schools need to

> ensure by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (NRC 2012, p. 1)

The *Framework* and the *NGSS* are based on the idea that students need to learn science because it helps them understand how the natural world works, because citizens are required to use scientific ideas to inform both individual choices and collective choices as members of a modern democratic society, and because economic opportunity is increasingly tied to the ability to use scientific ideas, processes, and habits of mind. From this perspective, it is important to learn science because it enables people to figure things out or to solve problems.

These two documents also call for a reappraisal of what students need to know and be able to do by time they graduate from high school. Instead of teaching with the goal of helping students remember facts, concepts, and terms, science teachers are now charged with the goal of helping their students become *proficient* in science. To be considered proficient in science, the *Framework* suggests that students need to understand 12 disciplinary core ideas (DCIs) in the Earth and space sciences, be able to use seven crosscutting concepts (CCs) that span the various disciplines of science, and learn how to participate in eight fundamental scientific and engineering practices (SEPs; called science and engineering practices in the *NGSS*).

The DCIs are key organizing principles that have broad explanatory power within a discipline. Scientists use these ideas to explain the natural world. The CCs are ideas that are used across disciplines. These concepts provide a framework or a lens that people can use to explore natural phenomena; thus, these concepts often influence what people focus on or pay attention to when they attempt to understand how something works or why something happens. The SEPs are the different activities that scientists engage in as they attempt to generate new concepts, models, theories, or laws that are both valid and reliable. All three of these dimensions of science are important. Students need to not only know about the DCIs, CCs, and SEPs but also must be able to use all three dimensions at the same time to figure things out or to solve problems. These important DCIs, CCs, and SEPs are summarized in Figure 1.

FIGURE 1

The three dimensions of science in *A Framework for K–12 Science Education* and the *Next Generation Science Standards*

Science and engineering practices	Crosscutting concepts
1. Asking Questions and Defining Problems	1. Patterns
2. Developing and Using Models	2. Cause and Effect: Mechanism and Explanation
3. Planning and Carrying Out Investigations	3. Scale, Proportion, and Quantity
4. Analyzing and Interpreting Data	4. Systems and System Models
5. Using Mathematics and Computational Thinking	5. Energy and Matter: Flows, Cycles, and Conservation
6. Constructing Explanations and Designing Solutions	6. Structure and Function
7. Engaging in Argument From Evidence	7. Stability and Change
8. Obtaining, Evaluating, and Communicating Information	

Disciplinary core ideas in the Earth and space sciences
• ESS1.A: The Universe and Its Stars
• ESS1.B: Earth and the Solar System
• ESS1.C: The History of Planet Earth
• ESS2.A: Earth Materials and Systems
• ESS2.B: Plate Tectonics and Large-Scale System Interactions
• ESS2.C: The Roles of Water in Earth's Surface Processes
• ESS2.D: Weather and Climate
• ESS2.E: Biogeology
• ESS3.A: Natural Resources
• ESS3.B: Natural Hazards
• ESS3.C: Human Impacts on Earth Systems
• ESS3.D: Global Climate Change

Source: Adapted from NRC 2012 and NGSS Lead States 2013

To help students become proficient in science in ways described by the National Research Council in the *Framework,* teachers will need to use new instructional approaches that give students an opportunity to use the three dimensions of science to explain natural phenomena or develop novel solutions to problems. This is important because traditional instructional approaches, which were designed to help students "learn about" the concepts, theories, and laws of science rather than learn how to “figure out” how or why things work, were not created to foster the development of science proficiency inside the classroom. To help teachers make this instructional shift, this book provides 23 laboratory investigations designed using an innovative approach to lab instruction called argument-driven inquiry (ADI). This approach promotes and supports three-dimensional instruction inside classrooms because it gives students an opportunity to use DCIs, CCs, and SEPs to construct and critique claims about how things work or why things happen. The lab activities described in this book will also enable students to develop the disciplinary-based literacy skills outlined in the *Common Core State Standards* for English language arts (NGAC and CCSSO 2010) because ADI gives students an opportunity to give presentations to their peers, respond to audience questions and critiques, and then write, evaluate, and revise reports as part of each lab. Use of these labs, as a result, can help teachers align their teaching with current recommendations for improving classroom instruction in science and for making earth and space science more meaningful for students.

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NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards*.

ABOUT THE AUTHORS

Victor Sampson is an associate professor of STEM (science, technology, engineering, and mathematics) education and the director of the Center for STEM Education at The University of Texas at Austin (UT-Austin). He received a BA in zoology from the University of Washington, an MIT from Seattle University, and a PhD in curriculum and instruction with a specialization in science education from Arizona State University. Victor also taught high school biology and chemistry for nine years. He specializes in argumentation in science education, teacher learning, and assessment. To learn more about his work in science education, go to *www.vicsampson.com.*

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Teacher Notes

Lab 7. Formation of Geologic Features: How Can We Explain the Growth of the Hawaiian Archipelago Over the Past 100 Million Years?

Purpose

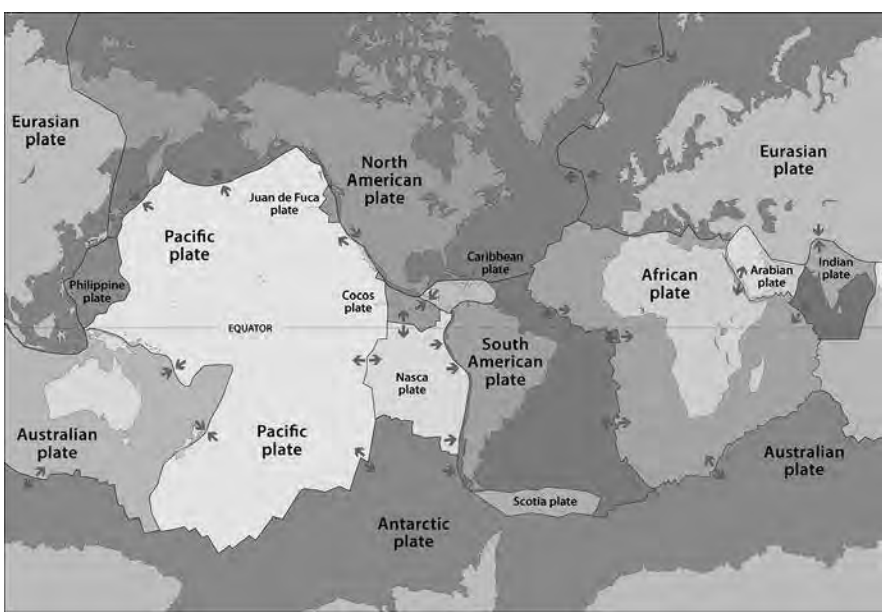
The purpose of this lab is for students to *apply* what they know about the disciplinary core ideas (DCIs) of (a) The History of Planet Earth and (b) Plate Tectonics and Large-Scale System Interactions by having them develop a conceptual model that explains how the Hawaiian archipelago formed over the last 100 million years. In addition, students have an opportunity to learn about the crosscutting concepts (CCs) of (a) Patterns and (b) Systems and System Models. During the explicit and reflective discussion, students will also learn about (a) the use of models as tools for reasoning about natural phenomena and (b) the assumptions made by scientists about order and consistency in nature.

Important Earth and Space Science Content

Scientists use the theory of plate tectonics to explain the origin of many geologic features on Earth. The theory of plate tectonics indicates that the lithosphere is broken into several plates that are constantly moving (see Figure 7.1). The plates are composed of the

FIGURE 7.1

The major tectonic plates



oceanic lithosphere and thicker continental lithosphere. The plates move because they are located on top of giant convection cells in the mantle (see Figure 7.2). These currents bring matter from the hot inner mantle near the outer core up to the cooler surface. The convection cells are driven by the energy that is released when isotopes go through radioactive decay deep within the interior of the Earth. Each of the plates is slowly pushed across Earth's surface in a specific direction by these currents. The plates carry the continents, create or destroy ocean basins, form mountain ranges and plateaus, and produce earthquakes or volcanoes as they move.

FIGURE 7.2

Mechanisms that drive the movement of plates

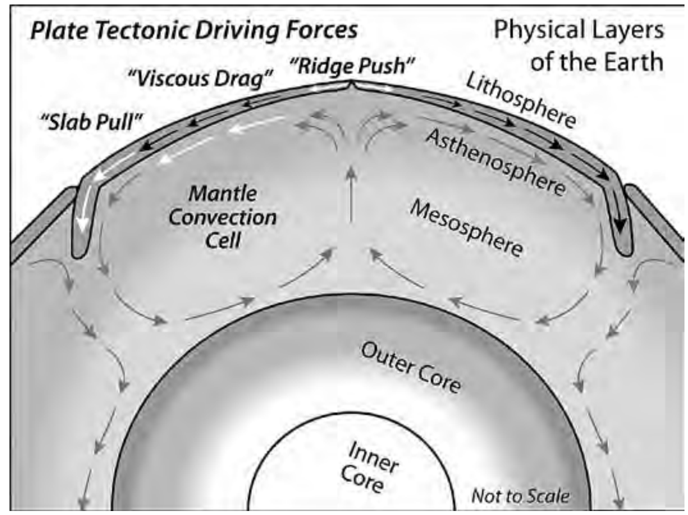
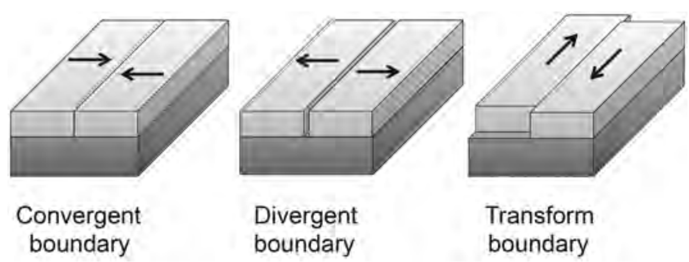


FIGURE 7.3

Tectonic plate boundaries

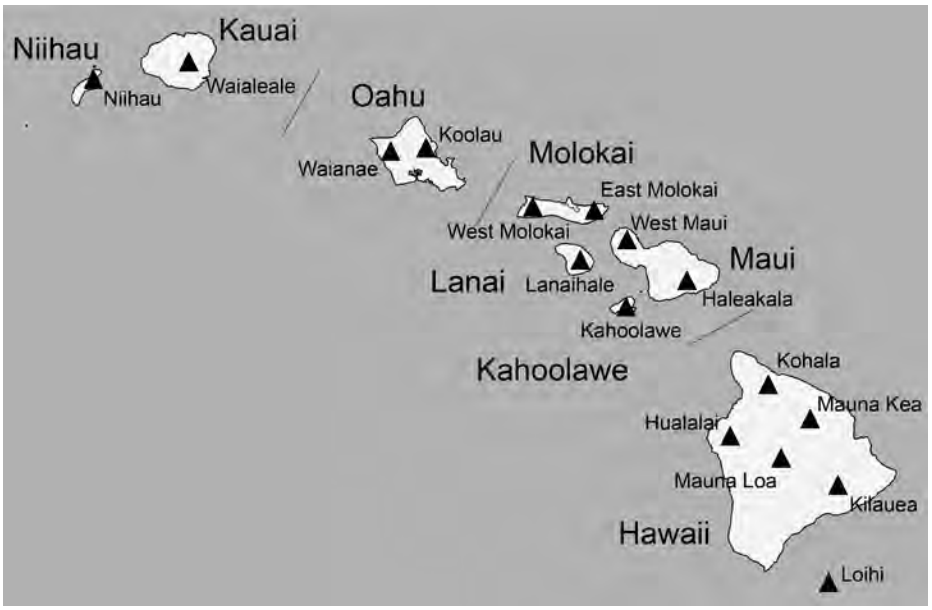


Most of the continental and ocean floor features that we see are the result of either constructive or destructive geologic processes that occur along different types of plate boundaries. There are three main categories of plate boundaries (see Figure 7.3): *convergent boundaries* result when two plates collide with each other, *divergent boundaries* result when two plates move away from each other, and *transform boundaries* occur when plates slide past each other. The nature of the geologic features that we see at a particular location depends on whether the plates are being pushed together to create mountains or ocean trenches, being pulled apart to form new ocean floor at mid-oceanic ridges and rift valleys on continents, or sliding past each other along surface faults.

Earth's surface is still being shaped and reshaped because of the movement of plates. One example of this phenomenon is the Hawaiian Islands, an archipelago in the northern part of the Pacific Ocean that consists of eight major islands, several atolls, and numerous smaller islets. It extends from the island of Hawaii over 2,400 km to the Kure Atoll. Each island is made up of one or more volcanoes (see Figure 7.4, p. 170). The island of Hawaii, for instance, is made up of five different volcanoes. Kohala, the oldest volcano on this island, last erupted about 60,000 years ago. It is an extinct volcano because it will never erupt again. Mauna Kea is the next oldest volcano. It is a dormant volcano because the last time it erupted was 3,600 years ago, but it will probably erupt again at some time in the future. The three youngest volcanoes on Hawaii—Hualalai, Mauna Loa, and Kilauea—are active (see *www.nps.gov/havo/faqs.htm* for more information).

FIGURE 7.4

The Hawaiian archipelago and some of its volcanoes (indicated by triangles)



At first glance, these islands look similar to a volcanic island arc, which is a chain of volcanoes that forms above a subducting plate and takes the form of an arc of islands. An example of a volcanic island arc is the Aleutian Islands (see Figure 7.5). The Hawaiian Islands, however, are not located near a plate boundary, so they are not an example of a volcanic island arc. The Hawaiian Islands are a hotspot volcanic chain. A hotspot volcanic chain is created when volcanoes form one after another in the middle of a tectonic plate, as the plate moves over the hotspot, and so the volcanoes increase in age from one end of the chain to the other. In the case of the Hawaiian Islands, the older islands such as Kauai are located in the northwest. These islands are over 4.5 million years old and lush. The big island of Hawaii, in contrast is, about 400,000 years old and much rockier. Volcanic island arcs do not generally exhibit such a simple age pattern like the ones observed with hotspot volcanic chains.

FIGURE 7.5

The Aleutian Islands, an example of a volcanic island arc

Timeline

The instructional time needed to complete this lab investigation is 220–280 minutes. Appendix 3 (p. 573) provides options for implementing this lab investigation over several class periods. Option A (280 minutes) should be used if students are unfamiliar with scientific writing, because this option provides extra instructional time for scaffolding the writing process. You can scaffold the writing process by modeling, providing examples, and providing hints as students write each section of the report. Option B (220 minutes) should be used if students are familiar with scientific writing and have developed the skills needed to write an investigation report on their own. In option B, students complete stage 6 (writing the investigation report) and stage 8 (revising the investigation report) as homework.

Materials and Preparation

The materials needed to implement this investigation are listed in Table 7.1. The *Natural Hazards Viewer* interactive map, which was developed by the National Oceanic and Atmospheric Administration's National Geophysical Data Center, is available at *http://maps.ngdc.noaa.gov/viewers/hazards*. It is free to use and can be accessed using most internet browsers. You should access the website and learn how the interactive map works before beginning the lab investigation. In addition, it is important to check if students can access and use the interactive map from a school computer or tablet, because some schools have set up firewalls and other restrictions on web browsing.

The Ages of Volcanoes in Hawaiian Islands Excel file can be downloaded from the book's Extras page at *www.nsta.org/adi-ess.* It can be loaded onto student computers before the investigation, e-mailed to students, or uploaded to a class website that students can access. It is important that the computers the students will use during this lab have a spreadsheet application such as Microsoft Excel or Apple Numbers loaded on them, or students must have access to an online spreadsheet application such as Google Sheets. In this way, students can analyze the data set using the computational and graphing tools built into the spreadsheet application. It is also important for you to look over the file before the investigation begins so you can learn how the data in the file are organized. This will enable you to give students suggestions on how to analyze the data.

TABLE 7.1

Materials list for Lab 7

Item	Quantity
Computer or tablet with Excel or other spreadsheet application and internet access	1 per group
Ages of Volcanoes in Hawaiian Island Excel file	1 per group
Investigation Proposal A	1 per group
Whiteboard, 2' × 3'*	1 per group
Lab Handout	1 per student
Peer-review guide and instructor scoring rubric	1 per student
Checkout Questions	1 per student

* As an alternative, students can use computer and presentation software such as Microsoft PowerPoint or Apple Keynote to create their arguments.

Safety Precautions

Remind students to follow all normal lab safety rules.

Topics for the Explicit and Reflective Discussion

Reflecting on the Use of Core Ideas and Crosscutting Concepts During the Investigation

Teachers should begin the explicit and reflective discussion by asking students to discuss what they know about the DCIs they used during the investigation. The following are some important concepts related to the DCIs of (a) The History of Planet Earth and (b) Plate Tectonics and Large-Scale System Interactions that students need to be able to develop a conceptual model that explains the formation of the Hawaiian archipelago:

- The lithosphere is broken into several plates that are constantly moving.
- Plate boundaries are found where one plate interacts with another plate.
- Convergent boundaries result when two plates collide with each other.
- Divergent boundaries result when two plates move apart.
- Transform boundaries are formed when two plates slide past each other.

To help students reflect on what they know about these concepts, we recommend showing them two or three images using presentation software that help illustrate these important ideas. You can then ask the students the following questions in order to encourage students to share how they are thinking about these important concepts:

1. What do we see going on in this image?
2. Does anyone have anything else to add?
3. What might be going on that we can't see?
4. What are some things that we are not sure about here?

You can then encourage students to think about how CCs played a role in their investigation. There are at least two CCs that students need to be able to develop a conceptual model that explains the formation of the Hawaiian archipelago: (a) Patterns and (b) Systems and System Models (see Appendix 2 [p. 569] for a brief description of these two CCs). To help students reflect on what they know about these CCs, we recommend asking them the following questions:

1. Why do scientists look for and attempt to explain patterns in nature?
2. What patterns did you identify and use during your investigation? Why was that useful?

3. Why do scientists often define a system and then develop a model of it as part of an investigation?
4. How did you use a model to understand the formation of the Hawaiian Islands? Why was that useful?

You can then encourage students to think about how they used all these different concepts to help answer the guiding question and why it is important to use these ideas to help justify their evidence for their final arguments. Be sure to remind your students to explain why they included the evidence in their arguments and make the assumptions underlying their analysis and interpretation of the data explicit in order to provide an adequate justification of their evidence.

Reflecting on Ways to Design Better Investigations

It is important for students to reflect on the strengths and weaknesses of the investigation they designed during the explicit and reflective discussion. Students should therefore be encouraged to discuss ways to eliminate potential flaws, measurement errors, or sources of uncertainty in their investigations. To help students be more reflective about the design of their investigation and what they can do to make their investigations more rigorous in the future, you can ask the following questions:

1. What were some of the strengths of the way you planned and carried out your investigation? In other words, what made it scientific?
2. What were some of the weaknesses of the way you planned and carried out your investigation? In other words, what made it less scientific?
3. What rules can we make, as a class, to ensure that our next investigation is more scientific?

Reflecting on the Nature of Scientific Knowledge and Scientific Inquiry

This investigation can be used to illustrate two important concepts related to the nature of scientific knowledge and the nature of scientific inquiry: (a) the use of models as tools for reasoning about natural phenomena and (b) the assumptions made by scientists about order and consistency in nature (see Appendix 2 [p. 569] for a brief description of these two concepts). Be sure to review these concepts during and at the end of the explicit and reflective discussion. To help students think about these concepts in relation to what they did during the lab, you can ask the following questions:

1. I asked you to develop a model to explain the formation of the Hawaiian Islands as part of your investigation. Why is it useful to develop models in science?

2. Can you work with your group to come up with a rule that you can use to decide what a model is and what a model is not in science? Be ready to share in a few minutes.
3. Scientists assume that natural laws operate today as they did in the past and that they will continue to do so in the future. Why do you think this assumption is important?
4. Think about what you were trying to do during this investigation. What would you have had to do differently if you could not assume natural laws operate today as they did in the past?

You can also use presentation software or other techniques to encourage your students to think about these concepts. You can show examples and non-examples of scientific models and then ask students to classify each one and explain their thinking. You can also show images of different scientific laws (such as the law of universal gravitation, the law of conservation of mass, or the law of superposition) and ask students if they think these laws have been the same throughout Earth's history. Then ask them to think about what scientists would need to do to be able to study the past if laws are not consistent through time and space.

Remind your students that, to be proficient in science, it is important that they understand what counts as scientific knowledge and how that knowledge develops over time.

Hints for Implementing the Lab

- Learn how to use the *Natural Hazards Viewer* interactive map and the Ages of Volcanoes in Hawaiian Islands Excel file before the lab begins. It is important for you to know how to use the map and what is included in the Excel file, as well as how to analyze the data, so you can help students when they get stuck or confused.
- A group of three students per computer or tablet tends to work well.
- Allow the students to play with the interactive map and the Excel file as part of the tool talk before they begin to design their investigation. This gives students a chance to see what they can and cannot do with the interactive map and with the data in the file.
- Encourage students to analyze the data in the Age of Volcanoes in Hawaiian Islands Excel file by making graphs. The best way to help students to learn how to use Excel (or another spreadsheet application) is to provide "just-in-time" instruction. In other words, wait for students to get stuck and then give a brief mini-lesson on how to use a specific tool in Excel based on what students are trying to do. They will be much more interested in learning about how to use the

tools in Excel if they know it will help solve a problem they are having or will allow them to accomplish one of their goals.

- Students often make mistakes when developing their conceptual models and/or initial arguments, but they should quickly realize these mistakes during the argumentation session. Be sure to allow students to revise their models and arguments at the end of the argumentation session. The explicit and reflective discussion will also give students an opportunity to reflect on and identify ways to improve how they develop and test models. This also offers an opportunity to discuss what scientists do when they realize a mistake is made.
- Students will likely first infer the existence of a plate boundary that has led to the formation of the Hawaiian Islands. Yet, when they use the *Natural Hazards Viewer* interactive map to locate plate boundaries, they will see that there is no plate boundary near Hawaii. This is a good opportunity to help students think about alternate explanations given that they know no boundary exists and that volcanoes are places where magma comes to the surface. This is also a good opportunity to help students think about ways scientists refine models. The model of plate tectonics as originally conceived could not account for the formation of the Hawaiian archipelago. Thus, scientists used new data to refine their model.
- This lab also provides an excellent opportunity to discuss how scientists must make choices about which data to use and how to analyze the data they have. Be sure to use this activity as a concrete example during the explicit and reflective discussion.

Connections to Standards

Table 7.2 highlights how the investigation can be used to address specific (a) performance expectations from the *NGSS* and (b) *Common Core State Standards* in English language arts (*CCSS ELA*).

TABLE 7.2

Lab 7 alignment with standards

***NGSS* performance expectations**	History of Earth • MS-ESS2-2: Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales. • MS-ESS2-3: Analyze and interpret data on the distribution of fossils and rocks, continental shapes, and seafloor structures to provide evidence of the past plate motions • HS-ESS1-5: Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.

Continued

TABLE 7.2 (*continued*)

***CCSS ELA*—Reading in Science and Technical Subjects**	Key ideas and details • CCSS.ELA-LITERACY.RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts. • CCSS.ELA-LITERACY.RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. • CCSS.ELA-LITERACY.RST.9-10.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. • CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. • CCSS.ELA-LITERACY.RST.9-10.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text. Craft and structure • CCSS.ELA-LITERACY.RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grade 6–8 texts and topics.* • CCSS.ELA-LITERACY.RST.6-8.5: Analyze the structure an author uses to organize a text, including how the major sections contribute to the whole and to an understanding of the topic. • CCSS.ELA-LITERACY.RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text. • CCSS.ELA-LITERACY.RST.9-10.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grade 9–10 texts and topics*. • CCSS.ELA-LITERACY.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*). • CCSS.ELA-LITERACY.RST.9-10.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address. Integration of knowledge and ideas • CCSS.ELA-LITERACY.RST.6-8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

Continued

TABLE 7.2 (*continued*)

***CCSS ELA*—Reading in Science and Technical Subjects** (*continued*)	Integration of knowledge and ideas (*continued*) • CCSS.ELA-LITERACY.RST.6-8.8: Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. • CCSS.ELA-LITERACY.RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. • CCSS.ELA-LITERACY.RST.9-10.7: Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. • CCSS.ELA-LITERACY.RST.9-10.8: Assess the extent to which the reasoning and evidence in a text support the author’s claim or a recommendation for solving a scientific or technical problem. • CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.
***CCSS ELA*—Writing in Science and Technical Subjects**	Text types and purposes • CCSS.ELA-LITERACY.WHST.6-10.1: Write arguments focused on *discipline-specific content*. • CCSS.ELA-LITERACY.WHST.6-10.2: Write informative or explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes. Production and distribution of writing • CCSS.ELA-LITERACY.WHST.6-10.4: Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience. • CCSS.ELA-LITERACY.WHST.6-8.5: With some guidance and support from peers and adults, develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on how well purpose and audience have been addressed. • CCSS.ELA-LITERACY.WHST.6-8.6: Use technology, including the internet, to produce and publish writing and present the relationships between information and ideas clearly and efficiently. • CCSS.ELA-LITERACY.WHST.9-10.5: Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.

Continued

TABLE 7.2 (*continued*)

***CCSS ELA*—Writing in Science and Technical Subjects** (*continued*)	Production and distribution of writing (*continued*) • CCSS.ELA-LITERACY.WHST.9-10.6: Use technology, including the internet, to produce, publish, and update individual or shared writing products, taking advantage of technology's capacity to link to other information and to display information flexibly and dynamically. Range of writing • CCSS.ELA-LITERACY.WHST.6-10.10: Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.
***CCSS ELA*—Speaking and Listening**	Comprehension and collaboration • CCSS.ELA-LITERACY.SL.6-8.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 6–8 topics, texts, and issues, building on others' ideas and expressing their own clearly. • CCSS.ELA-LITERACY.SL.6-8.2:* Interpret information presented in diverse media and formats (e.g., visually, quantitatively, orally) and explain how it contributes to a topic, text, or issue under study. • CCSS.ELA-LITERACY.SL.6-8.3:* Delineate a speaker's argument and specific claims, distinguishing claims that are supported by reasons and evidence from claims that are not. • CCSS.ELA-LITERACY.SL.9-10.1: Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively. • CCSS.ELA-LITERACY.SL.9-10.2: Integrate multiple sources of information presented in diverse media or formats (e.g., visually, quantitatively, orally) evaluating the credibility and accuracy of each source. • CCSS.ELA-LITERACY.SL.9-10.3: Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric, identifying any fallacious reasoning or exaggerated or distorted evidence. Presentation of knowledge and ideas • CCSS.ELA-LITERACY.SL.6-8.4:* Present claims and findings, sequencing ideas logically and using pertinent descriptions, facts, and details to accentuate main ideas or themes; use appropriate eye contact, adequate volume, and clear pronunciation. • CCSS.ELA-LITERACY.SL.6-8.5:* Include multimedia components (e.g., graphics, images, music, sound) and visual displays in presentations to clarify information.

Continued

TABLE 7.2 (*continued*)

***CCSS ELA*—Speaking and Listening** (*continued*)	Presentation of knowledge and ideas (*continued*) • CCSS.ELA-LITERACY.SL.6-8.6: Adapt speech to a variety of contexts and tasks, demonstrating command of formal English when indicated or appropriate. • CCSS.ELA-LITERACY.SL.9-10.4: Present information, findings, and supporting evidence clearly, concisely, and logically such that listeners can follow the line of reasoning and the organization, development, substance, and style are appropriate to purpose, audience, and task. • CCSS.ELA-LITERACY.SL.9-10.5: Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. • CCSS.ELA-LITERACY.SL.9-10.6: Adapt speech to a variety of contexts and tasks, demonstrating command of formal English when indicated or appropriate.

* Only the standard for grade 6 is provided because the standards for grades 7 and 8 are similar. Please see *www.corestandards.org/ELA-Literacy/SL* for the exact wording of the standards for grades 7 and 8.

Lab Handout

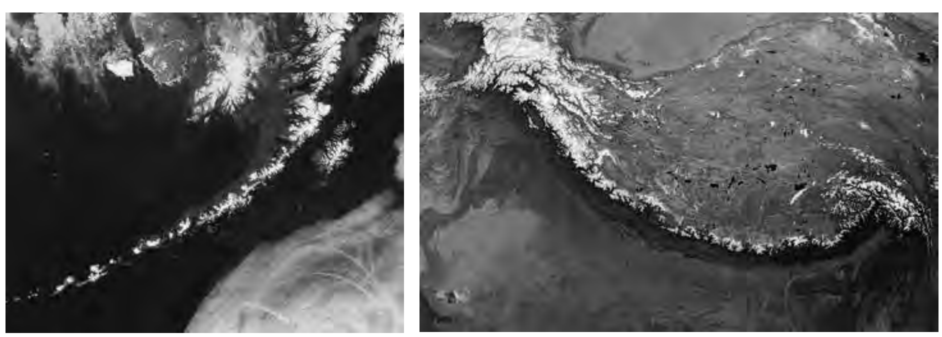
Lab 7. Formation of Geologic Features: How Can We Explain the Growth of the Hawaiian Archipelago Over the Past 100 Million Years?

Introduction

Scientists use the theory of plate tectonics to explain current and past movements of the rocks at Earth's surface and the origin of many geologic features such as those shown in Figure L7.1. The theory of plate tectonics indicates that the lithosphere is broken into several plates that are in constant motion. Multiple lines of evidence support this theory. This evidence includes, but is not limited to, the location of earthquakes, chains of volcanoes (see Figure L7.1A), and non-volcanic mountain ranges (see Figure L7.1b) around the globe; how land under massive loads (such as lakes or ice sheets) can bend and even flow; the existence of mid-oceanic ridges; and the age of rocks near these ridges.

FIGURE L7.1

(a) The Aleutian archipelago, a chain of volcanic islands in Alaska; (b) the Himalayas, a nonvolcanic mountain range in Asia separating the plains of the Indian subcontinent from the Tibetan plateau



a b

The plates are composed of oceanic and continental lithosphere. The plates move because they are located on top of giant convection cells in the mantle (see Figure L7.2). These currents bring matter from the hot inner mantle near the outer core up to the cooler surface and return cooler matter back to the inner mantle. The convection cells are driven by the energy that is released when isotopes deep within the interior of the Earth go through radioactive decay. The movement of matter in the mantle produces forces, which include viscous drag, slab pull, and ridge push, that together slowly move each of the plates across Earth's surface in a specific direction. The plates carry the continents, create or destroy ocean basins, form mountain ranges and plateaus, and produce earthquakes or volcanoes as they move.

Many interesting Earth surface features, such as the ones shown in Figure L7.1, are the result of either constructive or destructive geologic processes that occur along plate boundaries. There are three main types of plate boundaries (see Figure L7.3): *convergent boundaries* result when two plates collide with each other, *divergent boundaries* result when two plates move away from each other, and *transform boundaries* occur when plates slide past each other. We can explain many of the geologic features we see on Earth's surface when we understand how plates move and interact with each other over time.

Earth's surface is still being shaped and reshaped because of the movement of plates. One example of this phenomenon is the Hawaiian Islands. The Hawaiian Islands is an archipelago in the northern part of the Pacific Ocean that consists of eight major islands, several atolls, and numerous smaller islets. It extends from the island of Hawaii over 2,400 kilometers to the Kure Atoll. Each island is made up of one or more volcanoes (see Figure L7.4). The island of Hawaii, for instance, is made up of five different volcanoes. Two of the volcanoes found on the island of Hawaii are called Mauna Loa and Kilauea. Mauna Loa is the largest active volcano on Earth, and Kilauea is one of the most productive volcanoes in terms of how much lava erupts from it each year.

The number of islands in the Hawaiian archipelago has slowly increased over the last 100 million years. In this investigation, you will attempt to explain why these islands

FIGURE L7.2

Convection cells in the mantle

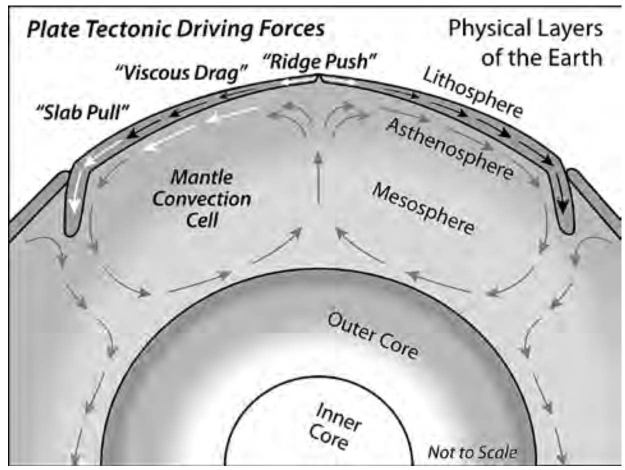


FIGURE L7.3

The three types of plate boundaries

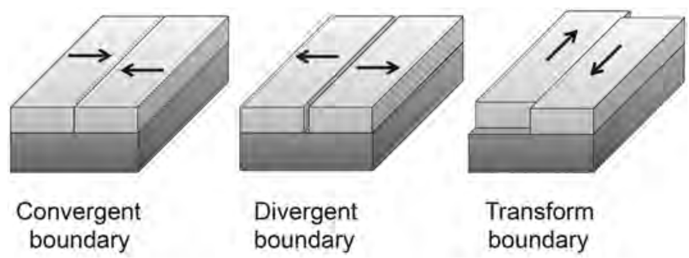
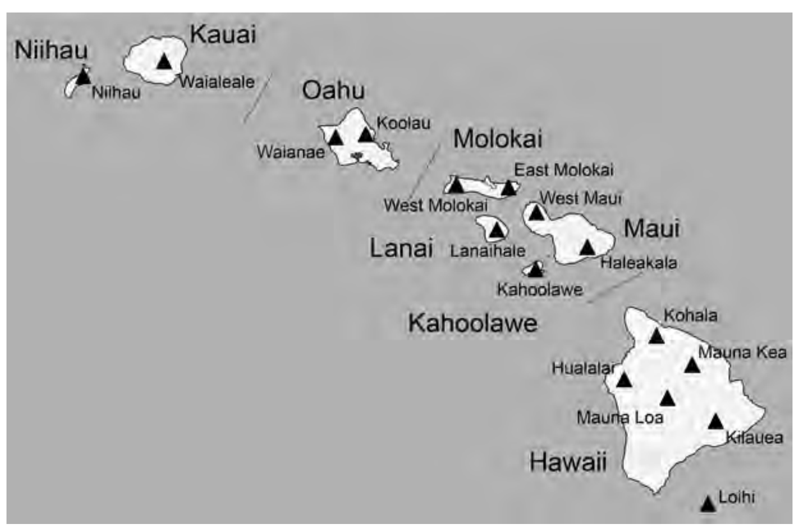


FIGURE L7.4

The Hawaiian archipelago and some of its volcanoes



are in the middle of the Pacific Ocean, why they form a chain instead of some other shape, why some of the islands are bigger than other ones, and why the number of islands in the archipelago has slowly increased over time.

Your Task

Develop a conceptual model that you can use to explain how the Hawaiian archipelago formed over the last 100 million years. Your conceptual model must be based on what we know about patterns, systems and system models, and the movement of Earth's plates over time. You should be able to use your conceptual model to predict when and where you will see a new island appear in the Hawaiian archipelago.

The guiding question of this investigation is, ***How can we explain the growth of the Hawaiian archipelago over the past 100 million years?***

Materials

You will use a computer with Excel or other spreadsheet application during your investigation. You will also use the following resources:

- *Natural Hazards Viewer* online interactive map, available at *http://maps.ngdc.noaa.gov/viewers/hazards*
- Ages of Volcanoes in Hawaiian Islands Excel file; your teacher will tell you how to access the Excel file.

Safety Precautions

Follow all normal lab safety rules.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

The first step in the development of your conceptual model is to learn as much as you can about the geologic activity around the Hawaiian archipelago. You can use the *Natural Hazards Viewer* interactive map to determine the location of any plate boundaries around the islands, the location of volcanoes on and around each island, and the occurrence and magnitude of earthquakes in the area. As you use the *Natural Hazards Viewer,* be sure to consider the following questions:

- What are the boundaries and the components of the system you are studying?
- How do the components of this system interact with each other?
- How can you quantitatively describe changes within the system over time?
- What scale or scales should you use to when you take your measurements?

- What is going on at the unobservable level that could cause the things that you observe?

The second step in the development of your conceptual model is to learn more about the characteristics of the volcanoes in the Hawaiian archipelago. You can use the Excel file called Ages of Volcanoes in Hawaiian Islands to determine which volcanoes are active and which are dormant, the distances between the volcanoes, and the age of each volcano. As you analyze the data in this Excel file, be sure to consider the following questions:

- What types of patterns could you look for in your data?
- How could you use mathematics to describe a relationship between two variables?
- What could be causing the pattern that you observe?
- What graphs could you create in Excel to help you make sense of the data?

Once you have learned as much as you can about Hawaiian archipelago system, your group can begin to develop your conceptual model. A conceptual model is an idea or set of ideas that explains what causes a particular phenomenon in nature. People often use words, images, and arrows to describe a conceptual model. Your conceptual model needs to be able to explain the origin of the Hawaiian archipelago. It also needs to be able to explain

- why the islands form a chain and not some other shape,
- why the number of islands has increased over the last 100 million years,
- why some islands are bigger than other ones, and
- what will likely happen to the Hawaiian archipelago over the next 100 million years.

The last step in your investigation will be to generate the evidence you to need to convince others that your model is valid and acceptable. To accomplish this goal, you can attempt to show how using a different version of your model or making a specific change to a portion of your model would make your model inconsistent with what we know about the islands in the Hawaiian archipelago. Scientists often make comparisons between different versions of a model in this manner to show that a model they have developed is valid or acceptable. You can also use the *Natural Hazards Viewer* to identify other chains of volcanoes that are similar to ones found in the Hawaiian archipelago. You can then determine if you are able to use your model to explain the formation of other chains of volcanoes. If you are able to show how your conceptual model explains the formation of the Hawaiian archipelago better than other models or that you can use your conceptual model to explain many different phenomena, then you should be able to convince others that it is valid or acceptable.

Connections to the Nature of Scientific Knowledge and Scientific Inquiry

As you work through your investigation, be sure to think about

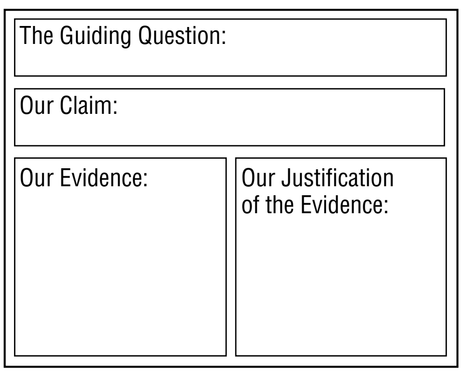
- the use of models as tools for reasoning about natural phenomena in science, and
- the assumptions made by scientists about order and consistency in nature.

Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your initial argument needs to include a claim, evidence to support your claim, and a justification of the evidence. The *claim* is your group's answer to the guiding question. The *evidence* is an analysis and interpretation of your data. Finally, the *justification* of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L7.5.

FIGURE L7.5

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One or two members of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. This is similar to what scientists do when they propose, support, evaluate, and refine new ideas during a poster session at a conference. If you are presenting your group's argument, your goal is to share your ideas and answer questions. You should also keep a record of the critiques and suggestions made by your classmates so you can use this feedback to make your initial argument stronger. You can keep track of specific critiques and suggestions for improvement that your classmates mention in the space below.

Critiques of our initial argument and suggestions for improvement:

If you are critiquing your classmates' arguments, your goal is to look for mistakes in their arguments and offer suggestions for improvement so these mistakes can be fixed. You should look for ways to make your initial argument stronger by looking for things that the other groups did well. You can keep track of interesting ideas that you see and hear during the argumentation in the space below. You can also use this space to keep track of any questions that you will need to discuss with your team.

Interesting ideas from other groups or questions to take back to my group:

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the best argument possible.

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections. Each section should provide an answer for the following questions:

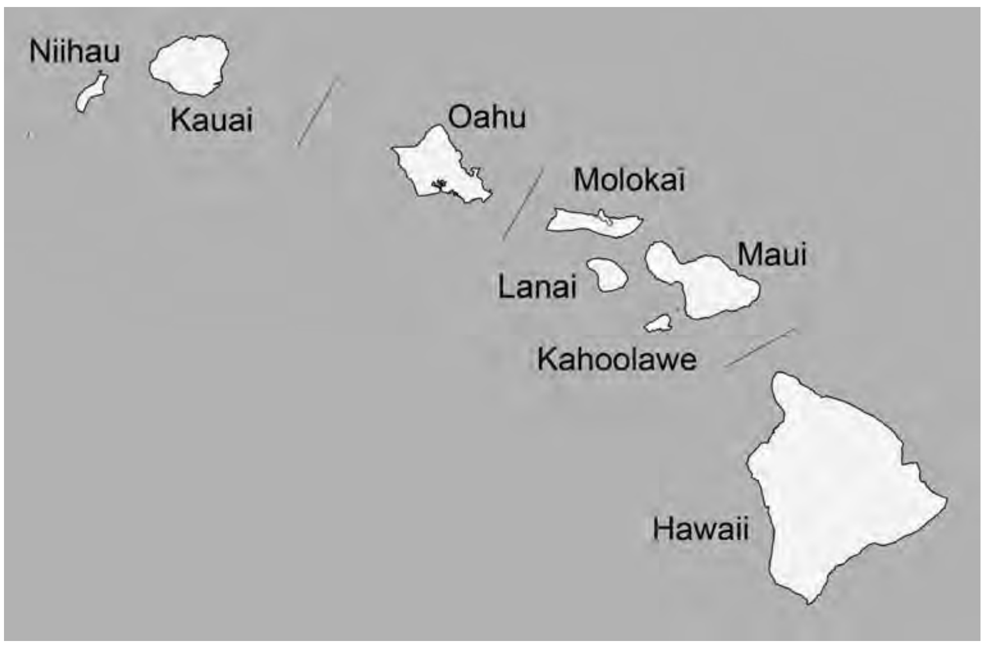
1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. You should write your report using a word processing application (such as Word, Pages, or Google Docs), if possible, to make it easier for you to edit and revise it later. You should embed any diagrams, figures, or tables into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid.

Checkout Questions

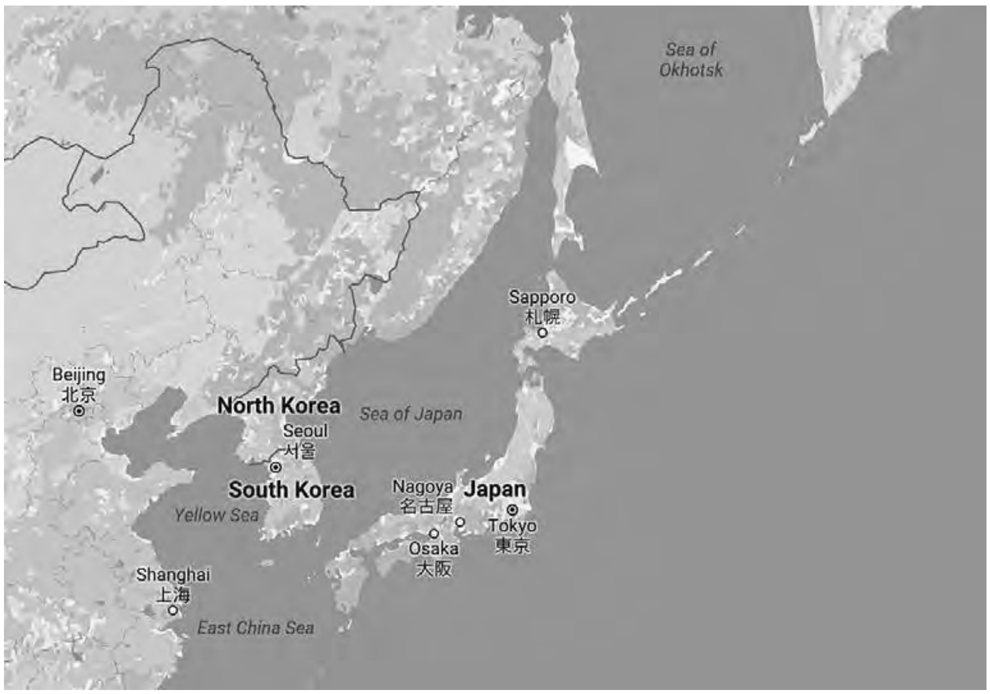
Lab 7. Formation of Geologic Features: How Can We Explain the Growth of the Hawaiian Archipelago Over the Past 100 Million Years?

1. Below is a map of the Hawaiian archipelago, shown from above. On the map, draw what you think the archipelago will look like in 100 million years.



Explain your drawing below.

2. Below is a picture of the Japanese archipelago. What information would you need to determine if the Japanese archipelago formed in the same way the Hawaiian archipelago formed?



3. Scientists can change or refine a model when presented with new evidence.

   a. I agree with this statement.

   b. I disagree with this statement.

Explain your answer, using an example from your investigation about the formation of the Hawaiian archipelago.

4. When trying to understand events that happened in the past, scientists assume that natural laws operate today in the same way as they did in the past.

   a. I agree with this statement.
   b. I disagree with this statement.

   Explain your answer, using an example from your investigation about the formation of the Hawaiian archipelago.

5. In science, it is important to define a system under study and then develop a model of the system. Explain why this is important to do, using an example from your investigation about the formation of the Hawaiian archipelago.

6. Scientists often look for patterns as part of their work. Explain why it is important to identify patterns during an investigation, using an example from your investigation about the formation of the Hawaiian archipelago.

Argument-Driven Inquiry in EARTH AND SPACE SCIENCE

LAB INVESTIGATIONS for GRADES 6–10

Are you interested in using Argument-Driven Inquiry (ADI) for middle and high school lab instruction, but just aren't sure how to do it? You aren't alone. *Argument-Driven Inquiry in Earth and Space Science* will provide you with the information and instructional materials you need to start using this method right away. The book is a one-stop source of expertise, advice, and investigations to help Earth and space science students work the way scientists do.

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This book is part of NSTA's best-selling series about ADI in middle school life science and physical science. Additional ADI books are available for high school chemistry, biology, and physics. Like its predecessors, this collection is designed to be easy to use, with teacher notes, student handouts, and checkout questions. The labs also support the *Next Generation Science Standards* and *Common Core State Standards*.

Many of today's middle and high school teachers—like you—want new ways to engage students in scientific practices and help them learn more from lab activities. *Argument-Driven Inquiry in Earth and Space Science* does all of this in addition to giving students the chance to practice reading, writing, speaking, and using math in the context of science.

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GRADES 6–10

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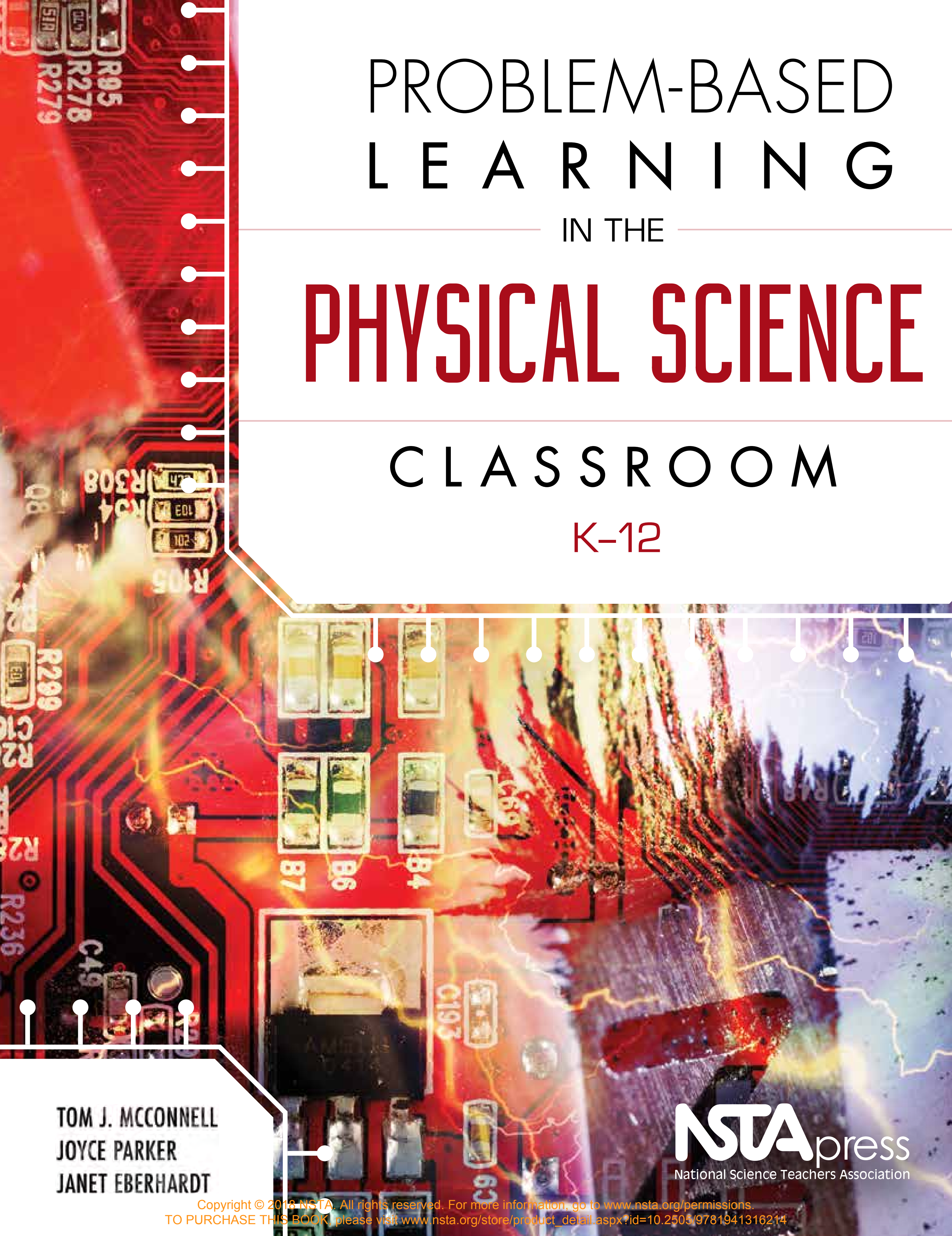

PROBLEM-BASED LEARNING IN THE PHYSICAL SCIENCE CLASSROOM

K–12

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CONTENTS

PREFACE

In science education, there are numerous strategies designed to promote learners' ability to apply science understanding to authentic situations and build connections between concepts (Bybee, Powell, and Trowbridge 2008). Problem-based learning (PBL; Delisle 1997; Gijbels et al. 2005; Torp and Sage 2002) is one of these strategies. PBL originated as a teaching model in medical schools (Barrows 1986; Schmidt 1983) and is relevant for a wide variety of subjects. Science education, in particular, lends itself to the PBL structure because of the many authentic problems that reflect concepts included in state science standards and the *Next Generation Science Standards* (*NGSS;* NGSS Lead States 2013).

The Problem-Based Learning Framework

PBL is a teaching strategy built on a constructivist epistemology (Savery and Duffy 1995) that presents learners with authentic and rich, but incompletely defined, scenarios. These "problems" represent science as it appears in the real world, giving learners a reason to collaborate with others to analyze the problem, ask questions, pose hypotheses, identify information needed to solve the problem, and find information through literature searches and scientific investigations. The analysis process leads the learners to co-construct a proposed solution (Torp and Sage 2002).

One strength of the PBL framework is that learners are active drivers of the learning process and can develop a deeper understanding of the concepts related to the problem starting from many different levels of prior understanding. PBL is an effective strategy for both novices and advanced learners. PBL is also flexible enough to be useful in nearly any science context.

One challenge for teachers and educational planners, though, is that implementing PBL for the classroom requires advance planning. An effective problem should be authentic, and the challenges presented in the problems need to be both structured and ill-defined to allow genuine and productive exploration by students. Meyer (2010) suggested that these problems help students learn to be "patient problem solvers." For most instructors, getting started with PBL in the science classroom is easiest with existing problems. However, there are very few tested PBL problems available in print or on the internet. Valuable resources exist that describe in general what PBL is, how to develop lessons, and how PBL can help students, but curriculum resources are much harder to find.

In this book, we present a discussion of the PBL structure and its application for the K–12 science classroom. We also share a collection of PBL problems developed as part of the PBL Project for Teachers (PBL Project), a National Science Foundation–funded professional development program that used the PBL framework to help teachers develop a deeper understanding of science concepts in eight different content strands (McConnell et al. 2008; McConnell, Parker, and Eberhardt 2013). Each content strand had a group of participants and facilitators who focused on specific concepts within one of the science disciplines, such as genetics, weather, or forces and motion. The problems presented in this book were developed by content experts who facilitated the workshops and revised the problems over the course of four iterations of the workshops. Through our work to test and revise the problems, we have developed a structure for the written problem that we feel will help educators implement the plans in classrooms.

Because the problems have been tested with teachers, we have published research describing the effectiveness of the problems in influencing teachers' science content knowledge (McConnell, Parker, and Eberhardt 2013). The research revealed that individuals with very little familiarity with science concepts can learn new ideas using the PBL structure and that the same problem can also help experienced science learners with a high degree of prior knowledge refine their understanding and learn to better explain the mechanisms for scientific phenomena.

Alignment With the *Next Generation Science Standards*

To ensure that the problems presented here are useful to science teachers, we have included information aligning the objectives and learning outcomes for each problem with the *NGSS* (NGSS Lead States 2013). The *NGSS* present performance expectations for science education that describe three intertwined dimensions of science learning: science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCs). The *NGSS* emphasize learning outcomes in which students integrate the SEPs, DCIs, and CCs in a seamless way, resulting in flexible and widely applicable understanding.

The learning targets for the PBL problems included in this book were originally written with attention to the science concepts—what the *NGSS* calls disciplinary core ideas. The aim of the PBL Project was to enhance teachers' knowledge of these core ideas. But implicit in the design of the PBL process is the need for learners to use the practices of science and make connections between concepts that reflect the CCs listed in the standards. PBL problems align well with the *NGSS* because these real-world situations present problems in a similar framework: SEPs, DCIs, and CCs are natural parts of the problems. We describe the alignment of the PBL problems with the *NGSS* in more detail in Chapter 2. As states begin to adopt these standards or adapt them into state standards, Chapter 2 should help teachers and teacher educators fit the problems within their local curricula.

Intended Audiences and Organization of the Book

As mentioned earlier, the PBL problems in this book have been shown to be effective learning tools for learners with differing levels of prior knowledge. Some teachers who participated in the PBL Project used problems from the workshops in their K–12 classrooms, and facilitators with the project have also incorporated problems from this collection into university courses.

Chapter 2 discusses the alignment of the PBL problems and analytical framework with the *NGSS.* Chapter 3 describes strategies for facilitating the PBL lessons. In Chapter 4, we share tips for the classroom teacher on grouping students, managing information, and assessing student learning during the PBL process.

Chapters 5–8 present the problems we have designed and tested. Each chapter includes problems from one content strand (describing motion, forces and motion, engineering energy transformations, or engineering electricity and magnetism), alignment with the *NGSS,* the assessment questions we used to evaluate learning, model responses to the assessments, and resources for the teacher and students that help provide relevant information about the science concept and problem. To help you locate the problems that are most appropriate for your classroom, we have included a catalog of problems (see p. xi); the catalog is in tabular format and will let you scan the list of problems by content topic, keywords and concepts, and grade bands for which the problems were written.

We hope that this collection of problems will serve as a model for educators who want to design and develop problems of their own. For instance, some problems in this book, such as Rescue Force (Chapter 6) and Rube Goldberg Machine (Chapter 7), use materials that may not be available or procedures that may not be possible in some classroom settings. A teacher with a different set of available materials should modify the problems and activity guides to match the context of his or her classroom. In these cases, we encourage teachers to modify and adapt problems to fit contexts familiar to their own students. Chapter 9 discusses features of an effective problem that can help guide the efforts of teachers wishing to create their own PBL lessons.

This book is the third volume in a series. The first volume presented life science problems, and the second volume offered problems specifically written for teaching Earth and space science. This volume features physical science problems. The fourth volume will contain tips and examples for planners of teacher professional development programs. As you modify and implement lessons from these books, you can begin to develop your own problems that meet the needs of your students.

Safe and Ethical Practices in the Science Classroom

With hands-on, process- and inquiry-based laboratory or field activities, the teaching and learning of science today can be both effective and exciting. Successful science teaching needs to address potential safety issues. Throughout this book, safety precautions are described for investigations and need to be adopted and enforced in efforts to provide for a safer learning and teaching experience.

Additional applicable standard operating procedures can be found in the National Science Teacher Association's Safety in the Science Classroom, Laboratory, or Field Sites document (*www.nsta.org/docs/SafetyInTheScienceClassroomLabAndField.pdf*).

Disclaimer: The safety precautions of each activity are based in part on use of the recommended materials and instructions, legal safety standards, and better professional practices. Selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

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CATALOG OF PROBLEMS

Problem	Page Number	Keywords and Concepts	Grade Band: Grades K–2	Grade Band: Grades 3–5	Grade Band: Grades 6–8	Grade Band: Grades 9–12
CHAPTER 5: GET MOVING						
1. Get Me Out of Here	70	Distance, direction, motion	•	•	•	
2A. Fastest Beetle	82	Distance, position, speed		•		
2B. Fastest Human	91	Distance, position, instantaneous and average speed or velocity			•	•
3. Constantly Moving	101	Distance, position, time, speed, velocity		•	•	•
4. Good Driver	109	Distance, position, time, speed, velocity, acceleration		•	•	•
CHAPTER 6: FORCES AND MOTION						
1. Asteroid Field	130	Force, acceleration, direction, speed, velocity, Newton's first and second laws of motion	•	•	•	
2. Cartoon Cliff Escape	141	Force, acceleration, velocity, speed, direction, gravity, vertical motion		•	•	
3. Rescue Force	149	Force, acceleration, direction, mass		•	•	
CHAPTER 7: ENGINEERING ENERGY TRANSFORMATIONS						
1. An Energetic Ride	164	Conservation of energy, kinetic energy, potential energy, energy transfers and transformations		•	•	
2. Rube Goldberg Machine	176	Energy conservation, kinetic energy, potential energy		•	•	•
3. Keep It Warm, Keep It Chill	189	Thermal energy, energy transfer, insulation, conduction			•	•
CHAPTER 8: ENGINEERING ELECTRICITY AND MAGNETISM						
1. A Light in the Dark	205	Electrical circuits, batteries, light bulbs, electricity		•	•	•
2. Wiring a Cabin	218	Electrical circuits, electricity, batteries, light bulbs, fuses, switches		•	•	•
3. Cool It	229	Electricity, magnetism, electric current, electric magnet, electric motor, polarity		•	•	•

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3

FACILITATING PROBLEM-BASED LEARNING

The experience of being the teacher in a science classroom during a problem-based learning (PBL) activity is a bit different from what you might experience for other types of lessons. In some learning activities, your role is that of content expert or presenter of information. The students might be involved in recording information, listening, or perhaps applying new ideas. Alternatively, students might be carrying out some kind of science investigation as you direct and guide with questions. These roles are certainly appropriate, but PBL requires something different.

In PBL, the teacher definitely steps away from the lead role and instead becomes a *facilitator.* Educators use this term a lot in teaching, but for our model of PBL, we believe this role is accentuated. The facilitator's role is to supply minimal information but to provide resources and ask questions to guide the process. The students become more active participants in the discussion and even take the lead in identifying next steps and issues that need to be explored and evaluating their own ideas.

These new roles take practice—for both teacher and students. Students need to take risks in sharing and defending their ideas using information and evidence. Your role requires skillful questioning to guide without leading and, just as important, the ability to say nothing and let students explore their own ideas to find their misconceptions. In this chapter, we will use a vignette format to provide examples of what you might see in a classroom in which PBL is being taught, with a focus on how the teacher can guide discussions during the lesson. We will also share tips and strategies for successful facilitation of a PBL lesson; additional tips are provided in Chapter 4, "Using Problems in K–12 Classrooms." Some of what we share in this chapter is the result of our research on effective facilitation of PBL (Zhang et al. 2010), and some is based on our personal experience and teaching styles.

Remember, as you implement the lessons you select from this book, you may find that you need to practice your role as a PBL facilitator, and it takes time and practice to learn how to respond to students' ideas on the fly.

Moves to Make as You Go Along: Stage-Specific Advice

Facilitating PBL problems feels very different from traditional teaching and may require some strategies that are not part of your normal routine. Throughout this chapter, we will offer some "moves" you can plan to make. These are deliberate tactics to help your students think and talk about the problem they are analyzing, and the tips help you move into facilitator mode. It can be hard to remember that your role has shifted. You need to hold in some of your expertise and let your students struggle a bit with the challenges of solving a real problem. It is hard to do this, because you want to help them, but in the long run, stepping into the role of facilitator will help your students gain confidence and skills they need to think critically. And that's an important goal!

Still, there may be times when you need to share your knowledge of the concept. This may mean giving some examples of phenomena that demonstrate a process or explaining how certain ideas are connected. You also may need to ask questions to informally assess students' understanding or clarify what a student means by a comment or question. These moves are important in facilitating students' analysis of a PBL problem and in helping students make sense of the information they are finding. Part of the art of facilitation is learning when to use your content knowledge and when to hold back and let students explore an idea. For the beginning facilitator, we recommend patience. If in doubt, let students work for a bit, and then share your expertise.

Explaining Discussion Guidelines

Because you and your students may be experiencing PBL for the first time, it is important to set some guidelines for a PBL lesson. Discussion about real-world problems may reveal some strong opinions, some misconceptions, and some differences in beliefs and values that may be difficult for younger learners to understand. Before you start a PBL lesson, at least until your students learn to operate in this new type of lesson, setting some guidelines will help you manage the discussion and keep the conversation on task and respectful.

In the first section of the following vignette, Ms. Sampson shows the class a list of guidelines for discussing PBL problems. These guidelines are useful in creating a climate in which participants are able to share ideas, pose questions, and propose hypotheses. They may also help create a culture of open discussion in your classroom. Throughout the vignette in this chapter, we have tried to indicate how the science and engineering practices (SEPs) and the crosscutting concepts (CCs) from the *Next Generation Science Standards* (*NGSS;* NGSS Lead States 2013) appear in this lesson. See Chapter 2, "Alignment With Standards," for a complete list of the SEPs and CCs.

Helping Students Function in a Self-Directed Classroom

This recap of discussion guidelines is important to help students start to manage their own learning. Although the PBL framework introduced in Chapter 1 is a good foundation for critical thinking, students may not have experience using a structured process for solving problems. In essence, we are making the metacognition needed to support learning more explicit (Bandura 1986; Dinsmore, Alexander, and Loughlin 2008) in a process that will help students develop the type of self-directed learning abilities we hope all our students can achieve.

Ms. Sampson's Science Classroom: Discussion Guidelines

Ms. Sampson has been planning since the summer to try a new lesson idea. Today she's starting a PBL activity that she thinks will take about three days for her seventh-grade science class to complete. The topic is gravitational forces in her "Forces and Motion" unit, and today's activity follows some lab activities about velocity and the effects of forces on a toy car rolling across the table, as well as a reading from the textbook about gravity.

Ms. Sampson: Class, today we're going to begin a project in which each team will try to understand the motion of falling objects. This will be a chance to make a plan and test what affects how objects fall. We are going to use problem-based learning to look at this topic, so we need to set some discussion guidelines.

She projects a slide with the guidelines and discusses the list (see Box 3.1).

Box 3.1. Guidelines for Discussion

1. Open thinking is required—everyone contributes!
2. If you disagree, speak up! Silence is agreement.
3. Everyone speaks to the group—no side conversations.
4. There are no wrong ideas in a brainstorm—respect all ideas.
5. A scribe will record the group's thinking.
6. The facilitator/teacher will ask questions to clarify and keep the process going.
7. Support claims with evidence or a verifiable source.

The guidelines are important in helping students develop the habits of scientific discourse. A conversation in a scientific context is different from a conversation with friends about sports, music, politics, books, or other topics. So to help our students learn to function in a scientific community, or even just be able to understand the process behind scientific claims they might read about in an online news source, they need to know how we share and develop ideas in science.

At the same time, the guidelines are a reminder to you, as the facilitator, about your role in the discussion. As the facilitator, one of the most difficult tasks is avoiding the urge to give “right answers” to your students. But it is important for you to set an example by respecting new ideas or ideas you are uncertain about. Your role, especially at the beginning of a PBL problem, is to ask questions to clarify, to solicit responses from students who may be hesitant to share ideas, and to be the “referee” when the class rejects one student’s ideas before any evidence has been discussed.

Recording Information

In the guidelines that Ms. Sampson shares, she mentions a “scribe.” It is important to have a durable record of the ideas students generate. The written copy of the ideas students generate is also important as a “map” that students and the teacher can follow to see the development of their understanding. In a sense, posting the ideas as a list makes the learning “visible.” The facilitator will use this list to make choices about guiding questions, information search strategies, and activities that can support the type of learning each particular class needs.

In some cases, you may wish to have a student serve as the scribe, but this may pull that student out of the conversation. It is difficult to create or share his or her own ideas when the student is busy writing others’ ideas on the board, and your students probably will not be able to juggle those tasks. In our experience, it is best if you, the facilitator, can record students’ statements, questions, and hypotheses on large sheets of paper, on the board, or projected on the screen so all students can see the lists (see Figure 3.1).

TECHNOLOGY TIP

SMART boards (interactive whiteboards) and similar technology are a good option for recording group discussions! They allow you to record a “page” of notes, move to a new page, and return to previous notes when needed.

You can create areas in your recording space for each of the three categories of ideas in the PBL framework (“What do we know?” “What do we need to know?” and “Hypotheses”), but we suggest you use large pieces of paper taped to the board or the wall. This will let you add pages as the students’ list of ideas grows. You can make notations or cross off statements and hypotheses as the students find new information, but it is important to have those items to look back at during the process of working through the problem. Students can see how their understanding develops, question why they think an idea is true, and connect the evidence with their new understandings. The large pieces of paper or electronic files will also allow you to move back and forth between different sections, if you teach the subject more than once per day.

Launching the Problem

Once you have established discussion guidelines and procedures, it is time to launch the problem. For this stage, you can have students arranged whatever way works best for you, such as divided into small groups, seated on the floor in a circle, or seated at desks.

Figure 3.1. Recording Learners' Ideas in the PBL Framework

In Chapters 5–8, each PBL problem begins with an overview that describes the key concepts of the problem and aligns the problem with the three dimensions of the *NGSS* (NGSS Lead States 2013). This alignment includes a table describing the SEPs, disciplinary core ideas, and CCs addressed in the lesson. Keywords and a context for the problem are also offered to help you identify the problems that are most appropriate for your curriculum.

Following the overview and alignment page, each problem includes the text for the story arranged in two parts. Page 1 is the part of the story you will use to launch the activity. Some stories are short and can be printed on a half sheet of paper. In some cases, you might project the story on the screen, but we find that it is helpful to give each student or group a hard copy so that students can refer to it as they work through the analytical framework. You may choose to print one copy per student or let pairs or small groups read from the same page.

Start by handing out the copies of Page 1, and ask your students to read the story quietly. You might need to make accommodations for English language learners or special needs students. Once everyone has had time to read through the story, ask one person to read the story aloud. This may seem redundant, but it is actually a very important step. Our research has shown that groups that read both silently and aloud at the start of the story generate a significantly higher number of ideas, questions, and hypotheses than groups that only read the story silently. We posit that in the first reading, students are working to comprehend the story, and in the second reading, they begin forming their own ideas in their minds. The time to process the story and think quietly seems to be important in supporting the discussion in the group as they move forward. The vignette sections that follow provide examples of how this process looks in the classroom setting.

Ms. Sampson's Science Classroom: The Launch

Ms. Sampson: OK, class, today's PBL is called Cartoon Cliff Escape. Here is Page 1. Please read this story quietly. I'll give you about two minutes.

She hands out Page 1 of the Cartoon Cliff Escape problem. (See Chapter 6, p. 142, to read the story.) As her class reads, she tapes three large pieces of paper to the board, labels them "What do we know?" "What do we need to know?" and "Hypotheses," and gets her colored markers ready. After two minutes, she asks for a volunteer to read the story. David volunteers, stands, and reads the story aloud.

Ms. Sampson: Thanks for volunteering, David. Now that you've heard the story, let's look at our three categories on the board. What do we know about the story right now?

The class is quiet for a minute, but she notices the students look as though they are thinking.

Andrea: We are supposed to figure out the way to fall into the water at the slowest speed and the highest speed.

Ms. Sampson writes Andrea's comment on the "What do we know?" paper.

Ms. Sampson: OK, good. What else do we know?

Jamal: In the cartoon, three characters went off the cliff. One just ran off the edge, one jumped up, and the other pushed down off the cliff. But I think we have to know how high they were before we answer this problem.

Ms. Sampson: OK, "How high is the cliff?" goes under "What do we need to know?"

Marcus: The last part of story said something about jumping up counteracts gravity.

Mai: Yeah, but do we really know that? I'm not sure jumping up really does that. I think we need to find out more about that.

Ms. Sampson adds Mai's comment to the "What do we need to know?" list.

David: Will gravity act on them the same way if they jump up? That doesn't sound like a very good idea to me. But I'm not sure how to describe how gravity works in this case.

Ms. Sampson: David, should I add something about gravity to the "What do we need to know?" page? Good question!

David: Yeah, I think we need to find out how gravity works.

Carmela: The challenge says we need to test our answers. That goes under "What we know."

Ms. Sampson: I can put that under "What we know."

Carmela: Yeah, that's a good place for that.

Ms. Sampson: Great! OK, let's keep going. What else do we know?

The class continues the discussion by suggesting experiments they want to conduct.

Moves to Make: "Unpacking Ideas"

During a discussion in the three-column framework described earlier, students are likely to bring up terms and concepts that need to be "unpacked." *Unpacking* is a term commonly used in education and business conversations, but it is not always clear what unpacking an idea entails. In essence, students are using one of the SEPs as they analyze and interpret the information they are given (SEP 4: Analyzing and Interpreting Data). Students also use this stage to define the problem (SEP 1: Asking Questions and Defining Problems).

Let's focus on an example from the preceding vignette section. David brings up an idea to include in the "What do we know?" column:

> **David:** Will gravity act on them the same way if they jump up? That doesn't sound like a very good idea to me. But I'm not sure how to describe how gravity works in this case.
>
> **Ms. Sampson:** David, should I add something about gravity to the "What do we need to know?" page? Good question!

The concept of gravity is certainly important to the problem about falling from the cliff. But it is likely that not all the students in the class are familiar with it or know how it will influence this challenge. Ms. Sampson steers this comment to the "What do we need to know?" list and moves on.

It may be easy to imagine a discussion of gravity later in the lesson, but another useful strategy would be to "unpack" the concept right away. This can be done with questions that draw on what the students know about it already. These questions could be asked during the initial discussion, or they could wait until the class starts to explore the "What do we need to know?" list in more detail. But there are a couple of different ways to handle the discussion unpacking the concept.

Let's compare a "teacher as expert" approach with a "teacher as facilitator" approach (see Table 3.1, p. 24). In the "expert" role, the teacher shares what she knows, and the students become passive recipients. In the "facilitator" example, Ms. Sampson pulls information from the students, and the students' role shifts to either experts or problem solvers who recognize the need to find information. In the latter example, the students are active learners and consumers of ideas, a role we want students to master.

Table 3.1. Comparison of "Teacher as Expert" Approach With "Teacher as Facilitator" Approach

TEACHER AS EXPERT	TEACHER AS FACILITATOR
David: Will gravity act on them the same way if they jump up? That doesn't sound like a very good idea to me. But I'm not sure how to describe how gravity works in this case. **Ms. Sampson:** Gravity is important here. There will be no measurable difference in the way that gravity acts on the characters. The force of gravity will still accelerate the characters at 9.8 m/s^2 no matter what height they come from. **Denise:** But if the one that jumps falls from higher up, will he be moving faster by the time he hits? He is accelerating for a longer time. **Ms. Sampson:** Yes, he will, because he is accelerating for a longer time. **Mai:** What about Rambles? He runs off the cliff horizontally. Won't that slow down his fall? **Ms. Sampson:** That would add another direction to his motion, but gravity will still pull Rambles down at the same rate.	**David:** Will gravity act on them the same way if they jump up? That doesn't sound like a very good idea to me. But I'm not sure how to describe how gravity works in this case. **Ms. Sampson:** David, should I add something about gravity to the "What do we need to know?" page? Good question! Does anyone else have more information about that? **Andrea:** Well, that section we read in the book yesterday said that gravity on Earth is always the same amount. Let me find that number. … Here it is! 9.8 m/s^2. **Denise:** That m/s^2 thing is confusing. Is that how fast something falls? **Ms. Sampson:** OK, does anyone remember what that number describes? **Steven:** That's the acceleration. A falling object speeds up at that rate as it falls. **Marcus:** Yeah, so I think that means if Randy jumps up, he will be higher up and will accelerate a little longer. He should move faster. Maybe he will reach the ground faster … I think. **Denise:** That doesn't make sense to me. If he jumps up, he has to travel up for a while. That would make it take longer, wouldn't it? **Mai:** I think we should try it out. Can we do an experiment before we answer this? **Ms. Sampson:** That's a great idea. You can certainly do an experiment. **Rosa:** Yeah, it even says we are supposed to test it. I want to see what happens to the one that runs off horizontally. I think that will make it fall more slowly.

In the facilitator example, the students get much of the same information, but they have either reasoned or remembered the information on their own and in their own words. The students have begun to develop some independence in learning and are practicing the skills used by proficient problem solvers. Independent learners can do more than just recall and repeat ideas. They synthesize ideas from information they are given or collect themselves (SEP 4: Analyzing and Interpreting Data). To demonstrate deep understanding, students should be able to synthesize information by connecting ideas in the context of a real problem instead of repeating disconnected facts. In the expert example, Ms. Sampson is explaining how gravity affects the cartoon characters, but we cannot tell whether students are building their own understanding of the concept and the problem.

Generating Hypotheses

As students work through the analytical discussion of Page 1, they are likely to state ideas that reach beyond "What do we know?" and "What do we need to know?" In the next section of the vignette, watch for the comment that suggests an inference. Sometimes these are subtle, but as the facilitator, you can point out the step the student has made and suggest adding this new idea to the list of "Hypotheses."

As a facilitator, you will need to pay attention to the questions students ask during the discussion. One common pattern is that learners will present an idea as a question when they have some uncertainty about the statement. A student may suggest a question to add to the "What do we need to know?" list, but the question is actually a tentatively worded hypothesis. Let's look at an example of this.

Ms. Sampson's Science Classroom: Generating Hypotheses

Ms. Sampson: OK, class, you've covered a lot of ideas, so let's keep working. Any other things we need to learn about or ideas about this problem we should add?

Angie: I have a "need to know" thing. I want to know if the one that pushes down off the cliff is in the air for a shorter time. If he is, I think he will be going slower when he hits the water, but I'm not sure.

Ms. Sampson: Good question, Angie, but I think I hear a hypothesis in that statement. You're asking if an object that is thrown down hits the water sooner, but can we reword your question to make it a hypothesis?

Angie: I'm not sure if I'm right, though. I'm not sure this is a good hypothesis.

Ms. Sampson: But that's OK, Angie! Remember, a hypothesis is a proposed answer to a question that can be tested, and if the evidence eventually shows that it's not correct, that's all right! So do you want to try to build a hypothesis from your question?

Angie: I guess so. I'm not sure how to start it, though. "I think that if we throw a ball down …" Is that the way to start it?

Carlos: Shouldn't we use the same kinds of words we use in other labs? "*If*, *then*, and *because?*"

Ms. Sampson: That's what you learned to use when we're going to change a variable and see what the result is, Carlos. Since we are changing a variable, that makes sense.

Angie: OK, I think it should be "If we throw a ball down instead of dropping it, it won't be going as fast when it hits the ground."

Joseph: It needs a "because" statement.

Ms. Sampson: Yes, what would be the "because" part?

Angie: "Because … because it got to the water quicker and gravity had less time to pull on it."

Ms. Sampson: Good! That's our first hypothesis. Can anyone tell me more about what's going on with the forces in this example?

Jason: Wait a minute. Why are you talking about a ball? This is about a cartoon, isn't it? Where did the ball come from?

Angie: We have to test this, so I thought throwing a ball would be a way to set up an experiment.

Andrea: OK, so if you throw the ball down, gravity won't affect the ball as much?

David: No, that's not what happens. I don't think that's right.

Ms. Sampson: Remember, we're making hypotheses. We need evidence before we can reject a hypothesis, so I think we need to include it on the "Hypotheses" page.

Carlos: I have a different hypothesis. I think the ball thrown down will still hit the ground going faster than the one we drop.

Ms. Sampson: You need to put it in hypothesis form, too!

Carlos: How about this? "I believe the ball that's thrown down will be going faster when it hits the ground, because throwing gets it going downward."

In this example, a student initiated the first hypothesis, but it began as a "What do we need to know?" question. Note the way that Ms. Sampson directed the discussion toward the "Hypotheses" column in the analytical discussion and pointed out that Angie's question seemed to include a hypothesis. This is a very common pattern in the discussion of Page 1 with most problems, and you need to watch and listen for those types of questions. One cue is to look for a "because" statement in the question. For instance, if Denise said, "I want to know if a ball you throw upward falls slower, because a golf ball you hit seems to hang in the air and looks like it falls slowly," this suggests a hypothesis. The "because" indicates a connection between cause and effect (CC 2: Cause and Effect: Mechanism and Explanation) or a rationale for a possible solution to the problem (SEP 6: Constructing Explanations and Designing Solutions). The teacher could easily leave the question worded as it is, but it helps to move it to the "Hypotheses" column. Students can then "test" the hypothesis as they do information searches later in the lesson.

The strategy Ms. Sampson used was to point out the purpose of a hypothesis and mention that the question asked sounded like a testable question. She then asked students to rephrase the question rather than doing the rephrasing herself. This puts more control over the process in the hands of the students so they must practice this skill. Ms. Sampson is truly taking the role of facilitator by steering students with questions and letting the students generate the final version of the hypothesis. This facilitating includes reassuring Angie that it was okay to hypothesize and later find that the hypothesis is not supported. You've probably seen students' reluctance to be wrong about a hypothesis, and PBL helps them get over that fear.

It helped that Ms. Sampson's class had learned a deliberate pattern for writing hypotheses in other classes. If you have been working on SEP 3 (Planning and Carrying Out Investigations), your students will likely have begun learning this skill as well. In your class, part of the scaffolding is meant to help them learn to ask questions, write hypotheses, build data tables, and write explanations. PBL gives you yet another context in which students can use those same practices, so you have the flexibility to insert your particular format for structuring these elements of the science process.

Angie's hypothesis took quite a bit of scaffolding. Students contributed bits and pieces and made connections with the class "standard" for hypothesis writing. It was not an automatic process at first. This is typical of students who are still learning to think like scientists. Carlos was able to phrase his hypothesis in the appropriate format much more quickly because he was part of the process of working out that format during the discussion about Angie's hypothesis. This is also a common event. Students very quickly adopt the structure when the class works through the process out loud and can see the hypothesis on the list as a reference for later discussion.

If no students come up with hypotheses on their own, you will need to help students think about making some predictions or proposed solutions. As the list of "What do we know?" and "What do we need to know?" items grows, a facilitator can ask something like "So, what do you think is the answer to the challenge at this point?" This is usually enough to get the ball rolling with the first hypothesis.

Our experience suggests that once the first hypothesis emerges, other students become more comfortable suggesting possible solutions or hypotheses. In other cases, students may need a prompt from the facilitator. You can elicit hypotheses by asking, "So, what do you *think* is the answer to the challenge?" or "Do you have any hypotheses about a solution?" If students are really having trouble framing an initial hypothesis, you can ask if they think there is a relationship between any of the things listed under "What do we know?" Defining relationships is often the beginning of a hypothesis. Such initial hypotheses may not be complete answers to the challenge, but they start the ball rolling.

Introducing Page 2

As your students work through the PBL analytical framework and the information on Page 1, there will be a moment when they start to run out of new ideas to put in the three categories of the framework. They will exhaust the "What do we know?" ideas and address most of the learning issues on the "What do we need to know?" page. The list of hypotheses might be short, but the generation of these ideas will slow down. *When that happens, your job as the facilitator is to transition into Page 2.*

Page 2 continues the Page 1 story and adds new information that will help students work toward a solution to the challenge statement at the end of Page 1. Introducing Page 2 should work very much the way introducing Page 1 did; students will read Page 2 quietly, then a student will read it aloud. Once that happens, the class can repeat the analytical process, adding new ideas to the same three categories of the PBL framework.

One major difference in the way to handle information relates to the new content on Page 2. You may find that "What do we need to know?" items on your list will be answered with the Page 2 story, or that the hypotheses generated in the first discussion will be rejected based on the new information. You can certainly add new questions and hypotheses as well as "What do we know?" statements, but we strongly recommend that you keep the first set of ideas on the board and visible to students. As you answer items in the "need to know" list, cross them out but leave them on the list. Some facilitators keep a list of "summarized knowledge" under each question to connect the "need to know" items with the new information they use to answer the questions. When you learn enough to eliminate a hypothesis, don't delete or erase it, but cross it out. Having those ideas visible is helpful when students look at the path they have taken from their initial ideas to the final solution for the problem. Processing their own ideas this way gives students a way to know *why* the solution works, not just that this is the right answer. It also builds a habit for students to show their thinking and their work. You might even find that when students begin to adopt the PBL skills as habits, they apply them in other subjects as well!

Ms. Sampson's Science Classroom: Introducing Page 2

Jason: OK, I see that gravity is one of the forces, but when we drop the ball in different ways, we have to figure that in. We need to know what those forces are doing.

Ms. Sampson: So do you want to put that under "What do we need to know?"

Jason: Yeah, I think so.

Ms. Sampson: OK, got it. What else can we add to our lists?

(long pause)

Andrea: Don't we need to know how far the animals fall?

Jamal: We already have something about how high the cliff is under Need to Know.

Ms. Sampson: Yes, I think we have that covered. Any other ideas? Or new hypotheses?

(long pause)

Ms. Sampson: OK, then it sounds as if you're ready for more information, right?

Multiple students: Yeah! We need more information.

Ms. Sampson: All right then, here's Page 2. Let's do what we did with Page 1. Read the story to yourself, and then we'll read it out loud.

She hands out Page 2, the class reads it quietly, and then Devin reads Page 2 aloud.

Ms. Sampson: OK, good. Let's take a look at these videos.

The classes watches the videos, and then the teacher continues the discussion.

Ms. Sampson: Now let's add new pages for "What do we know?" "What do we need to know?" and "Hypotheses." We need to talk about each of these pages again with the new information we have. So … what do we know NOW?

Will: In the videos, you can kind of see the balls speed up as they are dropped.

Rose: Yeah, but we need a way to measure how fast they are going or the time it takes. We have to be able to compare the different balls. They don't all drop from the same height. And how do we know how heavy each ball is?

Marcus: We don't know that for sure. I think that should go under "What do we need to know?" Put "How heavy are the balls in the videos?"

Rose: We can't find that out, can we? What if we just put "Does the weight of a ball matter?" Then we can test it ourselves and know what the balls weigh.

Ms. Sampson: Testing it sounds like a good idea! Let's put that under "What do we need to know?"

Vince: Yeah, and we can try different heights. And maybe try different types of balls. Some of the balls in the videos were tennis balls. But the ones we have in gym class are old and don't bounce very well.

David: Yeah, they're pretty bad! Have you ever seen those pumps you can use to restore a tennis ball? My dad has one, and it really works. Maybe we need to test to see if that changes how bouncy other balls are.

Ms. Sampson struggles to let the conversation work its course—the students are getting off track and starting to talk about issues that are not important to the problem. But she adds Vince's hypothesis about different types of balls to the list.

Alyssa: But wait, we don't care what kind of ball we use. We're looking at how the ball is dropped or tossed. As long as we keep the type of ball the same, it doesn't matter. You're talking about testing a different variable now.

Anthony: But we need to keep the ideas for now and figure out which ones to test later.

Mai: I agree with Alyssa. Let's think about the main question, but I think we need to start experimenting right now. I think we need to test some hypotheses. I still want to test the downward throw. Maybe it will fall the same, but I think it will be moving slower when it hits, and that's what the challenge asks about.

Ms. Sampson: That's an interesting idea, Mai. If you think it's important, do you want to make that a hypothesis?

Mai: Well … I think the hypothesis should have something about gravity always acting the same and how long the ball is in the air, so it hits slower.

Ms. Sampson: Do you think your hypothesis is like Angie's?

Mai: Umm … I guess it is!

David: And I want to add a hypothesis, too. I think if we throw the balls down, they will fall at a higher speed because they started at a higher speed when gravity pulled on them. … Oh, I think that's the same as what we already have.

Ms. Sampson: I'll put your wording up too, David.

Devin: Does that mean we cross out that old hypothesis?

Ms. Sampson: Well, have we found evidence to rule any of these out?

Angie: No, not yet. But can we start doing some experiments to test them now?

Moves to Make: What If Students "Go Down the Wrong Path"?

In this section of the vignette, we see Ms. Sampson guiding the class through the analysis phase of Page 2. Students listed the new ideas they got from Page 2, raising questions about ideas they didn't understand and offering new hypotheses. But we also see an example of students "going down the wrong path." Some conversations take off on tangents, like the comments about tennis balls. Others may follow incorrect hypotheses that the teacher knows are going to lead to a dead end.

As the teacher, you will encounter those moments when you want to comment to prevent the class from following a "wrong" hypothesis. You should already know what some viable solutions to the problem are, and you simply want to help your students find the right answers. But it is important *not* to interject comments that stop students' exploration of incorrect ideas. A hypothesis that is later rejected is a powerful learning experience and is likely to lead to enduring understanding. So you need to let students explore those ideas, even when your instincts tell you to steer them in a new direction. Teachers likely will want to correct the inaccurate ideas right away, but the PBL framework emphasizes letting students find evidence that leads them to eliminate ideas on their own.

Note how Ms. Sampson handled this above. She included Vince's hypothesis about testing different kinds of balls on the list. You should avoid eliminating hypotheses for your class. Let students decide when the evidence means an idea should be rejected. That's a difficult thing for teachers to do, and it may take some practice, but it is important! When students get off track or propose hypotheses you know are not correct, be assured that these things are normal in the PBL process. Each of the authors has experienced this, and we have felt the same internal conflict between providing content knowledge and letting students learn or discover for themselves. We've all learned to be patient, let the students drive the discussion, and wait for the learners to see all the information before we simply give answers.

In the previous case, when class discussion started to drift, Mai and David helped keep the process on track by introducing a new way to word a hypothesis. Including the different wordings will allow students to focus on the ideas instead of a particular wording when they compare hypotheses with evidence and information they collect. Eventually, the students will have all the tools they need to decide which hypothesis is most viable. If Mai and David had not pulled the conversation back to the main point, Ms. Sampson could have done this by asking students how their present discussion topic related to the challenge.

There are also other good strategies for redirecting the discussion. One suggestion is to establish a practice in which you, the teacher, are free to participate as a learner. This gives you permission to ask the same type of questions students should be asking. In this co-learner role, you can model critical thinking and questioning while using your comments to keep students on task and on track.

Here are some questions or statements, or "steering tools," that you can use to keep your class discussion on track:

- "So, how does that apply to the challenge for this problem?"
- "Maybe we should restate the question we are trying to answer."
- "Do we have a source that can verify that idea?"
- "What kind of evidence do we need to support that?"
- "How does this information from Page 2 relate to Page 1?"
- "That sounds like a 'need to know' issue."

Researching and Investigating

Once your students have completed the discussion of Page 1 and Page 2, you should have an extensive list of items under each of the three categories in the PBL framework: "What do we know?" "What do we need to know?" and "Hypotheses." On some of the lists, you may have crossed out questions you've answered or hypotheses you've ruled out as new information becomes available. The information that is left should point to learning issues and predictions that have potential as solutions to the challenge presented on Page 1. Remember, the goal is to propose solutions to the challenge, so the research and investigation should focus on this goal.

The next step in the process of facilitation is to help the class develop a plan for gathering information or conducting an investigation that will answer the "What do we need to know?" questions that are still unresolved. In this phase of the PBL process, you are faced with some choices that will determine what the next part of the lesson will include. Would an inquiry-based lab or hands-on investigation help students understand the concepts that underlie the problem? Will students use a computer lab or classroom computers to search for information on the internet? Are there text resources that can help them answer the questions? Should you provide a limited set of readings to ensure that students find productive information? All of these may be appropriate choices!

Investigations

In some problems, there may be a hands-on activity, such as a model that students can build, that would help illustrate a concept. For instance, in the "Engineering Energy Transformations" chapter (Chapter 7), the Keep It Warm, Keep It Chill problem is an ideal situation in which to do tests with various containers to test their insulating qualities with both hot and cold materials. This allows students to experience a real-world phenomenon and use data as one type of evidence in constructing their final solutions.

You may also have your students conduct inquiry-based investigations to learn or reinforce specific concepts. Motion problems such as the Constantly Moving problem (see Chapter 5, p. 101) may give you the opportunity to insert your favorite demonstration, model, or simulation of a skateboard or ball rolling on a surface. Problems from Chapter 8, "Engineering Electricity and Magnetism," provide a context for doing a project with different types of circuits and maybe even different types of energy sources.

One of your roles as the teacher is to plan for these investigations. You may have activities in your textbook resources that would be appropriate, or you may find or create new lab activities to meet your needs. In Chapters 5–8, we have provided some lab activities that fit with specific concepts, including instructions to help you plan and implement these activities.

An important component of any activity is safety. Students and teachers need to learn how to properly analyze hazards, assess risks, and take actions to minimize risks. Safety issues to be considered include the use of sharp objects, the use and disposal of chemicals, and the presence of fire hazards. You are responsible for precautions such as having students wear safety goggles or glasses, providing disposal containers for sharps and chemicals, and ensuring that students know where fire extinguishers, eye washes, and chemical showers are located.

Information Searches

Other problems are best addressed by helping students search relevant resources for answers to the learning issues they have identified. For teachers who need to integrate literacy standards into science teaching, the skills of finding and evaluating information from multiple sources are clearly featured in this part of the PBL process.

Sources for answering the learning issues your students have identified may include web searches, their science texts, books in the school's library, or magazines and newspapers.

Although our first thoughts seem to turn toward technology as the go-to source, there are many text-based tools that are certainly appropriate. You can decide which are best suited for the context in which you are teaching based on access, convenience, or the fit for the topic at hand.

The search for information also offers multiple choices for scheduling. Perhaps you will have students work on this the same day they analyze Page 1 and Page 2, or you may need to plan this phase for the next day or as homework. The number of days you spend on this task also depends on your specific needs.

Ms. Sampson's Science Classroom: Finding Information and Experimenting

Ms. Sampson: All right, class, you've created a good list of ideas, hypotheses, and things we "need to know." Now we need to plan some experiments. We know we will be dropping balls in sand and measuring crater size. Let's look at the "What do we need to know?" list. Are there specific ideas that groups will offer to find out more about?

The students talk softly with their groups about what they want to research.

Jamal: Our group wants to compare how hard the ball hits the floor if you throw the ball down versus if you toss the ball up. But I think we need to look up some numbers about the force of gravity. Can we do that?

Ms. Sampson puts Jamal's name next to "Toss Down vs. Toss Up." You got it, Jamal! Your group can get started. When you find the information about the force of gravity, please write it on the whiteboard. We all should see that information.

Mai: And we want to test the dropping the ball from different heights.

Ms. Sampson: OK, your group can do that experiment.

Denise: I'm not sure how to measure the speed of the ball when it hits. Can we look up some experiments for measuring the time it takes other things to drop? We want to see how others have done that.

Ms. Sampson: OK, Denise, that's a good topic to look at.

Rose: We want to try the motion sensors we have in the cabinet. Maybe we can figure out a way to test how fast the balls are moving when they hit the ground, like Jason said.

Ms. Sampson: Good idea! If you'll volunteer, you can do that. All right then, folks! You need to get started. In the time we have left today, you should plan your experimental procedures, and we'll continue working on this tomorrow.

Angie: Can we look stuff up at home tonight, too?

Ms. Sampson: Sure! But make sure you write down what sources you find and bring it with you tomorrow. Remember, when we're done, each group is responsible for describing its experimental design. Be organized!

Teacher-Selected Sources

For some classes, "searching" for information may require more assistance from the teacher. In these cases, you might pick a limited collection of resources and provide these resources to groups when they are ready to find answers to their learning issues. Perhaps the problem is complex enough that you want to steer students to specific resources such as the videos on Page 2 of the problem. Maybe the information they need is not easily accessible to your students, either because very little is published online about the topic or because your school filters access to the necessary sites. Even the age or technology skills of your students may suggest that you should preselect the sources.

One strategy for doing this is to create sets of articles or websites that address specific topics. You can either give each group of students all of the sets or distribute each set to a different group. The latter option forces students to read and analyze the texts and share what they find with other groups. This type of communication is common among practicing scientists and addresses skills that students need to develop across the curriculum.

To help you select problems for which preselected sets of sources are useful, we strongly recommend that you work through each problem in advance. Think of the types of "need to know" issues you expect students to identify, and try searching for those concepts. If you can't find them easily, your students may also struggle to locate sources. Many of the problems in Chapters 5–8 include a Page 3 with links to websites and references to other materials that are relevant to the science concepts.

Sharing and Resolving the Problem

When your students have completed the investigation or information search, the next phase includes sharing what they found. If each group has selected specific learning issues to research, this sharing is critical to the challenge presented to the class. No one group is likely to find all the information it needs to solve the problem or build a complete solution to the challenge. But if students share information, the class can co-construct some solutions, much as project teams do in the workplace. This phase of the PBL process gives students a chance to hone their skills with SEPs 6–8: Constructing Explanations (for science) and Designing Solutions (for engineering); Engaging in Argument From Evidence; and Obtaining, Evaluating, and Communicating Information.

The class sharing session should still focus on the three pages of analysis they created during the discussion of Page 1 and Page 2, especially the "What do we need to know?" and "Hypotheses" pages. The information search should address specific "need to know" items, and students' findings should help in the evaluation and adjustment of some of the hypotheses as they apply what they have learned to the challenge presented in the story. Post the three pages on the board or on a wall for all to see, and take a minute to recap what the class has done so far.

Each group should be asked to share. Although some students may be reluctant to speak in front of the class, building their comfort with such a task is an important learning goal. We find that when the presentation is informal, the task is less threatening. One way to promote sharing is to ask a student in each group to share one thing he or she learned. This leaves room for others in the group to share their ideas. Sharing their findings also helps students learn to pay attention to evidence and reliable sources.

As groups present what they found, it may also help to have other students take notes or record concepts in a journal or science notebook. They should also be encouraged to ask questions that help clarify ideas. Let your class know that the goal is not to stump or quiz each other, but to help the entire class understand the information.

If your class or specific groups did an investigation, this is a good time to have the class look at the procedures and results and talk about what the evidence means. If you have a standard procedure for presenting scientific explanations from an investigation, this is a perfect time to apply that structure. For instance, you can establish a procedure in which students share observations and data, identify patterns in the data, and suggest an explanation for the patterns. In the case of developing a solution for a problem, another approach is to describe the proposed solution, explain why it will work, and explain how evidence supports the ideas. If you have a structure you use for this in your current lab activities, you can use the same structure with your PBL lessons.

When all the information has been presented, you have options on how to construct solutions. One way to come to a final answer to the problem or challenge is to discuss the problem as a group. The focus on this should be the hypotheses created by the class. When a group wants to support a specific hypothesis, you can ask for a rationale: What evidence makes you think this is a good hypothesis? Other students should also be allowed to make counterclaims about a hypothesis or to present ideas that would refute the hypothesis or solution. This discussion can be a rich assessment of students' learning and ideas because it forces students to reveal the connections they make between concepts as they apply them to an authentic problem. Recording their ideas may be helpful if you wish to assess these connections, or you may choose to have a checklist so you can keep track of evidence of new learning.

In some of the classrooms in which we have observed teachers using PBL lessons, we have also seen another approach. Some teachers elect to have the students in each group talk about the evidence they have found and create their own solution to the problem. This works best if each group was responsible for looking up more than one concept from the "What do we need to know?" list. It is helpful to set a time limit for this discussion, and you may want to have a structure for the group's response as described earlier in this section. You may also have a handout with general questions for the group to answer. This can include what hypothesis the group was investigating, what "need to know" issue it explored, what evidence it collected through research or experimentation, and how the evidence leads to a solution. The group then presents its ideas to the class, and other groups are encouraged to ask questions or explain what they see as problems in the solution.

In both of these scenarios, the next step is to ask for a solution to the challenge at the end of Page 1. This is the ultimate goal of the activity, so make sure you pay attention to the challenge. Students might present more than one solution. That's okay! In the real world, there may be multiple ways to solve a problem, and we want students to understand that. But when more than one solution is presented, you can ask the class to discuss the strengths and weaknesses of each solution, ask students to vote on which one they prefer, or ask each student to write a short response or exit ticket with a prompt such as the following: "Which solution do you think is the most useful? Explain why you chose this solution over the others." (See the "Assessing Learning" and "Responding to Assessment Data" sections later in this chapter for more information on exit tickets.)

Ms. Sampson's Science Classroom: Sharing and Building Solutions

Ms. Sampson: Today we're going to share the information you found about the Cartoon Cliff Escape problem we've been working on. As you present, remember that you need to describe how you got the data you used, any sources you found, and the results you want to share with the class. We'll use that information to see what we can cross out on the "need to know" list and how your information fits with our "Hypotheses" list. I need each group to share what it found. Jamal, I'd like your group to start, if you don't mind.

Jamal: OK. We looked up the force of gravity, and it's 9.8 m/s^2, just like we talked about on the first day. We read that a ball tossed up should hit the ground at the same speed as the ball that's tossed down. That didn't make sense to us. Then we did our experiment—and the data were kind of weird. First, we had a lot of trouble figuring out if we were tossing the balls up the same way we were tossing down. We each took turns holding the ball and swatting it up or down. The balls we batted up always took a little longer to hit the floor than the ones we batted down. But when we used the motion detector to measure the velocity near the floor, there was a fair amount of variation, but it looked like each person's tossed-up and tossed-down balls had about the same speed.

Rose: We had trouble with the motion sensors because they have to be aimed just right. But we found another way to find the velocities. There's an app we used on the tablets that lets us take a video and find the times by analyzing the video. Then we figured out the ball's speed in the video over the last meter.

Anthony: What? That's totally cool! Did it work better than the motion sensor?

Rose: Definitely! Our numbers were really consistent. It's kind of like what they do on Myth Busters.

Ms. Sampson: It's the same idea, Rose. But what did you find out when you tested the dropped and the tossed balls? Didn't I see your group doing the same tests as Jamal's group?

Rose: Yeah, we did. And we found the same weird thing. The balls are going about the same speed whether we toss them up or down.

Mai: Whoa, that's not what I expected! Our results were kind of unexpected, too. We found that the ball took the same time to drop if it was dropped or if it was pushed sideways. We decided that since, either way, the ball had to fall the same distance from the table to the floor, and they both took the same amount of time, both had the same speed. Here is our data table.

Mai put the data on the document camera to show the class.

Ms. Sampson: OK, let's put both sets of data on the board. Did anyone else get data about this?

Jason: Yeah, we tested dropping, horizontally tossing, and tossing upward. Our numbers for the dropped and horizontally tossed balls are almost as close as Mai's, but we tested with stopwatches. We thought the horizontal toss would take longer, but those trials were almost the same as for the dropped ball. It didn't make sense at first, so we did some research. There are some physics demonstrations that show that a bullet fired horizontally drops at the same rate as an object dropped straight down. It just travels horizontally at the same time it is falling. One website we saw said that gravity works in one direction, while the force of shooting the bullet acts in a different direction. We're pretty sure the same is happening with the balls. The trials when we tossed the balls up took longer than the others, but you could tell from size of the crater the ball makes in the sand that the balls are hitting the floor harder. We don't understand why, though.

Ms. Sampson: OK, that's a pretty strong pattern then. And your data match some sources you found online. Do you want me to add this to the board?

Andrea: Yeah, but then we want to share some other data. We tested the force when the ball hit the floor. I think we have some ideas to share.

Ms. Sampson: Sure, use the document camera.

Andrea: OK, we found a couple of ways to measure the force. One of them uses a "force table." That's a sensor that measures the force. We wanted to try that, but we don't have one. So we used the crater size method. The more force, the bigger the hole.

David: Wait a second. That doesn't sound like it would work. Wouldn't the sand just move back into the hole? And how can you measure that?

Andrea: Well, there's a website that suggests how to do it. Debbie, can you put that site on Ms. Sampson's computer so we can show how we did it?

Debbie found the website on the teacher's computer.

Andrea: See. You leave the ball in the sand, and it really seems to work!

Ms. Sampson: OK, that's one way we have learned to design experiments—borrow ideas from other sources. So, what did you find out?

Andrea: Well, first, we found that if you toss the ball up, it hits with more force. We thought that made sense. It's falling from higher, and if it's accelerating all the way down, it should be moving faster. We found a site that gave a formula that the change in velocity is equal to $a \times t$.

Ms. Sampson: Good! Take a look at this formula, class. It's telling us that the change in velocity will be more if the acceleration, a, is more or the time, t, is more. In this case, a is always the same. It's the acceleration due to gravity. But as you found, the balls are falling over a longer period of time, so they end up going faster.

Andrea: It was a lot harder to test the horizontal throw, though. It's really hard to hit the box of sand every time. We only hit the sand twice, and since the ball is moving horizontally, it kind of splatters sand all over. It's hard to tell where to measure the depth.

Rose: Hmmm … I wonder if there's a better way to test that?

Ms. Sampson: If we have time, maybe we can test that again.

Marcus: Yeah, I have some ideas. But we need to work out our design first.

Ms. Sampson: OK, I understand that. Hey, Denise and Steven, did you do some tests, too?

Denise: Yeah, we did. Hey, guys, come up and help me show the trials we tested, then we can show our data.

Each group showed the results of its experiments and discussed its methods. Once all the groups were done, Ms. Sampson redirected the discussion to the original problem.

Ms. Sampson: OK, I think we've gone over these data pretty thoroughly. Now, it's time for your teams to start thinking about how your evidence relates to the Cartoon Cliff Escape problem. You have the rest of the class to talk about it, and you can share ideas outside of class. By tomorrow, I want each group to write its solution to the problem.

Moves to Make: Correcting Misconceptions or Nonscientific Solutions

When your students are constructing and selecting solutions, they are considering information their class has shared, but they also are influenced by prior knowledge. Sometimes this prior knowledge is not accurate, and it is likely to be durable and difficult to change. These ideas can lead to solutions at the end of the analysis process that are not practical, fail to really solve the problem, create other problems, or omit concepts you have identified as an important learning goal. Resources such as Keeley and Harrington's (2010, 2014) publications can help teachers anticipate the types of inaccurate or incomplete understandings that may emerge during the PBL analysis process.

So what should you do when that happens? Our first suggestion is to assume the role of a classmate by asking questions you know will force the class to think about an important concept or piece of evidence. In the problem described in the vignettes, many students intuitively believed that the ball tossed horizontally would take longer to reach the ground. When skillfully used, asking questions can help students notice the problems with their claims. One of the most effective approaches is to have students compare a problematic claim with information they have listed under the "What do we know?" column of the analysis charts.

One strategy that can be effective is to ask questions such as "Do any of the 'what we know' statements contradict these findings?" In the vignette, Jason's group couldn't explain its results. Andrea's group had found the answer, but if the whole class had been stuck, having students examine the "what we know" list would have been helpful. Because the students had done research on gravity, they had a "What do we know?" item about gravity acting on an object in the same way regardless of horizontal movement, which may force the students to question their claims and conclusions. By asking students to use information from the sources they found, you can help them develop connections between evidence and concepts and among concepts (SEP 8: Obtaining, Evaluating, and Communicating Information). This is a critical practice in our world of abundant information. Students will be exposed throughout their lives to many claims and proposals in the news, at work, through advertising, and in legislative bills that need critical analysis against the available evidence. This also helps address at least two of the "Essential Features of Classroom Inquiry" listed in the supplement to the *National Science Education Standards* (National Research Council 1996, 2000), by asking students to give priority to evidence as they form and evaluate explanations.

Another approach would be to ask students to list the strengths and weaknesses of each source of information. As in the strategy above, this places students in the role of evaluators and requires comparison of evidence and conclusions of their classmates. This also models the type of analysis used in the workplace for problems related to science and engineering, as well as many other contexts. Remember, the phase of the PBL process in which students generate solutions highlights both synthesis and critical thinking, so having students engage in these types of thinking is important.

But what if this doesn't do away with a misconception? Or what if the class didn't grasp a key concept that makes a big difference in the problem? Scientifically incorrect ideas can be durable and may get in the way of students' assimilation of new ideas. Some of the peripheral information may draw students' attention as they create solutions. Thus, you need to be prepared to correct ideas and guide the development of solutions during this final part of the PBL lesson.

When your students just aren't applying concepts accurately, you now have a chance to explain ideas. There are times when your students need you to be the expert. Although we suggest you be patient with students' thinking processes, you may have to step in and present information that students need. If necessary, you can lecture, lead a discussion, show a simulation or an image, or introduce some type of activity to help guide the learning. A good example of this is illustrated in the vignette when Ms. Sampson explained the connection between acceleration time and the change in velocity. The formula was beyond what her students needed to know, but it applied directly to their questions, so she used her expertise to make it accessible to the students. There are many other ways to explain concepts using models, examples, and diagrams (Keeley and Harrington 2010, 2014; Schwarz, Passmore and Reiser 2017).

Assessing Learning

When implementing a PBL lesson, you should respond to the learning needs of your students as they emerge. Flexibility is key, but to be flexible, you need information about what students are thinking. Assessment is an important part of the facilitation process. As you lead a class through PBL problems, you should be planning to assess and to use the information from your assessments to adjust your teaching.

The PBL process as we have described it provides for continuous assessment. The process of analysis using the PBL framework allows you to hear and see what students are thinking as they talk about their ideas and record information, questions, and hypotheses under the three columns of the analytical structure. Each comment from a student gives you insight into their understanding.

But be aware that what you hear in a group discussion may not reveal what every individual is thinking. In a whole-class discussion, you see a "group think" picture of what students know. There may be bits of information from a handful of students that seem to make sense when the entire group shares ideas, but you need to know what each student understands. It is helpful to have strategies that let you assess individual students rather than the entire group of students.

The need for individual assessments is even more pronounced if the activity takes more than one class period. As we developed our model in the PBL Project for Teachers, our facilitators found it helpful to implement informal assessment strategies such as exit tickets. These are brief prompts asked before the end of a class period for which students write a short response. These prompts may focus on one idea the students learned, one idea they found confusing, or one question they have based on what happened in class. You might also ask students or groups to give a written summary of the information they found during their research, their choice of the best hypothesis so far, or a drawing of the concept they are exploring.

Another form of assessment is the transfer task. *Transfer of knowledge* refers to the ability of students to apply knowledge of the concept in new contexts. For instance, students may know that a ball falls at the same rate whether dropped or thrown horizontally, but we also want them to understand how gravity acts on other moving objects such as airplanes and rockets. The importance of transferring knowledge to new situations is supported by Schwartz, Chase, and Bransford (2012), who suggested that a deep understanding of a concept must be accompanied by transfer. To help you perform this type of assessment, the problems in Chapters 5–8 include transfer tasks. The transfer tasks accompany specific problems, but they can also inform the choices you make about the next activities to include in a unit. Application questions are also offered as examples of summative assessments for the unit.

In Chapters 5–8, we also present open-response questions that we have developed and tested for each content strand. There are two types of these questions (general and application) to address the concepts and standards included for the problems in the content strand. We discuss more about the role of these assessments in Chapter 4, as well as options for when to use the assessments and how to interpret responses.

Responding to Assessment Data

Assessment of learning is important, but you also need to consider how you can use the assessments to respond to students' needs. We've introduced a couple of assessment strategies that can help you select your next moves as a facilitator in the PBL lesson. But it may help to share some examples. These examples include exit tickets and group summaries of solutions to PBL problems.

Exit Tickets

Exit tickets (Cornelius 2013) are a simple and quick way to collect information about your students' understanding and issues that need to be resolved. An exit ticket can ask one of several different kinds of questions, including "What's one thing you've learned?" "What about today's topic are you still confused about?" or "What's one question you have about today's lesson?" Each student then writes a short response and turns it in to you at the end of class. The next step is for you to read through the tickets to see if there are important issues that need to be handled in the next day's class.

The following vignette section provides an example of how this might work in Ms. Sampson's class.

Ms. Sampson's Science Classroom: Exit Tickets

Ms. Sampson asked her class to write exit tickets after Page 2, using the prompt "What's one question you have about the Cartoon Cliff Escape problem?"

Ms. Sampson: OK, I looked over the exit tickets you wrote yesterday, and I think we need to add something to the "need to know" list. Several of you wrote that you want to know if air resistance will change the time it takes objects to drop or their impact speed, depending on their size. Can we add that to our list?"

The class agrees, so this is added to a list of topics to be researched. Another possible result might be …

Ms. Sampson: Your exit tickets tell me that there may be some questions about forces working on the ball you threw horizontally. Let's talk more about that.

She explained that any moving object may be influenced by forces acting in different directions. She set up a demonstration on a lab table using a table tennis ball. She had one student blow on it gently with a straw to show its motion. The force of blowing on it pushed the ball in a straight line. In a second trial, the first student blew on the ball, then a second student blew on it from a 90-degree angle. The ball changed direction but was still moving toward the far end of the table. Ms. Sampson explained that each force was independent and had pushed in a straight line. To make the ball stop moving toward the end of the table, a force would have to push back in the opposite direction from the first force.

Group Summaries

In the PBL Project for Teachers, we found that an entire class may agree on a solution, but some individuals may have a different level of understanding of the concept. One strategy we tested, group summaries, proved to be useful.

In this assessment, students in each group are asked to write a summary of their group's proposed solution. The summary should include a description of the solution they think best solves the problem or answers the challenge, along with a rationale that explains what evidence they used to construct their solution (SEPs 6, 7, 8). In the process of discussing and writing this summary, group members are able to solidify their understanding. When groups are asked to complete a summary, individual scores on content tests are often higher than if the summaries are not used.

The following vignette section offers an example of how this assessment might be implemented in Ms. Sampson's lesson.

Ms. Sampson's Science Classroom: Group Summary of Solutions

After the students thought about the Cartoon Cliff Escape problem and their experimental results, Ms. Sampson asked each group to write and turn in a summary of the plan they had developed with an explanation of how the plan worked. In these summaries, she noticed an issue that needed to be explained. Some of her students wrote that the ball that was tossed up had more velocity because a stronger force was acting on that ball.

Ms. Sampson: All right, I saw in your solutions that many of you wrote that the ball tossed upward has more force acting on it, so it is moving faster when it hits the ground. So I have a question for you. Which spaceship would move faster in outer space: one when you give a one-second burst of thrust with the rocket or one with same amount of force but the thruster firing for a four-second burst?

The students looked confused at first, so she asked them to view an online computer simulation that let them experiment with the movement of a spaceship in which they could control the thruster and see the velocity. She gave groups time to try out several scenarios and take some notes.

Ms. Sampson: So what did you find out about the movement of the spaceships?

Sarah: Our ship keeps accelerating if you leave the thruster on for a longer time.

Carlos: Yeah, and a short burst pushes the rocket, and it keeps going the same speed after that. If you keep firing the thruster, the velocity graph keeps going up.

Mai: We got the same thing, but I'm not sure I see what this has to do with the balls.

Ms. Sampson: OK, those are some good observations. So let's talk about the forces on the balls.

Jason: Well, gravity is pulling on the balls. It's that 9.8 m/s^2 thing. That's the rate of acceleration.

Angie: Oh, I think I get it now. When you toss the ball up, gravity is pulling it down for a longer time. It's like a thruster left on a little longer. So it will end up moving faster. It's not the force that's bigger. It's the amount of time the force is pulling it down.

Ms. Sampson: That's a great comparison! Keep in mind that the force of gravity is the same for all the balls—the force is constant. Now let's see how that might change your answers a bit.

Summary

Facilitating PBL requires a slightly different set of skills than direct teaching does, and it requires practice. Your role as the facilitator means you need to be prepared for several possible paths students may take. Your role also shifts from provider of information to a guide who needs to skillfully ask questions that allow students to reveal their own thinking, resolve their own misconceptions, and base their own ideas on evidence rather than an "expert" source. This questioning also requires you to moderate disagreements and keep students on task, so facilitating PBL lessons will feel very different from other lesson formats.

You will also need to anticipate what kinds of information, models, and explanations you should be ready to offer your classes. If you teach multiple sections of the same class, each may have different needs, so you will find yourself selecting different responses. Assessment is a key factor; you need to know what your students are thinking!

Box 3.2 presents some tips to remember as you facilitate your PBL lessons.

Box 3.2. Dos and Don'ts of PBL Facilitation

Do ...

- Use open-ended prompting questions.
- Count to 10 or 20 before making suggestions or asking questions.
- Allow learners to self-correct without intervening.
- Be patient and let learners make mistakes. Powerful learning occurs from mistake making. Remember that mistakes are okay.
- Help learners discover how to correct mistakes by clarifying wording, seeking evidence, or checking for discrepancies between ideas and evidence.

Don't ...

- Take the problem away from the learners by being too directive.
- Send messages that they are thinking the "wrong" way.
- Give learners information because you're afraid they won't find it.
- Intervene the moment you think learners are off track.
- Rush learners, especially in the beginning.
- Be afraid to say, "That sounds like a learning issue to me" instead of telling them the answer.
- Rephrase learners' ideas to make them more accurate.

Source: Adapted from Lambros 2002.

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PROBLEM-BASED LEARNING IN THE PHYSICAL SCIENCE CLASSROOM

K–12

"There is a lot to like about this text, and I truly believe that teachers will both like it and use it. Implementing PBL is difficult for teachers, and few curriculum guides are available to support their efforts. This book fills that gap by providing the kinds of strategies and examples teachers need to facilitate open-ended inquiry in their science classrooms."

—**Peggy A. Ertmer**, Professor Emerita of Learning Design and Technology, Purdue University, and Founding Editor of the *Interdisciplinary Journal of Problem-Based Learning*

❖❖❖❖❖

Bring new energy to both your teaching and your physical science students with problem-based learning (PBL). This all-in-one guide to PBL shows you how to use scenarios that evoke real-world science in all its messy, thought-provoking glory. The creativity-igniting scenarios lead K–12 students to get involved in analyzing problems, posing questions and hypotheses, and constructing solutions.

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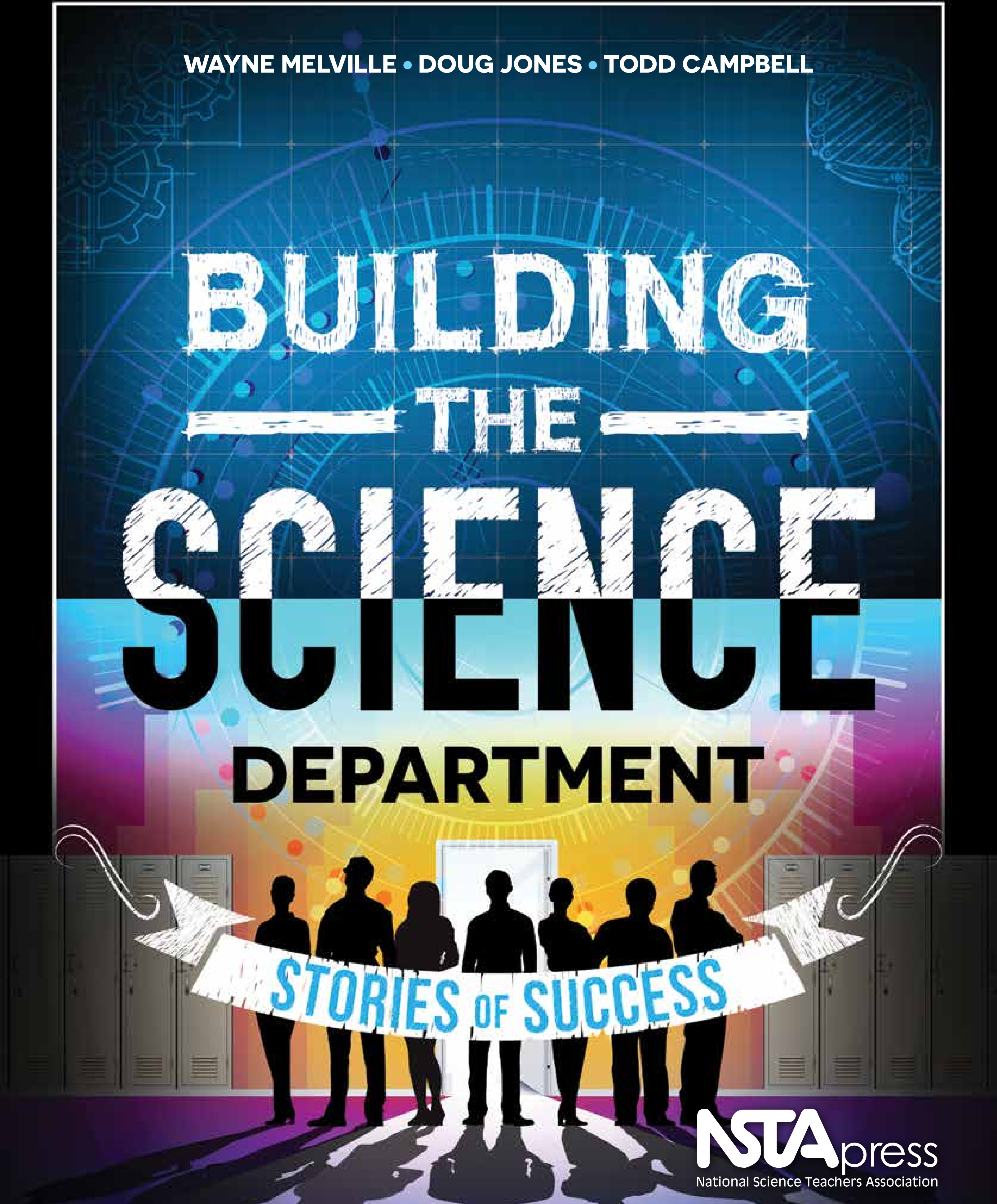
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Foreword

Stories. Teachers love to tell stories of their classrooms and their practices. The stories can be about their successes, their difficulties, their triumphs, and their disasters. They can be inspiring and they can be harrowing. They can also instruct, guide, and help us learn.

In our early thinking about this book, we decided that we wanted to work with the stories of teachers who had negotiated—and continue to negotiate—the (at times) perilous paths of reform. What were their stories, and what could we, as a larger audience, learn from them? What were the contexts that supported their learning? What did they need to know, learn, and understand as they looked to challenge their practices? What activities did they engage in that helped them change their classrooms? And what were the processes by which they came to begin to understand the lofty ambitions of reform documents in terms of their own classrooms and departments? These are all important questions, as the work of teachers is at the heart of any and all reform efforts.

We were also interested in the stories of teachers at different stages in their careers, for we know that the professional learning needs of teachers are constantly evolving. The stories that new teachers tell are necessarily different from the stories told by teachers with many years of experience. The stories told by teachers who take on leadership roles, either formally as department chairs or informally as teacher leaders, are different again from those teachers who are more focused on their classrooms. Regardless of experience or leadership role, the work of becoming a teacher never ends, so we suspected that there may be some common themes running throughout the teachers' stories, regardless of career stage.

In planning to ask teachers to write of their teaching and learning, we were aware that just asking somebody to write on such an open-ended topic was bound to be met with the question "Where do I start?" Clearly we needed a framework that would provide a guide for the stories to be told but not restrict what was important to the story writer. To this end, we used the framework developed by Helen Timperley, Aaron Wilson, Heather Barrar, and Irene Fung and published in New Zealand in 2007 (available from *www.oecd.org/edu/school/48727127.pdf*).

Synthesizing research into the professional learning of teachers, the framework developed four basic components of effective professional learning opportunities for teachers:

1. Professional learning context
2. Content of the professional learning opportunities
3. Activities that promote professional learning
4. Learning processes that teachers engage in

For each of these components of professional learning, the framework identifies specific constituent areas that can have a positive impact on student learning in science. The full framework is shown in the appendix (p. 137).

Having a framework to guide writing is one thing—having teachers to work within that framework and tell their stories is quite another. To bring the framework to life, we decided to approach teachers with whom we had worked and who were committed to reforming their teaching and learning or who came to our attention by the contributions they were making to science education, both in their own schools and further afield. The teachers who agreed to work with us have taught from 4 years to more than 28 years in secondary schools in Canada and the United States. Some have worked as department chairs, and all are teacher leaders in some capacity. All are exemplary teachers committed to both their students and our profession. Working with Jason, Shawn, Liz, Mike, Steve, and Julie has been a privilege for us, and we are indebted to them for their candor and their ongoing contributions to teaching and learning. We trust that you will find their stories as insightful as we found them.

This book can be seen as comprising two parts—the first sets out an understanding of scientific activity (one of the key tenets of the current reforms in science education in North America), the rationale for concentrating on the department as a place for building and sustaining teacher professional learning, and the aforementioned professional learning framework. In Chapter 1, we begin by outlining how scientific activity can be used to frame professional learning within science departments on the grounds that one of the major roles of the science department is to accurately represent the discipline for *all of our students.* It should be noted that Chapter 1 connects the accurate representation of the discipline to the *Next Generation Science Standards* (*NGSS*). In addition, it should be noted that the *NGSS* were developed from *A Framework for K–12 Science Education* (referred to as the *Framework*). This is an essential compendium document necessary for understanding the rationale, organization, and commitments of the *NGSS.* Although not all U.S. states have adopted the *NGSS,* most have aligned their new state standards with the *Framework.* In Chapter 1, we assume that the reader has some familiarity with the *NGSS,* the *Framework,* and three-dimensional learning as the cornerstone of these documents. If you are not familiar with these documents, we recommend referring to some of the following introductory resources for supporting a beginning understanding of these foundational documents:

- "Three-Dimensional Instruction: Using a New Type of Teaching in the Science Classroom" (available from *http://static.nsta.org/files/tst1508_50.pdf)*
- "Next Generation Science Standards: What's Different, and Do They Matter?" (available from *http://stemteachingtools.org/brief/14*)
- STEM Teaching Tools (available from *http://stemteachingtools.org*)

Chapter 2 provides an understanding of the science department as it currently exists in secondary schools and the powerful influence that it has on teaching, learning, and professional development. Chapter 3 details the professional learning framework developed by Timperley et al. (2007), thus setting the stage for the second section of the book—the teachers' stories.

The second part, starting with Chapter 4, is structured so that we work through each of the components of the professional learning framework (context, content, activities, and processes) through the stories (hereafter called *vignettes*) told by our colleagues. Each chapter starts with Jason providing a brief overview of his experiences before Shawn, Liz, Mike, Steve, and Julie take turns discussing their thoughts on professional learning within the framework. The arrangement here is deliberate; the vignettes are arranged in order of experience, from beginning teacher to more experienced teachers. Following the vignettes is a commentary that highlights the key points and implications for teacher learning that emerge from the work of our colleagues. An important feature of our previous book, *Reimagining the Science Department* (NSTA Press, 2015), that we have included in this book are questions to ask yourself as both a science teacher and a teacher leader. Such questions are important because to challenge our own stories is to start to make changes that improve our practices and start to bring those practices into greater alignment with the ideals of the current reform documents.

As you start looking at and learning from the stories of other teachers, please remember to contact us if there is any way we can help you in your work.

About the Authors

Wayne Melville is a professor of science education and assistant dean at Lakehead University in Thunder Bay, Ontario, Canada. He taught secondary science in Australia from 1989 to 2005, eventually becoming a department chair. During his school teaching career, he completed a master's of science and a doctorate in science education and was a national finalist for a science teaching award organized by the Australian Academy of Science. Since moving to Lakehead University in Ontario, Canada, he has published more than 70 articles in the field of science education. He has been a committed member of the National Science Teachers Association (NSTA) for many years and contributes to NSTA journals and conferences. His e-mail address is *wmelvill@lakeheadu.ca.*

Doug Jones is a science faculty member at Sir Winston Churchill Collegiate and Vocational Institute in Thunder Bay, Ontario, Canada. He has served as a science chair for 20 years of his 34-year career. Doug has taught in the Lakehead University department of education for several years and has developed several courses in science education. Doug and his department are well known in science education circles for their paradigm-shifting work in the teaching and learning of secondary science, along with significant work regarding scientific literacy, professional learning communities, assessment and evaluation, and growing one's personal professional practice. The department has also mentored more than 150 preservice teachers over the past 20 years. Doug enjoys the research and writing relationship he has with Wayne and Todd and is proud to be a contributing member of both the Science Teachers' Association of Ontario and NSTA. His e-mail address is *dougyjones@gmail.com.*

Todd Campbell is a faculty member in the Neag School of Education at the University of Connecticut. His research focuses on cultivating imaginative and equitable representations of STEM activity. This is accomplished in formal science learning environments through partnering with preservice and in-service science teachers and leaders to collaboratively focus on supporting student use of modeling as an anchoring epistemic practice to reason about events that happen in the natural world. This work extends into informal learning environments through a focus on the iterative design of informal learning spaces and equity-focused STEM identity research. Todd is a former high school and middle school science teacher and is a proud member of NSTA. He consistently contributes to NSTA journals as an author and reviewer. His e-mail address is *todd.campbell@uconn.edu.*

About Our Colleagues

This book would not have been possible without the thoughtful contributions of our colleagues, who have written of their experiences in science education.

Jason Pilot is currently the head of science at Sir Winston Churchill Collegiate and Vocational Institute in Thunder Bay, Ontario, Canada. He has taught general science, chemistry, and environmental science for 14 years. He also taught grades 4 and 5 for one year and spent two years as a secondary resource teacher for Lakehead Public Schools. As a teacher, he is always trying to bring real-world activities into the classroom, which has driven his development of problem-based learning and inquiry.

Shawn Devin is a secondary school science teacher in the Toronto Catholic District School Board. As a young and passionate teacher, now in his fourth year, he strives to foster an exciting and engaging learning environment that uses investigatory activities, cool experiments, differentiated teaching strategies, social learning, and real-life connections. He was fortunate to be awarded the Don Galbraith Preservice Teacher Award of Excellence from the Science Teachers' Association of Ontario in 2012.

Elizabeth (Liz) Potter-Nelson is a science teacher at Stevens Point Area Senior High School in Wisconsin and has taught for 11 years. Before recently returning to the classroom, she spent five years as a department chair working closely with teachers to transition their curriculum to be phenomena-driven and aligned with the *Next Generation Science Standards* (*NGSS*).

For more than 28 years, **Mike Sewards** has been a teacher of exercise physiology, general science, and chemistry in Thunder Bay, Ontario, Canada. He has been recognized provincially as producing classroom environments that encourage powerful learning and has worked on a number of Ontario Ministry of Education projects in this area. He has also nurtured many preservice teachers and has been an active member of his school's professional development team.

Steve Lankin is a chemistry and physics teacher in Thunder Bay, Ontario, Canada. Some say that he can make his subjects come alive for students with a combination of brilliant teaching strategies and humor. He believes that knowing what science should look like—in both classrooms and real-world scenarios—is fundamental to working with students, preservice teachers, and other teachers. He has taught for 18 years.

Julie Gaubatz, EdD, teaches science and chairs the science department at Hinsdale South High School in Darien, Illinois. With more than 20 years of teaching experience coupled with a background in laboratory research, she is particularly interested in models of change, inquiry, and leadership that improve students' experiences in secondary science education.

Finally, before we begin, we need to highlight an important point. Many of the teachers we have worked with have been involved in reforming their practices for many years. This means that many of the vignettes reference work that supports the teaching of science as inquiry as is emphasized in the *National Science Education Standards* (NRC 1996). Although the terminology has changed (see Bybee 2011 for a concise explanation), the importance of the vignettes lies in their power to reveal how teachers have gone about the work of change, which is necessary with *A Framework for K–12 Science Educatio*n and the *NGSS.* When our colleagues talk about "inquiry," rest assured that they are talking of evolving practices that align with the latest reform documents.

5

The Content of Professional Learning

The content of professional learning opportunities is an important consideration for science teachers, but the reforms of *A Framework for K–12 Science Education* (the *Framework*) and the *Next Generation Science Standards* (*NGSS*) mean that there is a change in emphasis for that content. As Reiser (2013) states, the reforms require that teachers

> *help students continually work toward explanatory models, developing these ideas from evidence. This focus … challenges … teachers in how to motivate lessons through phenomena that need to be explained, how to help learners develop these explanations, and tie them to the phenomena and questions that motivated them. (p. 4)*

What does this changing emphasis look like in departments that have been active in reforming teaching and learning? In Jason's experience:

> *Over two years we invested a lot of time and energy into redefining what learning looks like in our classrooms. We focused on learning goals, established what it meant for students to be successful, and what types of feedback we should give our students. For many teachers it was a quantum leap from where they were already teaching.*

In this chapter, our colleagues highlight how their relationship with content is evolving in response to the new and exciting challenges connected to recent reform. In considering their vignettes, we can see how that evolution changes over the course of a career.

A "STUDENT OF SCIENCE AND OF EDUCATION"

Shawn

Just as our current and future students learn from us, we must continue to evolve our own teaching and learning; one of the bases for this evolution is the information we learn and how it can be applied. In this vignette, I would like to address the content that has been conducive to my own professional learning and explain how this content has allowed me to extend my pedagogical knowledge.

The Disciplinary Knowledge of Science

Scientific content knowledge—or disciplinary core ideas—is an essential component of our teaching. As a young teacher of science, I have come to appreciate the grasp of knowledge I have and also be humbled by the knowledge I have not yet grasped as thoroughly as I'd like. This acknowledgment emphasizes the need to learn and incorporate new knowledge into my repertoire, in turn broadening students' understanding of scientific ideas and the practices of science. A strong and broad understanding of science allows me to engage directly with students in understanding more refined ideas. Most of us are specialists in at least one branch of science; however, increasing our knowledge across all sciences can prove to be useful when helping students make the connections between the major concepts of the disciplines and the knowledge expectations of the curriculum.

My professional learning of content knowledge has been an essential component to improving and expanding my existing teaching strategies. As students and teachers of science, our increasing knowledge can, in many respects, be gradually incorporated into our existing materials and teaching methods. A richer understanding of the practices of science also allows us to reconsider aspects of our teaching strategies. Understandably, this may increase the demands on teachers to further their knowledge in certain fields of science, even in the context of many teachers' family commitments, extracurriculars, or other time restrictions. However, from what I have experienced in my career so far, even the smallest pieces of knowledge we acquire can enhance our ability to support students in understanding concepts or disciplinary core ideas in science.

Considering How Students Learn

To teach content, we must be attentive to how our students learn, how we communicate concepts or ideas, and how we assess learning. The basics of my awareness of these ideas came directly from my teacher education training; teaching science from reformed perspectives and assessment strategies was an area I was familiar with but not practically experienced in before I obtained my bachelor's degree in education. Although earning this degree meant learning a combination of theoretical and practical applications, the emphasis was more on pedagogy. As my career has developed, there has been a shift from this emphasis to a more practical style of professional learning. Although additional qualification courses and workshops are an excellent source of information about student learning and assessment, I have found so far that colleagues and students are the best source of information in these areas. Who better to ask than the students who are learning from your teaching! Of course, the underlying pedagogy and theory must still be emphasized when taking colleagues' and students' opinions into account, but the prior experience of colleagues and the direct experience of students provide an excellent account of your teaching, especially in terms of how it can be modified to best accommodate student learning and how this learning is assessed.

Integrating Practice and Theory

Just as we can listen and learn from students and colleagues about how students learn, we may never discover if these ideas hold true if we do not desire to experiment with them. The majority of professional development workshops I have attended so far have provided theory on how best to approach different subjects and specific topics within those subjects; these ideas are always supported with practical exercises. These workshops, usually carried out by experienced teachers, have been incredibly informative and useful! I must stress from previous experience that a balance of theory and practice is critical in our growth as effective science educators. However, a question may arise from this statement: Does this balance lie more toward theory or practice? Unfortunately, this is not a black-and-white question; I can say, however, that a balance should be established that works best for the students you have! And that balance is always going to be shifting as you gain more experience.

One of the most important ideas I adhere to is that we will always be students of science and of education no matter how experienced we become; there is always something to learn from both disciplines. As educators, we work with students, teachers, administrators, and parents to assist with student aspirations and accomplishments of learning and life goals. Similarly, we must aspire to learn and strive to further our own expertise as science educators. These aspirations come in light of the disciplines that we love; from my own experience, the content most conducive to my professional development comes directly from the colleagues and students I work with and from my motivation and drive to acquire knowledge. Students and colleagues have proven to be some of the most valuable resources for expanding my foundation in teaching the content and practices of science in understanding how students learn and how to integrate the theoretical and practical aspects of teaching. There will always be great students and teachers to learn from, and I also believe that I will be a lifelong learner in education and science; as a result, I can safely say that my professional learning will continue indefinitely!

EXPERIENCE THE MATERIAL

Liz

Throughout my experience as an educator and leader, I have participated in a considerable number of professional learning experiences. Some of these have been outstanding, whereas others have left a lot to be desired. When I reflect on these experiences, I find that authentic and discipline-specific professional learning, which forces me to experience the material in a similar manner to which I will use it in the classroom, has been the most beneficial.

Modeling Authentic Engagement

Shortly after the *NGSS* were released to the public but before my state had adopted them, a local university offered a summer course called "Teaching K–12 Science With the *NGSS.*" I jumped at the chance to take this course for a number of different reasons. The *Framework* had been out for some time and although I knew it was important to read this prior to beginning work with the *NGSS,* I struggled to find the time to make it a priority during the school year. In addition, I knew that in my role as a department chair I would need to have a greater understanding of the *NGSS.* I would not only need to know about my area of expertise; I would need to know about additional disciplinary core ideas and their corresponding performance expectations, both within and leading into high school. This course seemed like the perfect exposure and—more importantly for me—I would be forced to make the time to look at both the *Framework* and the *NGSS.*

Although I expected the course to review the *Framework* and the *NGSS* from a K–12 perspective, I did not expect the course to engage us (teachers) as learners in ways that represented how the standards documents envisioned us engaging with students. I assumed that we would be participating in a book study—reading, discussing, and reading some more. Although there was reading, the course exemplified best practices in science education; instead of lecture, we were drawn into discussions and experiences that highlighted the intricacies of the *NGSS.* We held in-depth discussions about modeling and what made an effective model. We tried to explain how smells moved around the room. We looked at syringes and tried to model what happened to the air molecules when we compressed the plunger. We discussed phenomena and why they are compelling and necessary when designing lessons. We discussed how phenomena could drive a lesson and how student-generated questions about the phenomena could lead to experiences that would help students learn not only content but also scientific practices and skills. Finally, we put everything that we learned into practice and tried to write a unit of instruction, anchored by phenomena and supported by questions and subsequent experiences.

This experience was enriching, eye-opening, frustrating, and, most importantly, engaging. I was forced to work with the *Framework* and the *NGSS* in a manner that ultimately gave me a greater understanding of their complexities. I was also provided with experiences that I could bring back to teachers within the science department and students in the classroom. Through this experience, I gained confidence in working with the *Framework* and the *NGSS* that I would not have gained had someone just told me what I needed to know.

Using Past Experiences

Participating in authentic and discipline-specific professional learning that models classroom instruction is something that I had completed earlier in my teaching career as my district transitioned to the Physics First model of teaching. Going to Physics First was a huge curricular shift for us as a team, and for many it was a huge pedagogical shift as well. Although labs existed in our courses, there were not many, and those that did exist were cookbook in nature, which would need to change with Physics First. In addition to shifting pedagogy, we were also going to need to place teachers into areas that they were not necessarily comfortable teaching. For the first few years, we would need a number of different teachers to teach outside their content areas as our students worked their way into our new normal. We had enough teachers who were certified to teach physics; however, their backgrounds were in other content areas.

In working to get the entire department to a similar understanding of the pedagogy and content with regard to these changes in physics, every science teacher in the district was supported to attend a weeklong training about the philosophy of Physics First. During this training, we worked through labs as if we were students. We set up equipment, looked at data, compared results, had discussions, and were given the confidence to go into a school year with a new series of courses. When we modified our chemistry curriculum the following year, our chemistry teachers already knew the physics curriculum thanks, in part, to this professional learning experience. Participating in the program and knowing how our students were learning physics gave our chemistry team a strong foundation from which to build the chemistry curriculum.

Having been through a large curricular change and looking forward to a similar change with the implementation of the *NGSS,* we are looking to provide a similar professional learning experience for teachers. We brought in experts who have provided our teachers with authentic and discipline-specific learning experiences that exemplify the *NGSS.* We are sending teachers to conferences and professional development workshops where they can work with the *NGSS* and the *Framework.* We are providing teachers with time to understand the intricacies of a shifting pedagogical approach to science. Teachers have embraced the deliberate introduction to the *NGSS*, having seen the positive effects of successful professional learning in their classrooms not too long ago.

THIS LOOKS VERY DIFFERENT FOR ME TODAY

Mike

As I was cleaning up and organizing files and exemplars at the end of the last term, I came across some student inquiry products from more than 10 years ago. I thought to myself that I was holding some pretty good work but that today, in many respects, it didn't cut the mustard in terms of my current understanding of how to develop the process, product, and communicative skills about inquiry in the students—and their ability to apply that learning to producing a superior product.

Reform as Content

In my opinion, curriculum reform has been evolving from a time when importance was placed on what units will be in a course and the content that will be taught in those units to asking how students learn and how they can take control of their learning to maximize success. Beginning in grade 9, our department engages students with an accurate representation of science. Starting early gives us time to address the knowledge and practices in each unit and connect the two together as our students move through high school.

When you start teaching science with grade 9, you're teaching it in pieces, and often we have to relearn these pieces. Actually teaching what goes into a scientific report, helping students understand why that report is being written, and teaching students how to write is pretty daunting. If you can do that in little pieces, without them even realizing that they're writing a report, success follows. I have a lot of really cool things now developed as little pieces: how to teach students to develop a data set; how to teach students to write up an introduction to a lab; how to teach research; how to teach students to write a discussion, conclusions, and a hypothesis—all these are little pieces. I'm getting better now at putting those pieces together after 15 years of experience, learning from my mistakes, and reflecting with my colleagues. I also now share these things with younger teachers.

Focusing on Assessment and Evaluation

Although the heart of my professional development lies with the department, external expertise can have a significant impact. One initiative from the Ontario Ministry of Education and my board was professional learning in assessment and evaluation (A&E). The A&E initiative, combined with our work on inquiry, opened my eyes to the idea that assessment can be multifaceted, varied, and ongoing. That has had a major, ongoing impact on my practice, which is really something, considering that I'm in the last quarter of my teaching career. The major impact has been in terms of student success and my planning and delivery of lessons and assessments. As I worked with teachers and students, the initiative developed my ability to identify and communicate the success criteria necessary to guide the production of high-quality work and products.

Initially I was skeptical going into the work—"OK, here we go again." I was busy and remember being told that I was going to be on the A&E team. That probably ended up being the best thing for me, and my teaching, that I've done in years. It was exciting to have that happen toward the end of my career. One of the biggest impacts was my realization of how A&E can be used to support and strengthen a more accurate representation of science in the classroom. This was made clear by our professional development trainer from the Ministry of Education. He would tell our team that all of us learn best when we're doing and that we get better at it with practice. If I'm up in the front teaching, then I'm the one who's "doing science," and they're sitting there listening but not "doing science." We try to engage with our students as much as we can and have them carry out the little pieces of what we're teaching them. That's what makes the strategy different from being "hands on." For example, having students get together in a group and brainstorm several variables that you think might affect "the breathing rate of a fish" and then report back and discuss that with the class means that they are "doing science" rather than me telling them—the latter of which allows them to opt out of the thinking and learning. It's motivational, too, because the students are directing the conversation and engaging with scientific ideas and practices.

Learning and practicing more discipline-appropriate A&E strategies means that I can meaningfully assess a student's ability to communicate, observe, use critical thinking skills and understanding, self-assess, peer-assess, and give feedback. It's no longer just about performance on a test, exam, or product. All of this evidence allows me to sit back, reflect, and use the term *professional judgment* in a relevant way to come up with a final mark. It's now been a while since I have used software like Marks Manager as an accounting tool to crunch only the product or test data and come up with a student's average. For me now, if a student is sitting with a classmate having a conversation that is helping that other student come to a good understanding about a scientific idea or practice, then I have evidence that the student tutoring has mastered that scientific idea or practice. If I have another student who has developed a simple class resource package on how to negotiate Excel to generate a scatter plot, then I have evidence of his or her ability to graph as a sensemaking practice and am not limited by a small mistake that the student might make on a graphing test that ends up having a large impact on the overall mark.

The new knowledge I have about A&E has dovetailed with my inquiry understandings to increase student success. It all comes down to the question "What does a really good representation of science look like?" That's what I had to understand before I could improve my practice. Once you get that, you can also get at what constitutes success in each of the little pieces and how you assess and/or evaluate them. Once the students know what it is that they're attempting to do, they can start to coach each other. They should all have an understanding of what each of those little pieces should look like. In the real world, as in school, a lot of effective inquiry is done in teams. They'll divvy up the jobs and get to work. Back in the day, students would just put together the report they thought the teacher wanted, staple it, and hand it in. This looks very different for me today.

I'M A BIT OF A DINOSAUR, BUT I'VE LEARNED

Steve

Process is a big deal for me—not only those processes students go through to understand how science is carried out, but the processes that students use to manage their learning in the first place.

Colleagues Leading on Assessment

One of the major professional learning initiatives for our department has been the Ontario Ministry of Education's work on A&E, which Mike has already talked about. I wasn't selected to be part of the teacher teams, but because our department meetings provided opportunities for those who were involved to report back and discuss what they had learned, I was able to understand what was being conveyed and start to make changes to my practice. I think it's great that we have that communication. That's where I learned the content of the reform from, and then I followed up by talking to Mike on the side. Depending on the department, I believe it may not be necessary to take training sessions. If you've got a good, collegial department, the support structures, and teachers that are interested, then you have everybody on board and they're going to put in the effort. I think our department's been very, very good like that.

With the reforms to assessment, my initial thought was that this was a wonderful thing, especially as it allowed us to assess the practices of science across our subjects. So let's bring it into our classrooms and make the move from a predominance of summative assessments to a wide variety of formative assessments. I know that in my classes I never used to do that (formative assessment) too much, but I have started to do more over the last six years. Although the reform focused on assessment, in practice it also means working with students to get them to help each other, especially with descriptive feedback practices. It's important that these types of assessment take place before any testing or other summative practice. Students could have been working on an important assessment for a month and been totally lost. They hand in something that is unrelated to what you asked them to do. It's much more powerful for me and my students, when introducing practices such as argumentation, to do two formative assessments that don't end up getting a mark. Instead, there's an interview where I can give them descriptive feedback on where the work is headed and where questions can be clarified for both the students and myself. I'm a bit of a dinosaur, but I've learned.

AN APPRECIATION OF BOTH REAL SCIENCE *AND* REAL TEACHING

Julie

Learning styles were a cornerstone of teacher education when I began my teacher training in the mid-1990s. My previous academic pursuits had focused on scientific research, and my naïve mindset was that my own preferred way of learning worked really well. Discovering information about different learning styles and personality traits was one of the first times it struck me that not everyone liked the same approaches to learning that I did, and that my job as a teacher was not to change how students best learned but to work with these differences to help all students engage with and integrate new learning experiences. Although learning styles–based approaches have since come under increasing scrutiny (e.g., Pashler et al. 2008), understanding the diversity of learners' personalities was an important event for me as I moved from being surrounded by research-lab scientists to working with students and colleagues in K–12 educational systems.

The Unique Needs of Those Involved

Occasionally, when I work with teachers in other schools, my mindset can temporarily slip back into assuming that my audience enjoys the same approaches to learning as I do. Experience, however, has taught me that my consultations are most effective when I cater to a wider range of participants' proclivities. For instance, although most teachers in my own department enjoy learning about the underlying theory and empirical research base of a new educational method, other audiences may find the theory and research less important to their implementation of the work itself. Similarly, some audiences respond positively when I use more experiential learning strategies during professional development programs, whereas others prefer that I simply "get to the information." Appreciating audiences' varying comfort levels with different forms of presentation reinforces my understanding that my reflections on my own professional development preferences are bounded by my own experiences; therefore, what works for me and the teachers I interact with may not be the right approach for all science teachers.

Presenters are usually passionate about their subjects. Such passion often reveals a well-rounded understanding of a topic but other times can be experienced by attendees as a zeal that alienates other perspectives. From my experience as a teacher and educational leader, professional development must allow room for teachers' creativity, educational philosophies, and judgment of their students' interests and needs. Presenters are most effective when they understand that in order for teachers to embrace a new idea for their classrooms, they must be convinced of its likely effectiveness and its suitability for their idiomatic teaching approaches.

One of the many laudable aspects of teaching is that there is no "one" right way to do it; although there are globally effective strategies, sometimes what works for one teacher may not work for another. I think this is reflected in how teachers integrate reforms into their curriculum. There is a risk with dogmatic presentations on reform, which, although impassioned and possibly persuasive, can imply a lack of respect for the audience's knowledge and professionalism. For some audiences, this may be fine, but for others, a one-size-only approach to reform might ferment resistance where it doesn't need to be. When reforms are presented as flexible and adjustable approaches to science education, this lets them jive with current curricula, teacher skills, and student needs—it allows teachers to more easily see how the reform could work for them and their students.

The Content Is Most Important

I frequently attend workshops and conferences with teachers from my department, often seeking sessions on approaches to the teaching and assessment of the practices of science. Our comfort with the presenters' approach to professional development is important, but it is the content of their presentations that most influences us. Content that moves us toward implementing the practices and their assessment in our own classrooms usually involves instruction that includes an appreciation of both real science and real teaching. It also involves an openness to teachers adapting reformed ideas that match their comfort levels as well as their students' interests and needs.

Coupling an adaptable approach to the practices of science with a strong understanding of the nature of science increases the effectiveness of professional development offerings. Understanding science content fully and deeply, making the connections from one content area to another, seeing the possible lines of investigation: This level of engagement in science is what we want for our students, but it is also what we want for ourselves. Immersing ourselves in science content gives us the flexible foundation that broadens our conceptualization of science and expands how we can portray and explore the practices of science in our classrooms. Having a strong and continually reinforced science content base increases our ability to create lessons and laboratory experiences for our students and helps us problem solve as we inquire side by side with our students. Science content helps scientists as they conduct experiments, and it helps teachers as they create experiences that convey scientific ideas and processes to their students.

Grounded in Classroom Implementation

The final ingredient that I think increases the effectiveness of a presentation on reforms is an understanding of the real-world classroom. One of the most frustrating experiences for my teachers is sitting through a presentation by someone who has an intriguing idea that would be interesting to consider in an idealized world but that appears unworkable within the constraints of a normal classroom setting. Presenters who are aware of teachers' day-to-day work are also likely to understand that teachers lack the flexibility or the control to cut massive amounts of content from their curriculum. Reform projects that require six weeks to complete might work if they are carefully crafted to integrate with required course content; however, if they simply add six extra weeks of classwork, then teachers will struggle (or, more accurately, won't bother) to identify which of their existing lessons and activities to correspondingly remove.

This is especially true if teachers work on a team in which a single teacher has to persuade team members to try something new. If new instructional and assessment strategies fit with the team's philosophies and do not require the removal of key units of work that are valued by the team, then the task is not as difficult as it would be to persuade a team to cut an entire unit. Practices that can be incorporated into teachers' existing curricula have a much better chance of success than reform that requires a large, immediate curricular overhaul. The beauty of incorporating reforms into the curriculum in "half-steps" is that as teachers experience success and attempt more small moves toward the ideal of the reform, these steps can accrue into substantial change over time.

Reflecting on how professional development best enhances teachers' growth and subsequent teaching, I think that the fit between the participants and the presentation is key. "Knowing their audience," effective presenters not only accommodate teachers' prior knowledge, confidence levels, and motivations but also listen sensitively to understand teachers' school structures and the needs of their specific student populations. I also think teachers are most receptive to content when it is presented with an openness to incremental adaptations. Finally, for my own department, professional development that affirms both of the fields we are immersed in—education and science—is critical. Science teachers like science—actually, we love science. The ongoing question that we work to answer through our experiences and our continued professional development is how we can best get students in our classrooms to understand, use, and love science, too.

Commentary on the Content of Professional Learning

If it ever was, science teaching can no longer be about the presentation of decontextualized, immutable "facts." The reforms of the past two decades have consistently stressed the need for teachers to develop classrooms in which students work to shape ideas from evidence that explain the *why* and *how* of natural phenomena. As a result, the content of professional learning opportunities must be more than disciplinary knowledge; it must also include how to use that knowledge in a way that reflects the human construct that is science. Each of our colleagues' vignettes reflects this wider understanding of content: a broader and deeper understanding of disciplinary knowledge (from science and education), the integration of theory and practice, and an understanding of how students learn.

Broader and Deeper Disciplinary Knowledge

Regardless of their years teaching, all of our colleagues spoke of a need to learn more about both science and education. In science, there was a need to learn disciplinary knowledge, not just in the specific topic area but also across the discipline and the practices that bind the topics together. This learning was not restricted to just the latest developments in the discipline but instead led to a richer understanding of the discipline and how it came to be. In education, there was a recognition of needing to learn how students learn, how to assess student work, and how to develop credible teaching strategies for the learning required by the reforms. As Shawn said, teachers need to simultaneously be "students of science and of education, no matter how experienced we become."

Science content knowledge is the foundation on which our work is based. Usually educated and certified as specialists in particular science topics, we are often called on to teach across the discipline. This can be daunting for beginning teachers, as it leaves us more confident in some topics than others. Having a "strong and broad understanding of science" allowed Shawn "to engage directly with students in understanding more refined scientific ideas." Developing our content knowledge builds confidence across and between topics, "helping students make the connections between major concepts and the knowledge expectations of the curriculum." For Mike, there was a desire to work as a department to "address the knowledge and practices in each unit and connect the two together as our students move through high school." Steve believed that the changes in assessment were beneficial in developing the practices of science across the topics that he taught. Julie, with an equal wealth of experience, reiterated the same point. For her, making connections between topics gives teachers and students the opportunity to develop "possible lines of investigation" and build the level of engagement in science that "we want for our students [but also] what we want for ourselves." As a teacher and chair, Liz expanded on the importance of content knowledge in her own specialization and "additional disciplinary core ideas" to the need to be aware of what to expect from students coming into high school science from elementary schools. This is an essential point, as reform documents such as the *Framework* and the *NGSS* discuss science education being a continuum from K to 12, and we ignore that continuum at our own risk. Education is a continuum, and teachers need to be cognizant of the knowledge students are bringing into the classroom. The disciplinary core ideas are also central to the other side of content knowledge—the practices that shape the scientific enterprise.

For Julie, content must be seen in its broadest sense: "Science content gives us the flexible foundation that broadens our conceptualization of science and expands how we can portray and explore the practices of science in our classrooms." The building of a "flexible foundation" can also act as a motivator for challenging existing teaching practices, as Shawn noted: "A richer understanding of the practices of science also allows us to reconsider aspects of our teaching strategies." Mike spoke of teaching in "pieces" and helping students understand—and have opportunities to practice—those pieces. By understanding the "pieces" himself, Mike was then in a position to help his students understand what success in "each of those little pieces should look like." By teaching science content and practices as "little pieces," Mike has moved his students beyond the point where "students would just put together the report they thought the teacher wanted, staple it, and hand it in." Similarly, Steve used the assessment reforms to help his students improve their understanding of the practices of science. Rather than allowing students to be "totally lost," the use of formative assessments allows for the provision of "descriptive feedback on where the work is headed and questions [that] can be clarified for both the students and [teachers]."

Understanding and constantly reinforcing the practices of science allows teachers to move beyond the transmission of science "facts" to the ability to "create lessons and laboratory experiences for our students and [to] problem solve as we inquire side by side with our students." In this nutshell, Julie has encapsulated the reforms promoted by the *Framework* and the *NGSS.*

Although we may pursue a broader and deeper understanding of science, we also need to move toward a greater alignment of our teaching practices toward the ideals of the reform documents. This means constantly evolving our understanding of teaching and learning. Even in the early stages of his career, Shawn was already noticing changes in how he was approaching the task of learning more about education. Moving away from the focus on pedagogy in his teacher education program, he was now focusing his learning on the areas of greatest importance to him: "how our students learn, how we communicate concepts, and how we assess learning." His preservice education gave him a familiarity with reformed perspectives on teaching, but not with the practical experience of teaching. Now as his career has developed, he is pursuing "a more practical style of professional learning," relying on additional qualification courses and workshops on student learning and assessment and working on weaving the "underlying pedagogy and theory" into his work with students and colleagues.

For Liz and her colleagues, the introduction of the Physics First model of teaching helped reveal similar issues of needing to be specific in focusing their professional learning on the needs of a particular reform. In her case, there was a recognition that professional learning needed to simultaneously focus on both content and pedagogy. There was a need to reimagine the way in which physics had been taught, leading to a common departmental understanding of the pedagogy and content of the new program. Developing this common understanding meant, for example, that the labs "that did exist were cookbook in nature, which would need to change with Physics First." Such an approach was invaluable, as a number of teachers "were not necessarily comfortable teaching … outside their content areas." The concentration on working with both the content and the pedagogy required for the Physics First program has given the department confidence in how it can approach the implementation of the *NGSS:* "We brought in experts [and now send] teachers to conferences and professional development workshops."

Mike and Steve's teaching and learning of a reformed vision of science was heavily influenced by the work of their department. Mike was initially skeptical of being involved in the A&E professional development: "OK, here we go again." Two aspects of Mike's vignette are instructive for us. The first is that he made connections between his previous professional learning and the new information he was working with: "One of the biggest impacts was my realization of how A&E can be used to support and strengthen a more accurate representation of science in the classroom." Such an openness to learning allowed Mike to understand *what* aspects of his practice needed to change, *why* they needed to change, and *how* to reform his teaching. All of this is encapsulated in the statement, "If I'm up in the front teaching, then I'm the one who's 'doing science,' and they're sitting there listening but not 'doing science,' … which allows them to opt out of the thinking and learning." The second important aspect of Mike's vignette is that the A&E professional development opportunity was discipline specific. Mike could take the content that was being offered and make use of it in his classroom: "I can meaningfully assess a student's ability to communicate, observe, use critical thinking skills and understandings, self-assess, peer-assess, and give feedback."

Steve was not part of the formal training, but working in a collegial department that made time to talk about practices and working closely with Mike "on the side" allowed Steve to experiment with the reforms in his classroom. Steve noted that communication was key to his learning about the reforms and that the communication needed to reach everybody to build interest in the reform. What is also interesting from Steve's vignette is that the assessment reforms built on the work that the department had already put into teaching the practices of science. Steve instantly saw the value of the assessment reforms: "This was a wonderful thing, especially as it allowed us to assess the practices of science across our subjects. So let's bring it into our classrooms and make the move." In turn, the assessment reforms led to further changes in Steve's classroom practice: "It also means working with students to get them to help each other, especially with descriptive feedback practices." This is an important point, as it highlights how reform is a gradual process and needs to be seen as evolutionary, not revolutionary. As in Liz's department, professional learning opportunities are at their most valuable when they involve teachers with authentic and discipline-specific learning experiences.

Julie learned an important lesson early in her career: "It struck me that not everyone liked the same approaches to learning that I did, and that my job as a teacher was not to change how students best learned but to work with these differences to help all students engage with and integrate new learning experiences." This understanding has shaped a strong commitment to professional learning that respects teachers as learners. In teaching, "there is no 'one' right way to do it; although there are globally effective strategies, sometimes what works for one teacher may not work for another. I think this is reflected in how teachers integrate reforms into their curriculum." This means that a key component in aligning our teaching practices with the ideals of reform documents is encouraging "teachers to more easily see how the reform could work for them and their students." For chairs and other teacher leaders, this means that professional learning in the department must achieve two functions. First, it must affirm both of the fields we are immersed in, education *and* science. Second, it must take into account teachers' prior knowledge, confidence levels, motivations, school structures, and the needs of their specific student populations. The achievement of these functions relies on working with content that helps us implement "the practices and their assessment in our own classrooms [and involves] an appreciation of both real science *and* real teaching. It also involves an openness to teachers adapting reformed ideas that match their comfort levels as well as their students' interests and needs." To successfully develop such professional learning opportunities requires the integration of both theory and practice, a point made by each of our colleagues.

Theory and Practice

Teachers' knowledge is both tacit and explicit, and both forms need to be developed through professional learning opportunities. Teachers are experts at generating tacit knowledge through their classroom work. This tacit knowledge can become explicit knowledge when teachers work with their colleagues and tell stories of practice and "what works." The capacity to tell stories makes "tacit knowledge more visible, call[s] into question assumptions about common practices ... and make[s] possible the consideration of alternatives" (Cochran-Smith and Lytle 1999, p. 294). If we wish to develop teachers' knowledge, then we need to provide the conditions in which there is a "willingness to accept feedback and work toward improvement … respect and trust" (Hord 1997, p. 5). You may have already picked up on the dangers of leaving the responsibility for generating knowledge at a department, school, or even board level. The first is that telling stories of practice only provides information to another teacher; it does not provide knowledge. Second, the desire to tell stories must be fused with a desire to reflect on thoughts, words, and actions. And reflection can only be effective when alternatives become known and explored. In other words, theory and practice need to be two sides of the same coin.

Shawn recognizes just this point when he says that "we can listen and learn from students and colleagues about how students learn, [but] we may never discover if these ideas hold true if we do not desire to experiment with them." For Shawn, the mix of theory and practice is foundational to his learning: "The majority of professional development workshops … have provided a theory on how best to approach different subjects and specific topics within those subjects; these ideas are always supported with practical exercises. … a balance of theory and practice is critical in our growth as effective science educators." Where this balance between theory and practice lies, however, is problematic. For Shawn, in the early stages of his career, the motivating force in finding the balance is the needs of his students; the "balance should be established that works best for the students you have!" That is not a bad rule of thumb.

Liz's experience with the *NGSS* course encapsulates the need to integrate theory and practice: "Through this experience I gained a confidence in working with … [the] *NGSS* that I would not have gained had someone just told me what I needed to know." The strength of the course was that it went beyond making the theory known: "a book study—reading, discussing, and reading some more." Theory and practice were integrated to exemplify "best practices in science education; instead of lecture, we were drawn into discussions and experiences that highlighted the intricacies of the *NGSS*." The net result was "enriching, eye-opening, frustrating, and, most importantly, engaging. I was forced to work with … the *NGSS* in a manner that ultimately gave me a greater understanding of their complexities." And, as with Shawn, the integration of theory and practice was seen as benefiting the teachers and students in Liz's department: "I was also provided with experiences that I could bring back to teachers within the science department and students in the classroom."

The integration of theory and practice for Mike and Steve was much more specific, though no less valuable. Both were already well versed in teaching from a reformed perspective but also realized that their assessment practices had not evolved to align with their teaching. As Mike said, "I thought to myself that I was holding some pretty good work but that today, in many respects, it didn't cut the mustard in terms of my current understanding." For Steve, the benefit was in understanding more about the "processes that students use to manage their learning in the first place." The professional learning on assessment could be linked to his previous work on the practices of science, thus validating and amplifying the importance of his previous work: "It's much more powerful for me and my students when introducing processes such as argumentation." For Mike, the strength of the professional learning was that it involved working with a Ministry trainer, his colleagues, and his students to develop "[his] ability to identify and communicate the success criteria necessary to guide the production of high-quality work and products." The inclusion of students in this is interesting, as the student perspective is often ignored. Further, the focus was on assessing the different forms of evidence of learning that teachers can use rather than using "an accounting tool to crunch only the product or test data and come up with a student's average." By more closely integrating A&E with his reformed teaching practice, Mike has moved closer to more accurately representing science: "It's no longer just about performance on a test, exam, or product."

Julie's vignette brings a different perspective to this discussion. As an experienced chair and facilitator of professional learning opportunities, she highlights the variability in teachers' responses to the integration of theory and practice: "Although most teachers in my own department enjoy learning about the underlying theory and empirical research base of a new educational method, other audiences may find the theory and research less important to their implementation of the work itself." The challenge is to integrate theory and practice in ways that build the credibility of the reform. Teachers need to be "convinced of the likely effectiveness [of the reform] and its suitability for their idiomatic teaching approaches." The alternative is—well, we have all experienced this at some point in our careers—"dogmatic presentations on reform, which, although impassioned and possibly persuasive, can imply a lack of respect for the audience's knowledge and professionalism."

Understanding the relationships between theory and practice is crucial, as is the perceived credibility of the reform in the eyes of the teachers. Credibility can be built when the presentation of the reform is presented in a way that shows, in Julie's words, an "understanding of the real-world classroom" and how students learn in those classrooms. This is the final point that we wish to consider from these vignettes.

How Students Learn

As a beginning teacher, Shawn is clearly (almost idealistically) concerned with how his students learn and how he can learn from them: The "direct experience of students gives an excellent account of your teaching … how it can be modified to best accommodate student learning." This is an admirable position to take, as it appears to be a motivation for reflection on how Shawn can continue to improve this classroom practice "for expanding my foundation in teaching the content and processes of science … in understanding how students learn." Understanding how students learn is also important to Liz, as it gave her confidence in the professional learning that her teachers were undertaking as part of the Physics First and chemistry curriculum changes:

> *We worked through labs as if we were students. We set up equipment, looked at data, compared results, had discussions, and were given the confidence to go into a school year with a new series of courses. … Participating in the program and knowing how our students were learning physics gave our chemistry team a strong foundation from which to build the chemistry curriculum.*

This practical understanding of the professional learning requirements for particular reforms has been reinforced by other forms of professional learning such as collaboration with external experts and sending teachers to conferences.

Despite the apparent success of these professional learning opportunities, Liz implied that they are not the norm. Referring to the *NGSS* course, she says, "I did not expect the course to engage us (teachers) as learners in ways that represented how the standards documents envisioned us engaging with students." However, the content of the course reinforced the efficacy of understanding the content from a student perspective: "We discussed how phenomena could drive a lesson and how student-generated questions … would help students learn not only content but also scientific practices and skills."

Mike highlighted a long-term view of how student learning is changing, a change from discussing what "units will be in a course and the content that will be taught in those units to asking how students learn." This perception is based on the work—of more than 15 years—of his department in promoting a reformed vision of science education. For Mike and his colleagues, students learn by "doing science" rather than by passively listening. Mike's practice is to engage students with science and provide opportunities for them to work with both science content and practices. In addition, he is explicit in working with students to understand what success looks like for the work they are doing so that they know "what it is that they're attempting to do." He also relies on a range of evidence to make sure that learning is appropriately assessed or evaluated.

Not surprisingly, Steve shared a similar long-term view and is concerned with understanding "those processes students go through to understand how science is carried out [and] the processes that students use to manage their learning in the first place." Even as he was working to incorporate the practices of science into his teaching, he also started to look at how assessment needed to change. As a result, he was ahead of the assessment reforms, which have only been implemented in the last few years: "I know that in my classes I never used to do [formative assessment] too much, but I have started to do more over the last six years." Working with students in developing assessment tools has meant changing his perception of himself as a teacher as well. Working with the reforms sees Steve as a co-inquirer into the practices of science, something he takes a quiet pride in: "Questions can be clarified for both the students and myself. I'm a bit of a dinosaur, but I've learned."

Similarly, for Julie, students also learn by doing, where doing is based on a sophisticated understanding of science and with teachers as co-inquirers with their students. The motivation here is the same as what drives Shawn, although they are years apart in terms of experience. For Julie, students learn when they have opportunities for understanding content and making connections and can pursue their own lines of investigation: "This level of engagement in science is what we want for our students, but it is also what we want for ourselves." The creation of lessons and laboratory experiences opens up opportunities that allow teachers to "problem solve as we inquire side by side with our students."

Conclusion

What is interesting in this series of vignettes is that our colleagues identified and have experienced all of the components of the Timperley et al. (2007) framework regarding the content of professional learning opportunities. Occupying different stages in their careers or positions within their departments has made little difference to the main concerns that our colleagues have about the content component of their work. All were driven by a desire to understand how students learn and then use this information to reform their classroom practices to align with the ideals of the reform documents that they were working with. From this intrinsic motivation comes a need to develop both disciplinary and pedagogical knowledge as well as to integrate this knowledge back into their classroom practices.

To support this virtuous cycle of learning, external expertise is important in helping advise and guide the implementation of reforms. The real bedrock on which changes to classroom practice occur, however, is at the department level. In every vignette, the opportunities to discuss teaching and learning—either as a department or with particular colleagues—are seen as crucial to learning and applying new knowledge to the classroom. As such, the content and the context of teacher professional learning become almost indivisible. If we are to build departments that promote teacher professional learning, then we need to embed the content of the reforms into reforming the department. This idea is well understood in the research literature; we need to make it equally understood in departments. It is the professional learning activities that teachers engage in that can become the vehicles for making this connection and then bringing it to life. It is these activities to which we turn our attention in the next chapter.

Summary

- Science teaching can no longer be about the presentation of decontextualized, immutable "facts." The reforms of the past two decades have consistently stressed the need for teachers to develop classrooms in which students work to shape ideas from evidence that explain the *why* and *how* of natural phenomena. As a result, the content of professional learning opportunities must be more than disciplinary knowledge; it must also include how to use that knowledge in a way that reflects the human construct that is science.
- Although we may pursue a broader and deeper understanding of science, we also need to move toward a greater alignment of our teaching practices with the ideals of the reform documents. This means constantly evolving our understanding of teaching and learning.
- Professional learning in the department must achieve two functions. First, it must affirm both of the fields we are immersed in—education *and* science. Second, it must take into account teachers' prior knowledge, confidence levels, motivations, and school structures, as well as the needs of specific student populations.
- Understanding the relationships between theory and practice is crucial, as is the perceived credibility of the reform in the eyes of the teachers. Credibility can be built when reforms are seen as credible and address how students learn in classrooms.

- A focus on how students learn is centrally important when considering the content of professional learning.
- Opportunities to discuss teaching and learning—either as a department or with particular colleagues—are seen as crucial to learning and applying new knowledge to the classroom.

Questions to Consider

1. What are the ways you and your colleagues can support or have supported each other in building robust and flexible content knowledge? How might the dimensions of the *Framework* (i.e., Chapters 3–8) be used within the department to support this pursuit?
2. In what ways can teachers in schools and departments be supported to learn continuously as our knowledge from research about science teaching and learning evolves? What strategies might the department use to ensure that new developments related to science teaching and learning are understood and integrated into the evolving departmental visions of science education? (Consider mechanisms to support teachers' reading and sharing resources from National Science Teachers Association journals or ways to connect with science education leaders outside of the school.)
3. What mechanisms are in place, or could be put in place, to support the integration of what teachers are learning with the expertise and experiences they already have from their years of experience in classrooms?
4. To what extent do departmental or individual discussions center on student work as a mechanism for focusing professional learning on how students learn? When could opportunities for such discussions occur in the school or department?
5. How might the discussions about science teaching and learning in the school or department be enhanced to further support teacher professional learning?

"Our book gives teachers at different points in their careers a voice in describing their professional learning needs. By combining these voices with theory, we can make use of the department as a place to support all teachers in their reform efforts."

—The authors of *Building the Science Department*

BUILDING THE SCIENCE DEPARTMENT

STORIES OF SUCCESS

If you believe it's important to give teachers a say in how their professional learning needs are met, *Building the Science Department* is the book for you. It asks how your science department can become a site for developing science teachers' professional learning. Then, it provides answers through stories told by teachers who walk the sometimes rocky path of reforming science teaching and learning. The authors also wrote *Reimagining the Science Department*, an NSTA Press guide to changing department-level factors so that reformed teaching and learning are both supported.

***Building the Science Department* is divided into two parts.**

- **The first part deals with scientific activity—its representation in *A Framework for K–12 Science Education* and the *Next Generation Science Standards* and its role in making the science department a place for building professional learning.**
- **The second part uses teacher stories, or vignettes, to work through the components of a professional learning framework—context, content, activities, and processes. After each vignette is a commentary that highlights the key points and implications for teacher learning. Also included are questions to challenge teachers to improve their instructional practices and align them with current reform initiatives.**

By featuring science teachers at different career stages, *Building the Science Department* highlights both the common themes in their professional learning and the ways their learning needs have changed over time. The stories are illuminating for teachers as well as for school administrators, other education leaders, and policy makers.

Grades 6–12

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BEYOND THE EGG DROP

Infusing Engineering Into High School Physics

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Preface

Arthur Eisenkraft

The "egg drop" is certainly a fun activity. Students are charged with designing packaging for an egg that will allow it to be dropped from a height of five meters onto a concrete floor without being damaged. The drop is even more fun—and messy—if students forget to first wrap the egg in a plastic bag. But, is this science? Is it engineering? The project is used in science classes and asks for an engineering design. But is that enough to qualify it as engineering?

The egg drop project can be given to engineers. The engineers will certainly use physics principles in solving this design challenge. They will bring to this problem an understanding of materials, design, and analysis. They may build prototypes and test them as part of their work. How do we assess students along the lines of how engineers would address this challenge? As teachers, how can we clarify our directions and alter our expectations so that the high school engineering students become student engineers? How can we interweave opportunities to learn engineering concepts and skills in an already packed science curriculum?

Using engineering design principles and engineering terminology (e.g., the following boldface terms) can move this activity closer to meeting the criteria for an exemplary engineering lesson. In the challenge to **design** packaging for an egg, we can include additional **constraints** to the given **criterion** of surviving the impact of the concrete floor from a drop height of five meters. For example, we can limit the packaging material to one piece of paper and one meter of masking tape. We can require the students to come up with three possible designs, and then choose their **optimum** design and provide **justification** for their choices. We can allow them multiple **iterations** of their design after **testing** from a height of one meter, requiring them to record in their **engineering notebook** their **analysis** of the present design and the reason for each **modification**. We can insist that they include the relevant **physics principles** such as impulse, force, time, and change in momentum and how their design takes these physics principles into account. But even this is not enough.

Engineering is defined in *A Framework for K–12 Science Education* (the *Framework;* NRC 2012, p. 11) as "any engagement in a systematic practice of design to achieve solutions to particular human problems." In asking the students to design packaging for an egg, the teacher should provide a rationale for the request. The rationale for an engineering design project is crucial. Who wants to protect this egg? Why is anyone dropping eggs onto concrete from five meters up? What is the human problem we are trying to solve? Are we really concerned that people are dropping eggs from five-meter heights onto concrete and the eggs are breaking? Of course not! However, we do know that when we buy a carton of eggs at the market, one or more eggs may be cracked or broken. The safe transportation of eggs is a problem and we have to decide how to test packaging. Packaging eggs for safe transport is one valid rationale. But the rationale for our engineering design may not be about eggs at all. We may be devising an improved safety device for a car. When testing this device, we can use the egg as a model for the human skull. If we can keep the egg safe, then we can assume that the human skull would also be safe. This, of course, depends on whether an egg is a useful **model** for a skull. Exemplary engineering projects are not contrived situations, and with a bit of effort, teachers and students can create the rationale for why students are engaging in the design challenge.

The *Framework* and the *Next Generation Science Standards* (*NGSS;* NGSS 2013) demand that engineering be a part of a student's education. One solution to this requirement is to adopt or create engineering courses in high schools. Some schools have been inventing or adopting a number of curricula. These courses require students to find room in their programs to enroll in such a course for a semester or more. Some of the curricula available are quite engaging and comprehensive. Given the staffing constraints in many schools and the impossibility of adding another course to some students' schedules, we advocate for a different model—infusion of engineering into all science courses.

Adopting the engineering infusion model implies that all students enrolled in science courses will get exposure to engineering and a sense of the interplay between science and engineering. Science and engineering coexist in our culture. We need engineers to help invent technologies to allow science to proceed. We need scientists to uncover new areas of knowledge and to develop new theories so that engineers can invent new technologies to solve problems. Too often in school instruction, engineering and technology are either ignored in the curriculum or seen as the handmaiden of science. The infusion model addresses this problem and brings out the rich relationship between the two subjects.

This book explores the model of infusing engineering into high school physics or physical science courses. Most of the book provides lessons that can be incorporated throughout the school year. The lessons vary in length. Some require only a part of a class period, while others require a full class period. Some are longer projects that go on for days or weeks. Sometimes those lessons are activators and are best used before any discussion of physics principles. Others are capstones and are best used after the physics lessons have been completed. These lessons have all been tested and are accompanied by artifacts of student work so that other teachers can get a better sense of student expectations.

The *Framework* and *NGSS* reference engineering design. Research shows that engineers have reached a consensus on the most important features of engineering. We will use those four features—design, analysis, modeling, and systems—to help frame engineering lessons. All science teachers will recognize that these same four terms are used throughout science instruction. Teachers and students should be able to distinguish between the uses of these terms in their different contexts. The following are examples:

- How are engineering models similar to and different from scientific models? An engineering model of an airplane is quite different from the scientific atomic model. The models also serve different purposes.
- How does one compare and contrast engineering systems and systems in biology or physics? In designing a new sound system, one engineer may focus on the electrical system, another may focus on the mechanical system, and a third may focus on the safety system. Biologists invent systems to help them understand the human body. They define the digestive system and the endocrine system but do not define the "left leg" system. Physicists use isolated systems to simplify the problem.
- Engineers design a product (e.g., a safety device for a car) that must meet certain constraints. Physicists design an experiment to find the relationship between variables (e.g., how does the stopping distance of a car relate to its speed?).
- Analysis is an important component of both engineering and physics. Engineers will use analysis to determine the type of fastener to use for a given situation. Physicists will use analysis of Newton's laws to determine the stability of an object on a ramp.

All of these are important distinctions that teachers should be able to articulate for students to understand these overlapping engineering and science concepts.

Through the lessons presented in this book, we articulate the use and examples of the terms—*design*, *analysis*, *models*, and *systems*. Among the lessons are "anchor activities" that can be used to provide a foundational understanding of these terms in engineering. Each anchor activity provides a memorable example of design, analysis, models, or systems. Each engineering-infused activity in the book includes a chart that will show the unique use of each of these terms.

Presenting engineering-infused lessons in not enough. Assessment must play a central role in the infusion of engineering into physics. The larger issue of assessment has three facets, which are all considered in this book: assessment of lessons, assessment of teaching and assessment of student learning. Each affects the others but uses a unique rubric.

Assessment of lessons has to do with the quality of the engineering activities. How does a teacher decide whether a lesson found on the internet in which students drop an egg onto concrete represents a high-quality engineering activity? What criteria should be reviewed? How can teachers modify and improve what they find? Rubrics are provided in this book to help guide teachers in the adoption of engineering-infused activities.

Assessment of teaching focuses on teacher practices. How should a teacher introduce an engineering design challenge? How much time should a teacher allocate to engineering principles? Should the engineering infusion activity be positioned before the science, during the science or after the science? How much help should a teacher provide students? At what point during the student design work should teachers make suggestions? How much time should students be provided to complete a design challenge? These questions are discussed here in general and then articulated through the sample lessons that follow.

We discuss assessment of student learning, as well as the difficulties inherent in any such an evaluation. For example, do we want to assess the product that the students submit or are we more interested in the process that got them to the product? If one student group converges on a single design, executes it, and has a product that meets the criteria, what grade does it get? If another student group looks at multiple solutions, chooses the best one (and defines why it is best), and pursues this through a number of iterations but fails to have a final product that meets the criteria, what grade does it get?

We begin the book with an example of an exemplary infusion of engineering and contrast it with a lower-quality infusion. We then discuss the role of engineering in the *Framework* and *NGSS*, and make distinctions between engineering and trial and error. Then we introduce approaches to engineering infusion. We discuss the themes of design, models, systems, and analysis and make distinctions between how these terms are used in science and in engineering. Finally, we introduce the three facets of assessment.

The major focus of the book is the classroom-tested engineering-infused lessons. Along with each lesson, we provide a detailed description of why teachers should consider adding the lesson to their science curriculum. We then present examples of student work to illustrate the demands the different lessons make on high school students at different times. The lesson plans are presented in the major content areas of physics and those given in the *Framework* and *NGSS*.

We close with suggestions to readers for how they can involve other teachers and students in the infusion of engineering into high school physics and physical science courses.

As teachers, we must take many things into consideration as we develop our curriculum. Every day, there is more science in the news that we could use to engage students. We must decide which current events to bring into the classroom or whether to debate a scientific controversy. Some may ask whether engineering infusion will push out some of the physics or physical science curriculum. No science teacher wants to give up valuable lessons just to include another topic in their curriculum. We think that engineering infusion is different in that instead of taking away from time on a subject, it will enhance the science we get to present and provide students with additional understanding of science concepts. This book is our attempt to find out if we are on the right track.

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Summary of Contents by Chapter

The egg drop activity is a classic physics classroom experience that is specifically mentioned in the *Next Generation Science Standards* (*NGSS*). However, with simple shifts in focus, it can also incorporate elements of engineering concepts and skills that are typically not addressed in a traditional physics classroom.

Chapter I: Justification

Teachers from the Greater Boston area share experiences of their own with infusing engineering, discuss some of the lessons learned, and offer some rationales for continuing to add engineering components to their classroom.

Chapter 2: Design, Analysis, Models, and Systems: Core Concepts for Engineering Infusion

Project Infuse focuses on four core concepts in engineering. Teachers can articulate different aspects and components in engineering practices that go beyond the general engineering design process.

Chapter 3: Implementation

Different experiences and methods have been developed by Project Infuse teachers. How can engineering be infused using the core concepts and engineering process in both larger project-based challenges and in smaller-scale anchor activities and case studies? The chapter ends with suggestions for timing, grouping, and structuring the classroom to make it more design-centered.

Chapter 4: Assessments

Engineering should be assessed alongside the science content. Teachers use rubrics to assess the quality of an engineering activity and the number of engineering concepts addressed and to self-assess the implementation of these engineering activities. This chapter explores the types of assessment for students and ways to support student success through a balance of assessing engineering process versus designed product.

Chapter 5: Engineering Infusion Using Anchor Activities

Brief activities that address specific engineering core concepts that can be used throughout the academic year.

Chapter 6: Engineering Infusion With Mechanics

Engineering-infused physics lessons that can be used throughout the mechanics unit. These address topics of forces, kinematics, and linear momentum and impulse.

Chapter 7: Engineering Infusion With Energy

Engineering-infused physics lessons that can be used throughout the energy unit. These address topics of mechanical energy, energy conservation, and thermal energy.

Chapter 8: Engineering Infusion With Waves

Engineering-infused physics lessons that can be used throughout the waves unit. These address topics of sound, light, reflection, and refraction.

Chapter 9: Engineering Infusion With Electricity and Magnetism

Engineering-infused physics lessons that can be used throughout the electromagnetism unit. These address topics of current electricity, electrical components, and magnetism.

Chapter 10: Professional Development and Growth in Engineering Infusion

The history of Project Infuse and how it supports professional development opportunities for groups of teachers to implement engineering concepts into the classroom.

About the Editors

Arthur Eisenkraft, PhD, is the distinguished professor of science education, professor of physics, and director of the Center of Science and Mathematics in Context at the University of Massachusetts (UMass) Boston. He is past president of the National Science Teachers Association (NSTA) and is past chair of the Science Academic Advisory Committee of the College Board. Eisenkraft is also project director of the National Science Foundation (NSF)–supported *Active Physics* and *Active Chemistry* curriculum projects, which introduce high-quality, project-based science to *all* students. In addition, he is chair and co-creator of the Toshiba/NSTA ExploraVision Awards, involving 15,000 students annually. Eisenkraft also leads the Wipro Science Education Fellowship program, which is bringing sustainable change to 20 school districts in Massachusetts, New Jersey, New York, and Texas, and he has recently been supporting novel educational initiatives in Thailand and India.

His current research projects include investigating the efficacy of a second-generation model of distance learning for professional development—a study of professional development choices that teachers make when facing a large-scale curriculum change—and assessing the technological literacy of K–12 students.

He has received numerous awards recognizing his teaching and related work, including the National Public Service Award, the Presidential Award for Excellence in Mathematics and Science Teaching, the American Association of Physics Teachers Millikan Medal, the Disney Corporation's Science Teacher of the Year, and the NSTA Robert H. Carleton Award. He is a fellow of the American Association for the Advancement of Science, holds a patent for a laser vision testing system, and was awarded an honorary doctorate from Rensselaer Polytechnic Institute.

Shu-Yee Chen Freake has taught physics and biology at Newton North High School (NNHS) in Newton, Massachusetts, since 2005. She has a BS in biology, with minors in physics and education, from Brandeis University. She also holds an MEd from Northeastern University. At NNHS, she has taught a wide range of levels in both physics and biology. As a secondary educator, she is constantly looking for ways to engage students, focusing mainly on scaffolding learning experiences that promote student science and engineering skills that are necessary to solve problems in novel situations. She field-tested the NSF-funded Energizing Physics curriculum, which led to her interest in incorporating engineering pieces into the physics curriculum. In 2014, she was part of a team that developed videos to demonstrate reflective teaching through a grant funded by the Massachusetts Department of Elementary and Secondary Education. In this project, she taught and revised a physics and engineering lesson as part of a professional learning community. Since 2012, she has been involved in the Project Infuse program as a participant for the first cohort and then a co-trainer for the second cohort. She has presented at NSTA conferences, and helped in the planning and writing of this book.

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See the "More About the Contributors" section (p. 457) for additional information about some of the individuals listed above.

5

Engineering Infusion Using Anchor Activities

A major emphasis of engineering infusion in this book is to consider teaching engineering concepts along with the engineering practices. The anchor activities in this chapter are designed to focus on one or more engineering concepts in depth. Without a common language, schema, or experience that the whole class can relate to, engineering design activities can be misunderstood simply as building exercises.

Some teachers have expressed concern that they have to follow a strict curriculum and cannot fit project-based engineering activities into the school year. One possible approach in that situation is to pick four anchor activities, each addressing a different core concept in engineering.

Even though the physics content is not the main focus in this chapter, using the anchor activity to introduce engineering concepts can also be a springboard into some of the science practices or concepts that are important in our classrooms. For example, you could start the forces unit with the wind tube challenge and ask students to draw the force vectors acting on their hovercraft. Similarly, you might finish the school year with a Rube Goldberg design and be sure to ask students about how the inputs and outputs of systems have to work together. Table 5.1 (p. 76) provides basic curricular details for the six anchor activities.

TABLE 5.1. Chapter 5 Anchor Activities

Activity Name	Core Concept(s)	Class Periods	Brief Description
Pasta Cantilever	• Design • Analysis • Systems	1	Construct a cantilever that supports the maximum amount of weight at the greatest distance from the edge of a desk.
Cards to the Sky Gummy Bear Tower	• Design • Analysis	1	Use playing cards to build a tower that can withstand wind such that gummy bears can stand on top of it.
Marshmallow Tower	• Design	1	Use tape, string, and 20 strands of spaghetti to build the tallest tower that will support one large marshmallow on its top.
Soda Can Clock	• Models	1	Create a mathematical model to predict the time it will take for a soda can punctured with holes of different sizes to drain.
Wind Tube Hovercraft	• Design • Analysis • Models	1	Predict and analyze how different materials will behave in a wind tube, then design and test a hovercraft that can stay in the wind tube for 10 seconds.
Rube Goldberg Device	• Systems	1	Create a Rube Goldberg device that includes at least three energy transfers and eventually pops a balloon.

ANCHOR ACTIVITY 5A: PASTA CANTILEVER

Contributors: Neil Kenny and Shu-Yee Chen Freake

Time frame: 1 class period

Engineering focus: Design, analysis, systems

Opportunities for Science Versus Engineering Concepts

Concept	Science	Engineering
Design	• Experimental design o Weight versus deflection o Placement of weight	• Design of the cantilever under given constraints
Analysis	• Net force = 0 N	• Testing of various properties of pastas
Models	• Free body diagram • Torque ➔ drawing diagram	• Model of a real cantilever
Systems	• Sum of the net force = 0 N • The cantilever itself • Net torque = 0 N	• Attachment to table • Interaction of materials

PROJECT OVERVIEW

Students using pennies to anchor the cantilever

In this activity, students are challenged to construct a cantilever that supports the greatest weight at the greatest distance from the edge of a desk using only the materials provided. Dried pasta works well as a construction material because it is both inexpensive and challenging to work with. This is an excellent activity for demonstrating the role of constraints in the engineering process (e.g., limited time, quantity of materials, and quality of materials). It also allows for creative solutions if each group is given a different type of dried pasta, requiring students to carefully consider the properties of the materials provided.

ENGINEERING VERSUS PHYSICS CONCEPT

Although the activity requires students to design, it can be used to focus on analysis of the material and the types of analysis that are necessary to solve a design problem. Students can use mathematical analysis (providing or deriving the torque equation) when applicable. Alternatively, students can simply graph the deflection versus the weight at different distances to analyze the behavior of a cantilever. If each group is given a choice of different types of dried pasta, students can also perform analysis of the materials to determine the weakest point, based on the pasta's dimensions.

Assessment: Determining Acceptable Evidence

Formative

- Mini-conferences with groups
- Class discussion and chart discussion of constraints and final test requirements
- "Do Now" activity, class notes and discussions, spot check homework assignments

Summative

- Individual: engineering notebook, homework assignments
- Group: demonstration of cantilever supporting weight

Materials and Preparation

Materials (Groups of 3–4)

- Dried pasta—50 pieces. The teacher may elect to give all groups the same type of pasta, or assign different types to each group. The amount of pasta may vary depending on type. For example, although each group may get the equivalent total mass of pasta, the group with lasagna pasta would receive fewer pieces than the group with angel hair pasta.
- Masking tape. At the teacher's discretion, groups may be given a limited quantity of masking tape (e.g., one meter) and students could be allowed to request additional tape.
- A weight to be supported by the cantilever (e.g., masses or a number of coins)
- Meter stick

- 1 meter of string

Materials per Student

- Safety glasses or goggles
- Engineering notebook

Safety

- Remind students about general lab safety procedures.
- Participants should wear personal protective equipment (eye protection) during the setup, hands-on, and takedown segments of the activity.
- Remind students not to eat any food used in this activity.
- Students should wash hands with soap and water upon completing this activity.

Pasta Cantilever Lesson Plan for Day 1 (55-minute block)

Time Allotted and 7e Model Stage(s)	Lesson Procedure: What Are the Students Doing?	Instructional Notes: What Is the Instructor Doing?	Engineering Opportunities
5 mins. **Engage**	—	• Place a piece of pasta on the lab table so it hangs over the edge and so that students can watch you bend it slowly, see it oscillate, and watch you bend it until it breaks. Repeat this with a longer piece of pasta.	—
5 mins. **Elicit** **Evaluate**	• Work on Do Now questions individually then share with the class. • View a picture of a cantilevered object (e.g., a hanging flower pot) and draw a free-body diagram showing the forces that act on that object. • Suggest ways the cantilever could be redesigned to support more weight.	• Elicit students' prior knowledge and help them make connection from previous experience. • At this point, evaluate where students are.	• Properties of materials • Functionality • Aesthetics
5 mins. **Engage**	• Engage in whole-class discussion about design challenge and how project success will be determined.	• Engage students by generating questions about the design task. • Clarify questions related to the task.	—
25 mins. **Explain** **Explore** **Evaluate**	• Work in groups on the cantilever construction.	• Coach students during group work (i.e., have them Explain) on materials testing. • Evaluate group dynamics, emphasizing exploring different design options. • Check for understanding (evaluate, explain) by asking students about their design process.	• Encourage students to consider multiple solutions and to test for failure before committing to a final design.
10 mins. **Explain** **Evaluate**	• Demonstrate their cantilever to the class and discuss the rationale for their design.	• Each cantilever is scored according to agreed-on criteria.	—

Optional Modification and Extension (Extend)

- Provide each group with a "budget" to stay within as they "purchase" materials. Tape could be sold by the centimeter and different pastas could vary in price (i.e., lasagna noodles would cost more than angel hair pasta). Students could be given time to test different materials before they submit an itemized materials request.
- Have students develop a mathematical model by collecting data at different points to optimize the model for the best distance-weight combination.

Supplemental Material

- Handout 5A: Pasta Cantilever

HANDOUT 5A: PASTA CANTILEVER

A *cantilever* is a device that supports a weight but itself is supported only at one end. Cantilevers are often used in the construction of bridges and as supports for traffic lights, flower pots, signs, and other objects. In this engineering project, you will design and construct a cantilever.

Examples of cantilevers in (a) nature, (b) art, and (c) technology

PROJECT OBJECTIVES

- Describe how the forces act on an object supported by a cantilever.
- Design and construct a cantilever using specified materials.
- Analyze your cantilever design for weaknesses and strengths.

YOUR TASK

Your group will be provided with the following equipment and materials:

- Safety glasses or goggles for each student
- 50 pieces of dried spaghetti or a given mass of different types of dried pasta
- 1 meter of masking tape
- A 20-g weight (or pennies or nickels)
- 1 meter of string

Using only these materials, your task is to design and construct a cantilever that supports the weight at the greatest possible distance from the edge of your lab table.

SAFETY PRECAUTIONS

- Follow all general lab safety procedures.
- Wear personal protective equipment (eye protection) during the setup, hands-on, and takedown segments of the activity.

- Do not to eat any food used in this activity.
- Wash your hands with soap and water upon completing this activity.

PRE-LAB QUESTIONS

1. What is a cantilever?

2. Give two examples of a cantilever.

3. Using the picture of the lamppost on the first page, draw a free-body diagram showing the forces acting on the lamp.

4. Draw a sketch showing a proposed design for your cantilever.

POST-LAB QUESTIONS

5. Draw a diagram of the final design of your cantilever.

6. What was the maximum distance from the lab table at which your cantilever supported the weight?

7. After looking at all the designs in class, sketch the design that was the most successful.

8. Describe the factors that you think led to the most successful design.

9. If you could redesign your cantilever, how would you change it to support the weight farther from the table edge? Explain your answer.

BEYOND THE EGG DROP

Infusing Engineering Into High School Physics

How can we interweave opportunities to learn engineering concepts and skills in an already-packed science curriculum? That was the problem that 30 Boston-area high school physics teachers aimed to solve when they took part in Project Infuse, a National Science Foundation study. Discover their practical solutions in this book, *Beyond the Egg Drop*, which is designed to enable physics teachers to expose students to engineering as they teach physics.

Beyond the Egg Drop is a user-friendly resource that does the following:

- Answers the *Next Generation Science Standards' (NGSS's)* call to add an engineering focus to your lessons so students can take part in authentic STEM experiences.
- Provides a thorough discussion on the rationale, justification, meaning, and implementation of integrating engineering into your science curriculum.
- Offers 24 engineering-infused physics lessons that include examples of student work; cover assessment, teaching, and student learning; and connect to the major content areas of physics, *A Framework for K–12 Science Education*, and the *NGSS*.
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Grades 9–12

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