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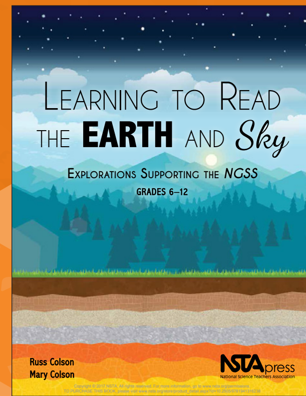

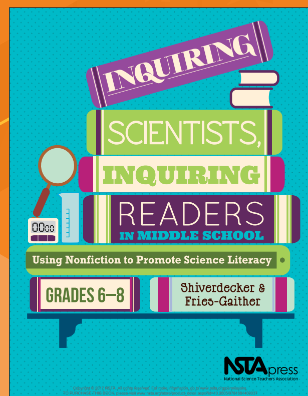

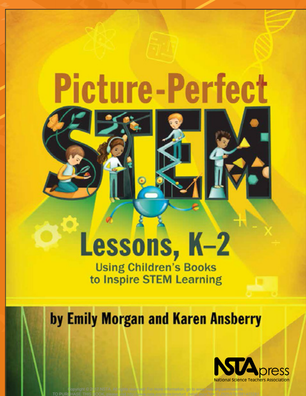

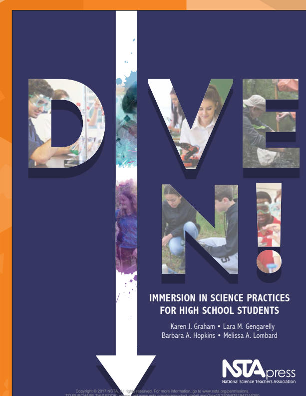

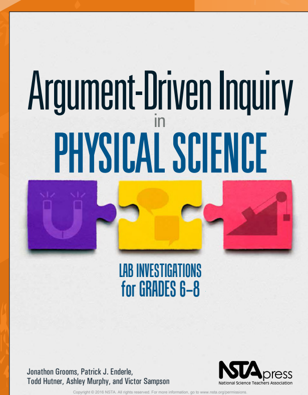

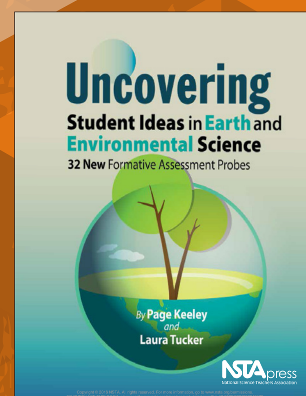

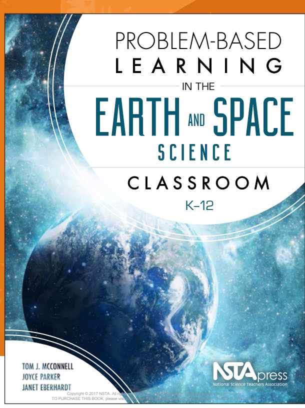

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Picture-Perfect

Lessons, K–2

Using Children's Books to Inspire STEM Learning

by Emily Morgan and Karen Ansberry

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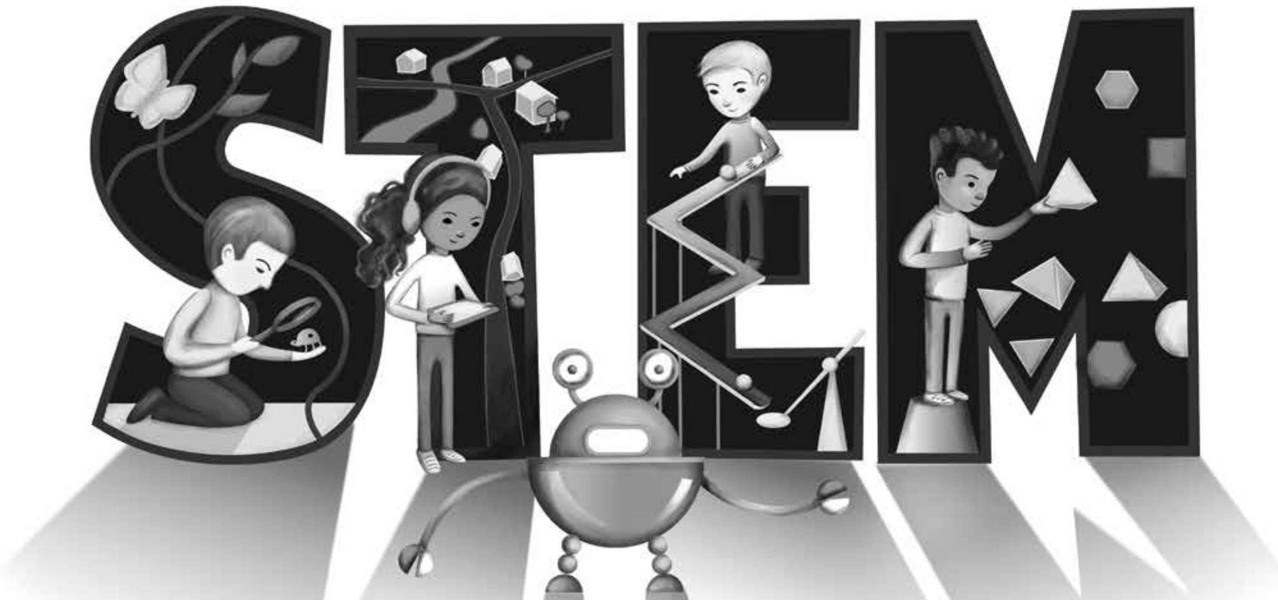
Picture-Perfect



Lessons, K–2

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Contents

Preface

First-grade students listen as their teacher reads *The Day the Crayons Came Home,* the clever story of a group of wayward crayons left in various places by a boy named Duncan. The crayons are sending postcards to Duncan, each with a woeful tale and a plea to return to the crayon box. One postcard (p. 10) reads as follows:

> *Duncan!*
>
> *It's us … Yellow and Orange. We know we used to argue over which of us was the color of the Sun … but guess what? NEITHER of us wants to be the color of the Sun anymore. Not since we were left outside and the Sun melted us … TOGETHER! You know the real color of the Sun?? HOT. That's what. We're sorry for arguing. You can make GREEN the Sun for all we care, just BRING US HOME!*
>
> *Your not-so-sunny friends,*
>
> *Yellow & Orange*

The first-grade students giggle at the silly postcards sent by the desperate crayons. After the read-aloud, they recount some of the ways the crayons were changed in the book—broken, melted by the Sun, chewed by a dog, sharpened, melted in the dryer, and so on. This discussion leads them to an exploration of crayon properties (including measurements), an investigation of ways crayons' physical properties can be changed, and a read-aloud and video about how crayons are manufactured. Students discover that there is a surprising amount of engineering and technology behind the design and production of this classroom staple, and they apply the steps of the engineering design process to come up with a way to recycle crayons into new and interesting shapes and colors. This activity addresses the engineering core idea that a situation people want to change or create can be solved through engineering. Finally, students incorporate English Language Arts standards by writing their own postcard from an adventurous crayon who has been through a number of changes. Thus, students demonstrate their understanding of the physical science core idea that heating or cooling a substance may cause changes that can be observed, and sometimes these changes are reversible. Through this engaging lesson found in Chapter 14, students learn about the interdependence of science, technology, engineering, and mathematics in the crayon-manufacturing industry—all within the context of an amusing fictional story.

What Is Picture-Perfect STEM?

The Picture-Perfect Science program was developed to help elementary teachers integrate science and reading in an engaging, kid-friendly way. Since the debut of the first book in the *Picture-Perfect Science Lesson* series in 2005, teachers across the country have been using the lessons to integrate science and literacy. This new series of Picture-Perfect books, *Picture-Perfect STEM Lessons: Using Children's Books to Inspire STEM Learning*, follows the same philosophy and lesson format as the original books but adds an emphasis on the intersection of science, technology, engineering, and mathematics in the real world. *Picture-Perfect STEM Lessons, K–2* contains 15 lessons for students in kindergarten through grade 2, with embedded reading-comprehension strategies to help them learn to read and read to learn while engaged in STEM activities. To help you set up a learning environment consistent with the principles of *A Framework for K–12 Science Education* (*Framework;* NRC 2012), the lessons are written in an easy-to-follow format of constructivist learning—the Biological Sciences Curriculum Study (BSCS) 5E Instructional Model (Bybee 1997, used with permission from BSCS; see Chapter 3 for more information). This learning cycle model allows students to construct their own understanding of scientific concepts as they cycle through the following phases: engage, explore, explain, elaborate, and evaluate. Although *Picture-Perfect STEM Lessons* is primarily a book for teaching STEM concepts, reading-comprehension strategies and the *Common Core State Standards for English Language Arts* (NGAC and CCSSO 2010) are embedded in each lesson. These essential strategies can be modeled while keeping the focus of the lessons on STEM.

Use This Book Within Your Curriculum

We wrote *Picture-Perfect STEM Lessons* to supplement, not replace, your school's existing science or STEM program. Although each lesson stands alone as a carefully planned learning cycle based on clearly defined objectives, the lessons are intended to be integrated into a complete curriculum in which concepts can be more fully developed. The lessons are not designed to be taught sequentially. We want you to use *Picture-Perfect STEM Lessons* where appropriate within your school's current STEM program to support, enrich, and extend it. We also want you to adapt the lessons to fit your school's curriculum, your students' needs, and your own teaching style.

Special Features of This Book

Ready-to-Use Lessons With Assessments

Each lesson contains engagement activities, hands-on explorations, student pages, suggestions for student and teacher explanations, elaboration activities, assessment suggestions, opportunities for STEM education at home, and annotated bibliographies of more books to read on the topic. Assessments include poster sessions, writing assignments, design challenges, demonstrations, presentations, and multiple-choice and extended-response questions.

Background for Teachers

This section provides easy-to-understand background information for teachers to review before facilitating the lesson. Some information in the background section goes beyond the assessment boundary for students, but it is provided to give teachers a deeper understanding of the content presented in the lesson.

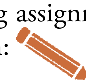
Time Needed

The information in this section helps you pace each lesson. We estimate a primary class period to be about 30–45 min.

Reading-Comprehension Strategies

Reading-comprehension strategies based on the book *Strategies That Work* (Harvey and Goudvis 2007) and specific activities to enhance comprehension are embedded throughout the lessons and clearly marked with an icon. Chapter 2 describes how to model these strategies while reading aloud to students.

Standards-Based Objectives

All lesson objectives are aligned to the *Framework* (NRC 2012) and are clearly identified at the beginning of each lesson. An alignment with the *Next Generation Science Standards* (NGSS Lead States 2013) is included in the appendix (p. 309). The lessons also incorporate the *Common Core State Standards for English Language Arts and Mathematics* (NGAC and CCSSO 2010). In a box titled "Connecting to the Common Core," you will find the Common Core subject the activity addresses as well as the grade level and standard number. You will see that writing assignments are specifically labeled with an icon: .

STEM at Home

Each lesson also provides an extension activity that is intended to be done with a parent or other adult helper at home. Students write about what they learned about each topic and share their favorite part of the lesson. Then, together with their adult helper, they complete an activity to apply and extend the learning. If students are unable to complete the extension at home, the activities in this section also work well as in-class extensions.

Ideas for Further Exploration

A "For Further Exploration" box is provided at the end of each lesson to help you encourage your students to use the science and engineering practices in a more student-directed format. This box lists questions and challenges related to the lesson that students may select to research, investigate, or innovate. Students may also use the questions as examples to help them generate their own questions. After selecting one of the questions in the box or formulating their own questions, students can make predictions, design investigations to test their predictions, collect evidence, devise explanations, design solutions, examine related resources, and communicate their findings.

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National Research Council (NRC). 2012. *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.

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

Children's Book Cited

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Editor's Note

Picture-Perfect STEM Lessons, K–2 builds on the texts of 29 children's picture books to teach STEM. Some of these books feature objects that have been anthropomorphized, such as crayons that pack their bags and travel the world. Although we recognize that many scientists and educators believe that personification, teleology, animism, and anthropomorphism promote misconceptions among young children, others believe that removing these elements would leave children's literature severely underpopulated. Furthermore, backers of these techniques not only see little harm in their use but also argue that they facilitate learning. Because *Picture-Perfect STEM Lessons, K–2* specifically and carefully supports science and engineering practices, we, as do our authors, feel the question remains open.

Acknowledgments

We would like to dedicate this book to the memory of Dr. Robert Yearout, who gave us the opportunity to present our first teacher workshop at the "Sharing What Works" Conference in Columbus, Ohio, in 2000. Dr. Yearout's leadership of the High Achievement in Math and Science Consortium, which we were both fortunate to be a part of for many years, provided us with opportunities and encouragement to grow as educators and advocates of science and math education. Dr. Yearout's selfless leadership style and utmost respect for the teaching profession continue to inspire us today.

We appreciate the care and attention to detail given to this project by Rachel Ledbetter, Wendy Rubin, and Claire Reinburg at NSTA Press.

And these thank-yous as well:

- To Linda Olliver for her "Picture-Perfect" illustrations
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- To Ted Willard for answering all of our *Next Generation Science Standards* (*NGSS*) questions and creating his helpful *NGSS* guides
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- To Christine Anne Royce for her help with research on using children's books to teach STEM
- To Andrea Beaty for giving us a sneak peek of *Ada Twist, Scientist;* promoting STEM education; and encouraging innovation, curiosity, and creativity in kids everywhere

The contributions of the following reviewers are also gratefully acknowledged:

- Kevin Anderson
- Mark McDermott
- Ruth McDonald
- Bill Robertson
- Kristina Tank

About the Authors

Emily Morgan is a former elementary science lab teacher for Mason City Schools in Mason, Ohio, and seventh-grade science teacher at Northridge Local Schools in Dayton, Ohio. She served as a science consultant for the Hamilton County Educational Service Center and science leader for the High AIMS Consortium. She has a bachelor of science in elementary education from Wright State University and a master of science in education from the University of Dayton. She is also the author of the *Next Time You See* picture book series from NSTA Press. Emily lives in West Chester, Ohio, with her husband, son, and an assortment of animals.

Karen Ansberry is a former elementary science curriculum leader and fifth- and sixth-grade teacher at Mason City Schools in Mason, Ohio. She has a bachelor of science in biology from Xavier University and a master of arts in teaching from Miami University. Karen lives in historic Lebanon, Ohio, with her husband, two sons, two daughters, and two dogs.

Emily and Karen enjoy facilitating teacher workshops at elementary schools, universities, and professional conferences across the country. This is Emily and Karen's fourth book in the *Picture-Perfect Science Lessons* series. For more information on this series and teacher workshops, visit *www.pictureperfectscience.com.*

Safety Practices for Science Activities

With hands-on, process- and inquiry-based science activities, the teaching and learning of science today can be both effective and exciting. The challenge to securing this success needs to be met by addressing potential safety issues relative to engineering controls (ventilation, eye wash station, etc.), administrative procedures and safety operating procedures, and use of appropriate personal protective equipment (indirectly vented chemicals splash goggles meeting ANSI Z87.1 standard, chemical resistant aprons and gloves, etc.). Teachers can make it safer for students and themselves by adopting, implementing, and enforcing legal safety standards and better professional safety practices in the science classroom and laboratory. Throughout this book, safety notes are provided for science activities and need to be adopted and enforced in efforts to provide for a safer learning and teaching experience. Teachers should also review and follow local policies and protocols used in their school district and/or school (e.g., employer OSHA Hazard Communication Safety Plan and Board of Education safety policies).

Additional applicable standard operating procedures can be found in the National Science Teacher Association's "Safety in the Science Classroom, Laboratory, or Field Sites" (*www.nsta.org/docs/SafetyInTheScienceClassroomLabAndField.pdf*). Students should be required to review the document or one similar to it for elementary-level students under the direction of the teacher. It is important to also include safety information about working at home for the "STEM at Home" activities. Both the student and the parent or guardian should then sign the document acknowledging procedures that must be followed for a safer working and learning experience in the classroom, laboratory, or field. The Council of State Science Supervisors also has a safety resource for elementary science activities titled "Science and Safety: It's Elementary!" Teachers can consult this document at *www.csss-science.org/downloads/scisaf_cal.pdf*.

Please note that 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.

Robots Everywhere

Description

After sharing what they know about different types of robots, students model how robots are programmed to perform tasks. They learn that every robot is designed for a specific job, and that job determines what a robot looks like. They also make a labeled drawing of a robot that could complete a particular task in their own home or at school, and they compare it with another technology designed to solve the same problem.

Suggested Grade Levels: K–2

LESSON OBJECTIVES Connecting to the *Framework*		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concept**
Developing and Using Models Constructing Explanations and Designing Solutions	**ETS1.B:** Developing Possible Solutions **ETS2.B:** Influence of Engineering, Technology, and Science on Society and the Natural World	Structure and Function

Featured Picture Books

TITLE: ***Beep! Beep! Go to Sleep!***
AUTHOR: **Todd Tarpley**
ILLUSTRATOR: **John Rocco**
PUBLISHER: **Little, Brown Books for Young Readers**
YEAR: **2015**
GENRE: **Story**
SUMMARY: *This fun, rhyming story will have kids giggling as a little boy tries everything to get his household robots to power down.*

TITLE: ***National Geographic Kids: Robots***
AUTHOR: **Melissa Stewart**
PUBLISHER: **National Geographic Children's Books**
YEAR: **2014**
GENRE: **Non-Narrative Information**
SUMMARY: *Young readers will learn about the most fascinating robots of today and tomorrow in this colorful, photo-packed book.*

Time Needed

This lesson will take several class periods. Suggested scheduling is as follows:

Day 1: **Engage** with *Beep! Beep! Go to Sleep!* Read-Aloud, **Explore** with Robot Arms, and **Explain** with Robot Arms Discussion and Chocolate Factory Video

Day 2: **Explain** with *National Geographic Kids: Robots* Read-Aloud and Robot Jobs Card Sort

Day 3: **Elaborate** with Robots of the Future and **Evaluate** with My Robot

Materials

For Robot Arms (per pair)

- 9 × 12 in. two-pocket folder with a mouse-hole-shaped opening (large enough for a student's arm to reach through) cut in the bottom center
- 1 small bowl
- Plastic sandwich bag with about 10 pieces of spiral-shaped pasta and about 10 pieces of tube-shaped or bowtie pasta
- 1 precut Robot Arm Program Card

Optional: For My Robot Advertisement (per student)

- White poster board or large construction paper
- Markers

SAFETY

- Check with your school nurse about wheat allergies, and substitute wheat-free pasta if necessary.
- Remind students not to eat any food used in the lab or activity.

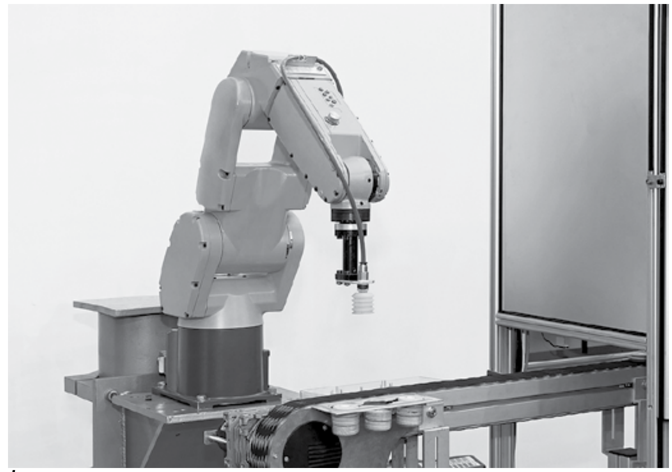
Student Pages

- Robot Jobs Card Sort
- Robot Job Descriptions
- My Robot and My Robot Advertisement
- STEM at Home

Background for Teachers

What do you think of when you hear the word *robot*? Most likely, you have a mental image of a walking, talking, blinking, and thinking humanoid machine. But most robots don't really look like people at all. Robots come in every shape and size you can think of and perform more jobs than you can imagine. If it seems as if robots are everywhere today, that's because they are! In this lesson, students learn about the influence of engineering, technology, and science on society by studying how people have come to depend on robots to do many jobs they could not (or would not) do.

So what exactly is a robot? Oddly enough, there is no widely accepted, standard definition of a robot. Even Joseph Engelberger, often referred to as the "father" of the modern robotics industry, was said to have remarked, "I can't define a robot, but I know one when I see one." In *National Geographic Kids: Robots,* author Melissa Stewart proposes this definition: "A robot, or bot, is a *machine* that has movable parts and can make decisions. People design it to do a job by itself." Although some robots lack computers and perform only simple, motor-driven tasks, the book explains that most robots have three main types of parts: a computer, sensors, and actuators. A robot's *computer* contains programs to help it make decisions. It makes these decisions based on data collected by its *sensors*. Some common robot sensors are video cameras to "see"; microphones to "hear"; pressure and temperature sensors to "feel"; ultrasound, infrared, and laser sensors to measure distance, navigate, and avoid obstacles; and even sensors that detect magnetic fields and certain types of chemicals.


INDUSTRIAL ROBOT ARM

To be called a robot, a machine must move. *Actuators,* also known as drives, are devices that receive messages from the computer and control the robot's movements. Most actuators are powered by pneumatics (air pressure), hydraulics (fluid pressure), or motors (electric current), but they all convert one kind of energy into motion energy. Actuators help the robot make sounds, flash lights, pick things up, move, and so on. Sometimes the whole robot moves, like the rovers that are rolling around the surface of Mars collecting rock samples and other data. Sometimes the robot is stationary with moving parts, like the robotic arms commonly used in industry for many different kinds of jobs. Welding or spray-painting robots don't have to move from place to place, but when a robot's job does require movement, robotics engineers (or *roboticists*) usually design it to have tracks, wheels, or legs (and some robots can even swim or fly). Robots need energy to move. They might be plugged in, battery powered, or even solar powered, depending on what they are designed to do.

In this lesson, students learn that a robot can only do things that engineers and roboticists *program* it to do. They learn that a robot's programming must be very detailed; each and every step must be spelled out for a robot to do its job properly. They model how a "pick-and-place" industrial robot arm needs a very precise and logical *program* to follow in order to complete a task, such as picking things up and sorting them. To model this, each student "programs" his or her partner's "robot arm" to pick up and sort pasta shapes into separate piles.

Students also learn that most robots are designed to do jobs that are too repetitive or dangerous for humans to do. Robots can explore places that humans can't go, such as Mars, the deepest trenches of the sea, or the craters of active volcanoes. But some of the handiest robots have less glamorous jobs: they are the domestic, or household, robots. There are robots to mow your lawn, clean your gutters, scoop out your cat's litterbox, entertain you, and even wake you up! Caregiving robots are being designed to help people with physical challenges move from a chair to a bed, fetch household items, or take a bath.

In this lesson, students look around their homes and classrooms and brainstorm problems that robots could solve. They design a robot and then compare its strengths and weaknesses with those of the technology (or the person!) currently solving the problem. Students share their designs through labeled drawings. Finally, they create an advertisement to "sell" their robot, explaining how it is a better solution than the technology (or person) currently solving the problem. The concept of structure and function is woven throughout the lesson as students explore how a robot's job determines what it looks like.

In the explore phase, students will get a sense of how robots are programmed by being exposed to simple IF-THEN-ELSE statements. Programming is a great way to teach problem-solving, creativity, and communication skills, and even very young children can be taught simple coding. To find out more about teaching young students to code, visit Reading Rockets (see “Websites” section) to view the article “IF kids code, THEN … what?” There are several suggested websites and apps listed at the end of the article, including Code, a nonprofit organization working to ensure that every student in every school has the opportunity to learn computer science. Its completely free curriculum for ages 4 and up consists of multiple courses, each of which has about 20 lessons that may be implemented as one unit or over the course of a school year. We hope that by learning about “robots everywhere” you and your students will be inspired to learn more about the wonderful world of coding!

engage

Beep! Beep! Go to Sleep! Read-Aloud

> Connecting to the Common Core
> **Reading: Literature**
> Key Ideas and Details: K.1, 1.1, 2.1

Engaging with Beep! Beep! Go to Sleep!

Inferring

Show students the cover of *Beep! Beep! Go to Sleep!* and introduce the author, Todd Tarpley, and illustrator, John Rocco. *Ask*

- ? Based on the cover, what do you think this book might be about? (a boy and some robots)
- ? How do you know? (The boy is reading a book called *3 Little Robots,* and there are three robots on the cover.)

Then, read the book aloud.

Questioning

After reading, *ask*

- ? What kinds of jobs do robots do? (Answers will vary.)
- ? What job do you think the robots in the book were designed to do? (entertain the boy or take care of the boy; students may notice that the first two-page spread has pictures on the wall showing that the robots have been with the boy since he was a baby)
- ? Do most robots look like the ones in the book? (Answers will vary.)

explore

Robot Arms

Tell students that most robots look nothing like the cute, funny ones featured in the book *Beep! Beep! Go to Sleep!* In fact, robots that consist of just a moving “arm” are among the most common robots used. Show students the robot arm on pages 22 and 23 of *National Geographic Kids: Robots.* Tell students they are going to do a fun activity to model how one of these robot arms works.

Before beginning the activity, divide students into teams of two. Tell students that one member of each pair is going to be the “robot arm” and the other member is going to be the “programmer.” (They will be switching roles after the first trial.)

ROBOT ARMS ACTIVITY

Explain that all robots need to be *programmed* to do their job. This means that engineers must write a very specific set of instructions called a *computer program* and then upload, or transfer, the program to a robot's computer. The student who is the programmer will be reading these instructions to the student who is modeling the robot arm so that this student knows how to do his or her job. (You may want to read the Robot Program together if your students are not yet reading independently.)

Give a sandwich bag of pasta (spirals and either tubes or bowties) and a precut folder (to act as a screen) to each pair. Give a Robot Arm Program Card to each programmer. Then, read aloud the directions below:

Directions for Robot Arms Activity

1. Stand the folder on the table. The first person to be the robot should place one hand through the hole in the folder and lean over until his or her forehead is touching the folder. The robot should not be able to see his or her own hand (but may use the other hand to keep the folder standing up).
2. The programmer should dump the pasta into a bowl in front of the folder, within reach of the robot arm.
3. The programmer will tell the robot how to do its job by reading a set of instructions called the *Robot Program*.

When all pairs are set up and ready to go, call out, "START!"

Robot Program

1. Pick up a piece of pasta from the bowl.
2. IF the pasta feels like a spiral, THEN place it to the left of the bowl, or ELSE place it to the right of the bowl.
3. IF any pasta is still in the bowl, THEN GO TO step 1, or ELSE END program.

After a few minutes of pasta sorting (or more if necessary), call out, "STOP!" Next, have the programmers remove the folder so their partners can see the results. Then, have students trade roles and repeat the activity.

explain

Robot Arms Discussion and Chocolate Factory Video

Questioning

After everyone has had a chance to be both a programmer and a robot arm, *ask*

- ? What was the job the robot arms had to do? (sort the pasta)
- ? How well did the robot arms do their job? (Answers will vary.)
- ? Is this a job you would want to do? (Students will most likely answer no.)
- ? Why or why not? (It would be boring or too repetitive, and your arm would get tired.)
- ? What parts or structures on the robot arms helped them do their job? (movable elbows, wrists, hands, fingers, etc.)
- ? Did the programmer ever have to give the robot additional instructions? (Answers will vary.)

Explain that real robots can *only* do what they are programmed to do. Every step of a task must be spelled out in the robot's program. If the program is not detailed and exact, the robot won't be able to do its job very well or at all. Discuss the Robot Program used in the model. Point out that many types of computer programs are similar to this one: They are made up of a series of logical statements that include the words IF, THEN, ELSE, GO TO, and END. You may want to give students the opportunity to write another simple program for a robotic arm, such as a program for sorting and placing different-shaped blocks into containers.

Next, explain that robot arms are typically used in factories, doing jobs that people might not want to do because they are so repetitive (meaning they are repeated over and over). There are many different types of robot arms used in industry. One kind is designed to spray paint cars. Another kind welds metal together. One of the most common kinds found in factories and warehouses is called a *pick-and-place robot* because it is designed to pick things up and place them somewhere else, usually into some sort of package. The robot arm they modeled is a type of pick-and-place robot.

After completing the Robot Arms activity, tell students that they will have an opportunity to see some real pick-and-place robot arms in action. The "M-430iA Robots in Food Industry: Pick&Place of Chocolates" video (see "Websites" section) features two FANUC Robotics robot arms in a chocolate factory "picking and placing" different kinds of chocolate truffles into blister packs. Have students watch the video carefully to observe the robot arms doing their jobs.

After watching, point out that these robots have vision sensors, which are cameras that help them "see" the chocolates. Also, explain that although the robots are automatically doing their jobs, a machine operator nearby is controlling the settings on the robots' computers. Robots can only do jobs they are programmed to do, and often their programs need to be changed or adjusted for them to do their jobs properly.

Connecting to the Common Core
Reading: Informational Text
Key Ideas and Details: K.1, 1.1, 2.1

Questioning

After watching the video, discuss the following:

- Is packaging chocolate a job that a person could do? (yes)
- Would you want to do that job? (Answers will vary.)
- Why do you think the chocolate factory uses robots instead of people to pick and pack chocolates? (The job is boring, it is repetitive, the robots are faster, the robots never get tired, etc.)

Making Connections: Text to Self

Then, help students make connections between the video and the robot arms activity. *Ask*

- How were the chocolate factory robot arms like the robot arms we modeled? (They were picking up food and sorting it, they stayed in one place, and they had to be programmed.)
- How were they different? (The factory robots were picking the food from a moving conveyor belt instead of a bowl, they were putting the chocolates into different kinds of packages instead of piles, they could "see" the objects whereas our robots could only feel the objects, they could work a lot faster, etc.)

Tell students that they are going to learn much more about what robots look like and the many kinds of jobs they do.

explain

National Geographic Kids: Robots Read-Aloud

Turn and Talk

Show students the cover of the book *National Geographic Kids: Robots,* and *ask*

? What's a robot? (Students will likely provide a variety of responses—even engineers don't always agree on the definition of *robot.*)

Making Connections: Text to World

Read and discuss pages 4–7, which describe these characteristics of a robot:

- Has movable parts or structures
- Can make decisions
- Is designed by people to do a job by itself

Remind students of the Robot Arm activity. Ask them to think about the pick-and-place robot arm that was programmed to sort the pasta. *Ask*

? If that had been a real robotic arm, and not a kid's arm, would it meet the characteristics of a robot?

Go through each characteristic, asking students to give a thumbs-up or thumbs-down to show whether they think their pick-and-place robot arms meets each characteristic. Then, ask them to explain why.

? Does it have movable parts or structures? (Yes, the arm moved at the elbow and wrist joints, and the fingers also moved.)

? Can it make decisions? (Yes, when it felt a spiral-shaped piece of pasta, it placed it to the left of the bowl. When the bowl was empty, it stopped.)

? Is it designed by people to do a job by itself? (Yes, it could do the job by itself with the right programming.)

Read pages 10–11 about the parts of a robot, and *ask*

? What part of a robot is like a person's brain? (computer)

? What parts of a robot receive messages from the computer and control the robot's movements? (actuators)

? What parts of a robot collect information about its surroundings? (sensors)

Explain that many robots have vision sensors—cameras that help them "see" and recognize the shapes or even the colors of objects. These sensors help the robot make decisions such as what object to pick up, where to put it, where to paint or weld on a car, and so on. *Ask*

? What kind of sensor did your robot arm have in the pasta sorting activity? (touch)

? What kind of sensors do you think the chocolate factory robots had? (touch, sight, or both)

Making Connections: Text to Text

The little blue robot in *Beep! Beep! Go to Sleep!* said, "My sensor aches!" *Ask*

? What kind of sensor do you think it had? (Answers will vary.)

Robot Jobs Card Sort

Explain that every robot is designed for a specific job, and that job determines what a robot looks like. Tell students that in the book *National Geographic Kids: Robots,* they will learn about the jobs that robots do at work, at home, and in space. Before reading, pass out the Robot Jobs student pages, and have the students cut out the pictures of the robots. Read each robot job description aloud, and then have students place their cards where they think the cards go. Students will have the opportunity to move their cards as you read the book.

Connecting to the Common Core
Reading: Informational Text
KEY IDEAS AND DETAILS: K.1, 1.1, 2.1

Explain that, because this book is nonfiction, you can enter the text at any point. You don't have to read the book from cover to cover if you are looking for specific information. Tell students that parts of this book will help them match their robot cards with the robot jobs. Ask students to signal (by giving a thumbs-up, making "robot arms," or using some other method) when they see or hear one of the robots from the picture cards. Stop each time you read about a robot from the Robot Jobs Card Sort student page, and have students move their cards if necessary.

Chunking

Follow the steps below to "chunk" the book into the following sections: Robots at Work, Robots at Home, and Robots in Space. Note that you will not read the entire book aloud.

1. Robots at Work: Read pages 22–25, featuring factory robots and the volcano-exploring robot.
2. Robots at Home: Read pages 26–29, featuring the robot alarm clock and the fetch bot.
3. Robots in Space: Read pages 38–41, featuring the robonaut and the Mars rovers.

After reading, students may glue the picture cards onto the Robot Job Descriptions student page once they are all in the correct spaces. The answers to the Robot Jobs Card Sort are as follows:

1. F (Factory Robot)
2. E (Dante II)
3. A (Robot Alarm Clock)
4. C (Fetch Bot)
5. B (Robonaut)
6. D (Curiosity Rover)

Questioning

After reading, ask students to fill in the blanks as you make the following statements:

- ? Every robot is designed for a specific _____. (job)
- ? What a robot looks like depends on _________. (the job it was designed for or built to do)

Turn and Talk

Ask

- ? What was your favorite robot in the book, and why? (Answers will vary.)

elaborate

Robots of the Future

Read pages 44–45 about robots of the future. *Ask*

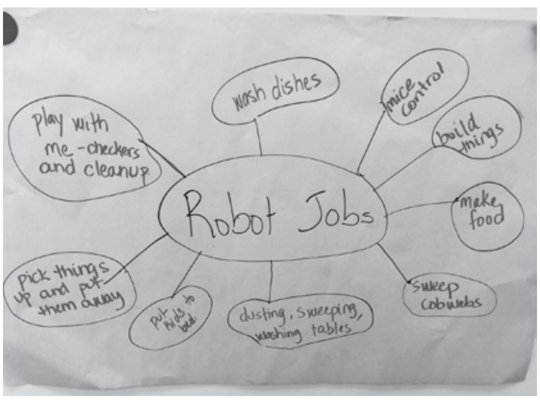
- ? After learning about robots and the jobs they can do, would you want to be a person who designs or builds robots? (Answers will vary.)
- ? Would you want a robot in your home? (Students will likely say yes!)

Tell students they are going to have the opportunity to be roboticists—engineers who design, program, and test robots! They will be designing their very own robot with the purpose of solving a human problem or meeting a human need in their own home or classroom. Tell students that in the not-so-distant future, robots in homes and schools may be commonplace. For inspiration, you can show students the first two-page spread of *Beep! Beep! Go to Sleep!* and have them imagine what it would be like to have a friendly robot in their home or school like the ones pictured.

Word Web

Next, students can brainstorm jobs a robot could help them do. Make a word web with the target words *Robot Jobs* in the middle, and organize student ideas in circles that surround it. Ask guiding questions, such as the following:

- ? What are some jobs that you do around your home or at school?
- ? What tools or machines do you or your parents or teachers use to help get the jobs done?
- ? Are there any jobs that a robot could do around your home or school that you could not?



Robot Jobs Word Web

- ? Are there any jobs that a robot could do around your home or school better than you could do them?
- ? What are some ways that a robot might entertain you or teach you better than another toy or game that you play with?

Then, brainstorm some robot ideas together. Examples might include a robot designed to take out the trash that can carry heavier trash bags than you can carry and can see in the dark to take out the trash at night; a robot designed to play chess that can teach you to play better than your brother or sister and can also put away the chess pieces when you are finished; or a robot that can feed the classroom fish during weekends or vacations and can give the fish exactly the right amount of food every time.

evaluate

My Robot

Connecting to the Common Core
Writing
Text Types and Purposes: K.1, 1.1, 2.1

Writing

Next, have each student select an idea from your brainstorming session, or come up with an idea of his or her own. Give each student a copy of the My Robot student page. Read the first page together.

You may choose to have students use the My Robot Advertisements student page, or have them draw their robot on construction paper or poster board. You can have students present their robots to the class, have a "Robotics Fair," invite other classes to attend a gallery walk, or display the posters in the classroom or hallway.

Our Robot Designs

STEM at Home

Have students complete the "I learned that …" and "My favorite part of the lesson was …" portions of the STEM at Home student page as a reflection on their learning. They may choose to do the following at-home activity with an adult helper and share their results with the class. If students do not have access to the internet at home, you may choose to have them complete this activity at school.

"At home, we can watch a short video together called 'Sandeep Yayathi: Robotics Engineer' about Robonaut 2, or R2, a human-like robot designed to assist astronauts in space."

Search "Sandeep Yayathi: Robotics Engineer" at www.pbslearningmedia.org *to find the video at* http://cet.pbslearningmedia.org/resource/mss13.sci.engin.design.robeng/sandeep-yayathi-robotics-engineer.

"If you were a robotics engineer, what kinds of robots would you want to design and why?"

For Further Exploration

This section is provided to help you encourage your students to use the science and engineering practices in a more student-directed format. This box lists questions and challenges related to the lesson that students may select to research, investigate, or innovate. Students may also use the questions as examples to help them generate their own questions. After selecting one of the questions in the box or formulating their own questions, students can individually or collaboratively make predictions, design investigations or surveys to test their predictions, collect evidence, devise explanations, design solutions, or examine related resources. They can communicate their findings through a science notebook, at a poster session or gallery walk, or by producing a media project.

Research

Have students brainstorm researchable questions:

- ? What is the world's largest walking robot?
- ? How did the Mars rovers get onto the surface of Mars?
- ? What is biomimicry, and what are some examples of it in robot design?

Investigate

Have students brainstorm testable questions to be solved through science or math:

- ? How many pieces of pasta can your partner's "robot arm" sort in 1 min. without looking?
- ? Survey your friends: Would you rather have a robot take care of you if you were sick, or would you prefer a human nurse? Graph the results, then analyze your graph. What can you conclude?
- ? Survey your friends: What household chore would you most want a robot to do? Graph the results, then analyze your graph. What can you conclude?

Innovate

Have students brainstorm problems to be solved through engineering:

- Can you write a code to program your partner's "robotic arm" to sort blocks by their shape or color?
- What kind of robot would you design to help you at school?
- What kind of robot would you design to explore a volcano, the deep ocean, or outer space?

Websites

"IF Kids Code, THEN … What?" (article)
www.readingrockets.org/article/if-kids-code-thenwhat

"M-430iA Robots in Food Industry: Pick&Place of Chocolates" (video)
www.youtube.com/watch?v=ZSbFW_ncldU

More Books to Read

Becker, H. 2014. *Zoobots: Wild robots inspired by real animals.* Toronto: Kids Can Press.
Summary: This book for older readers (grades 3–6) explores the world of robo-animals, or "zoobots." Twelve two-page spreads reveal vivid, Photoshop-rendered illustrations of robot prototypes such as the bacteria-inspired Nanobot, which can move through human blood vessels, and the OLE pill bug, which can fight fires. Each spread shows a smaller illustration of the animal on which the zoobot is based.

Fliess, S. 2013. *Robots, robots, everywhere*. New York: Golden Books.
Summary: This delightful rhyming picture book for very young readers features robots of all kinds, from the ones up in space to the ones we use at home.

Shulman, M. 2014. *TIME for Kids: Explorers—Robots.* New York: TIME for Kids.
Summary: Full of facts and photos, this book in the popular *TIME for Kids* series shows young readers just how useful robots are and why we need them.

Swanson, J. 2016. *National Geographic Kids: Everything robotics—All the photos, facts, and fun to make you race for robots*. Washington, DC: National Geographic Children's Books.
Summary: With stunning visuals and an energetic design, this book for grades 3–7 reveals everything kids want to know about robotics.

Robot Arm Program Cards

ROBOT PROGRAM

1. Pick up a piece of pasta from the bowl.
2. IF the pasta feels like a spiral, THEN place it to the left of the bowl, or ELSE place it to the right of the bowl.
3. IF any pasta is still in the bowl, THEN GO TO step 1, or ELSE END program.

ROBOT PROGRAM

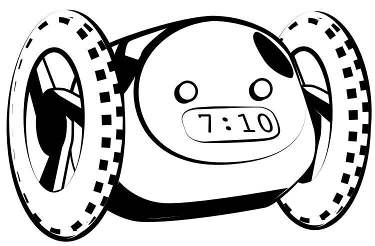
1. Pick up a piece of pasta from the bowl.
2. IF the pasta feels like a spiral, THEN place it to the left of the bowl, or ELSE place it to the right of the bowl.
3. IF any pasta is still in the bowl, THEN GO TO step 1, or ELSE END program.

Robot Jobs Card Sort

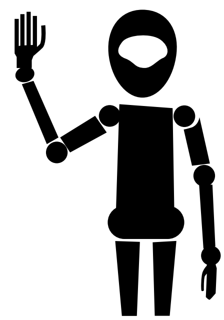
Robots do many different kinds of jobs. They often do jobs that people don't want to do or can't do. What a robot looks like depends on the job it was designed to do.

Directions: Cut out the robot cards below and match each robot to its job description on the next page. Then, listen as your teacher reads the book *National Geographic Kids: Robots*. You will have the chance to move the cards again as your teacher reads the book.

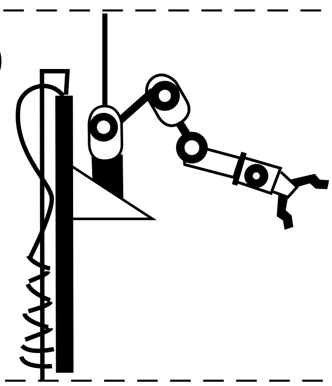
A



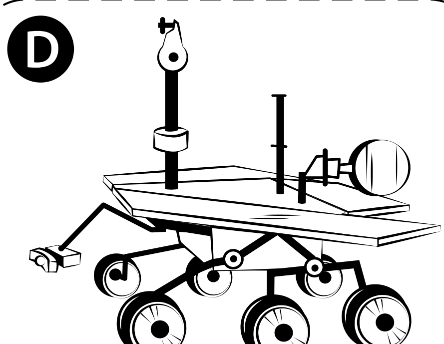
B



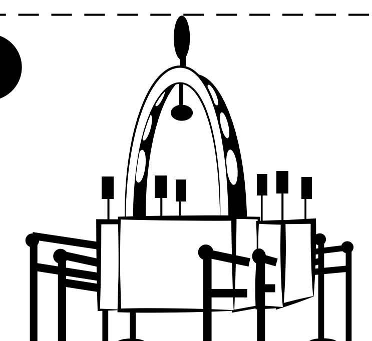
C



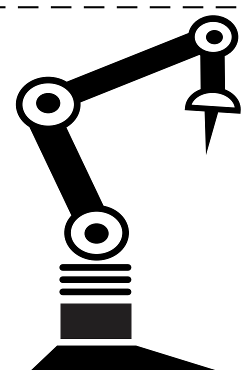
D



E



F



Name: ____________________________________

Robot Job Descriptions

Match the robot picture with the right description.

1 This robot arm welds together metal parts in a factory.

2 This eight-legged robot was designed to explore an active volcano.

3 This robot alarm clock is on wheels and rolls around your room.

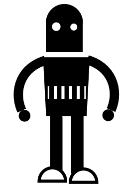
4 This robot can pick up an object you want and bring it to you.

5 This human-like robot works on the International Space Station.

6 This six-wheeled robot was designed to explore the surface of Mars.

Name: ________________________________

My Robot



Challenge: Design a robot to do a job in your home or classroom.

Robot's name: ________________________________

Robot's job: ________________________________

____

____

Think about how your robot can do the job better than a person could do it, or how it can do the job better than another technology. Then, list some reasons that people should buy your robot.

____

____

____

____

____

____

____

Next, draw your robot and create an advertisement to sell it! Include the robot's name and its job, and label the parts of your robot that help it do its job.

My Robot Advertisement

Name: ______________________________

STEM at Home

Dear ________________________,

At school, we have been learning about **robots.** Every robot is designed for a specific job, and that job determines what a robot looks like.

I learned that:

____

____

____

My favorite part of the lesson was: ______________________________

____

At home, we can watch a short video together called "Sandeep Yayathi: Robotics Engineer" about Robonaut 2, or R2, a human-like robot designed to assist astronauts in space.

Search "Sandeep Yayathi: Robotics Engineer" at ***www.pbslearningmedia.org*** to find the video at ***http://cet.pbslearningmedia.org/resource/mss13.sci.engin.design.robeng/sandeep-yayathi-robotics-engineer.***

If you were a robotics engineer, what kinds of robots would you want to design and why?

____

____

____

____

Picture-Perfect STEM Lessons, K–2

Using Children's Books to Inspire STEM Learning

"Teachers in our district have been fans of *Picture-Perfect Science* for years, and it's made a huge impact on how they fit science into their school day. We are so excited to do more of the same with these *Picture-Perfect STEM* books!"
—**Chris Gibler,** elementary instructional coach, Blue Springs School District in Missouri

"This lively mix of picture books and engaging, standards-based STEM content will be a powerful tool to inspire STEM learning."
—**Andrea Beaty,** author of *Ada Twist, Scientist; Rosie Revere, Engineer;* and *Iggy Peck, Architect*

For teachers who are eager to integrate STEM into their school day, *Picture-Perfect STEM Lessons* is an exciting development. This book's 15 kid-friendly lessons convey how science, technology, engineering, and mathematics intersect in the real world. They embed reading-comprehension strategies that integrate the STEM subjects and English language arts through high-quality picture books. You'll help your K–2 students engage in STEM activities while they learn to read and read to learn.

Picture-Perfect STEM Lessons, K–2 draws on diverse and attention-grabbing books such as *The Handiest Things in the World, The Day the Crayons Came Home,* and *I Wanna Iguana*. The lessons will lead your students to ask questions and define problems; obtain, evaluate, and communicate information; and engage in argument from evidence. Along the way, students invent a handy backpack, design their own process for recycling crayons, and build a model habitat for an imaginary pet. Through these lessons and activities, all young students, including reluctant scientists and struggling readers, will quickly find themselves absorbed in STEM-related discovery.

Along with these new lessons come the easy-to-use features that have made *Picture-Perfect Science* a bestselling series for more than a dozen years:

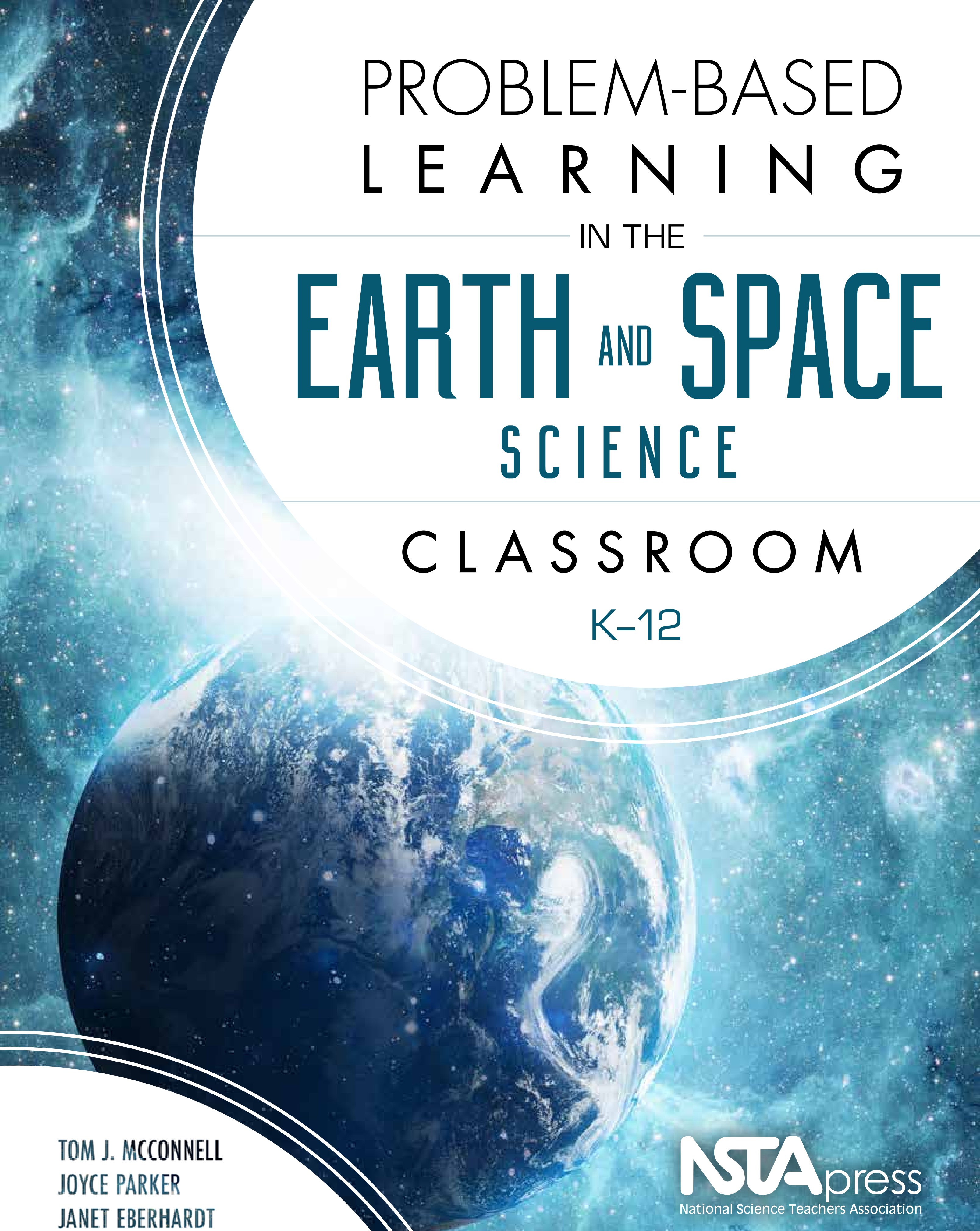
- Fiction and nonfiction book pairs
- Background reading, materials lists, student pages, and assessments for each lesson
- Connections to science standards and the *Common Core State Standards* for both English language arts and mathematics

Picture-Perfect STEM Lessons is a powerful tool for guiding instruction. You'll love how effective this book is, and your students will love learning about STEM.

PB422X1
ISBN: 978-1-68140-328-1

Grades K–2

NSTApress
National Science Teachers Association



PROBLEM-BASED LEARNING IN THE EARTH AND SPACE SCIENCE CLASSROOM

K–12

TOM J. MCCONNELL
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NSTA press
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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 of the strengths 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 of the challenges 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. Dan 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

Problem-Based Learning 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 force 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 to 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 the 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* call DCIs. 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 of the 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 (Earth's landforms and water, rock cycle and plate tectonics, weather, or astronomy), 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, there are problems included in this book that relate to the local landforms and examples that reflect contexts relevant to Michigan, where the PBL Project was located. A teacher in a place that does not share similar conditions may find that his or her students cannot relate to the scenario described in the problem. 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. As you modify and implement lessons from these books, you can begin to develop your own problems that meet the needs of your students.

This book is the second volume in a series; the first volume presented life science problems. We present Earth and space science problems in this volume, and we will offer problems specifically written for teaching physics in the next volume to be published. The fourth volume will contain tips and examples for planners of teacher professional development programs.

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 Teachers 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	Grades 3–5	Grades 6–8	Grades 9–12
CHAPTER 5: EARTH'S LANDFORMS AND WATER						
1. An Eagle's View	70	Landforms, geologic forces, plate tectonics		•	•	
2. Diving With Dolphino	80	Landforms, geologic forces, plate tectonics	•	•	•	
3. Water, Water Everywhere	90	Water cycle, erosion, gravity, heating and cooling	•	•	•	
CHAPTER 6: ROCK CYCLE AND PLATE TECTONICS						
1. Keweenaw Rocks	108	Rock cycle, formation of rocks, plate tectonics, divergent margin, rift zone			•	•
2. Lassen's Lessons	118	Rocks as evidence of past events, plate tectonics, convergent boundary, subduction zone, metamorphic rocks			•	•
3. San Andreas	129	Plate tectonics, transform boundary, subduction zone, strike-slip fault			•	•
CHAPTER 7: WEATHER						
1. Northern Lights	148	Seasons, motion of Earth around the Sun	•	•		
2. Water So Old	159	Water cycle	•		•	
3. Leave It to the Masses	172	Air masses, weather, and weather forecasting			•	
CHAPTER 8: ASTRONOMY						
1. E.T. the Extra-Terrestrial	191	Moon phases			•	
2. Obsidian Sun	201	Solar eclipse			•	
3. Copper Moon	210	Lunar eclipse			•	
4. Morning Star, Evening Star	218	Movement of planets relative to Earth			•	

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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 provide 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.

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!

At the same time, there are times when the teacher needs to share his or her knowledge of the concept. This may mean giving some examples of phenomena that demonstrate a process or explaining how certain ideas are connected. The teacher 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 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 to 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.

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 weather forecasting in her "Weather" unit, and today's activity follows some readings about weather and a video about the importance of weather forecasts.

Ms. Sampson: Class, today we're going to prepare you to make a weather forecast. As we work, you will take the role of a team of meteorologists, and you need to learn some information that will help you report the forecast on TV. 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.

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.

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 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 the facilitator about his or her 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 the "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 your own ideas when you're busy writing others' ideas on the board, and your students are probably not 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?" "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.

Figure 3.1. Recording Learners' Ideas in the PBL Framework

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 in small groups, seated on the floor in a circle, seated in desks, or whatever arrangement works best for you.

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. Most of the 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 they 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 Leave It to the Masses. Here is Page 1. Please read this story quietly. I'll give you about two minutes.

She hands out Page 1 of the Leave It to the Masses problem. (See Chapter 7, p. 174, 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 like they are thinking.

Andrea: We are going to have to explain four different weather maps on TV.

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

Ms. Sampson: OK, good. What are the four maps?

Andrea: Temperature, wind, Doppler radar, and a map with highs and lows marked.

Jamal: What is Doppler radar? I hear that a lot, but is that different from other radar?

Ms. Sampson: OK, "Doppler radar" goes under "What do we need to know?"

Marcus: The story says air masses take on the characteristics of the surface if they stay there for very long.

Mai: And the map with highs and lows … I'm not sure what the highs and lows are showing.

Ms. Sampson: Mai, I can add that to the "What do we need to know?" page, too. Good question!

David: Well, down here it says something about high pressure. Warmer air is less dense, so it has lower pressure than cooler air.

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

Carmela: There's also a definition of air mass. It's a body of air with similar temperature and moisture properties. I'm not sure what "body of air" means … doesn't it all mix?

Ms. Sampson: I can put that under "what we know," but do you want to put something about "body of air" under "need to 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 to add more ideas to the pages on the board.

Moves to Make: "Unpacking Ideas"

During a discussion in the three-column framework described earlier, students are very 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. Mai brings up an idea to include in the "What do we need to know?" column:

> **Mai:** And the map with highs and lows … I'm not sure what the highs and lows are showing.
>
> **Ms. Sampson:** Mai, I can add that to the "What do we need to know?" page, too. Good question!

The concept of "highs and lows" is certainly important to the problem about forecasting weather. But it is clear from Mai's question that not all the students in the class are familiar with it or know why it is relevant to weather forecasting. 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 highs and lows 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 the expert or the problem solver who recognizes 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.

In the facilitator example, the students get much of the same information, but they have either discovered 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

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

TEACHER AS EXPERT	TEACHER AS FACILITATOR
Mai: And the map with highs and lows … I'm not sure what the highs and lows are showing. **Ms. Sampson:** The highs and lows are areas where there is either high or low barometric pressure. **Denise:** How can some areas have different pressures? Won't they all mix? **Ms. Sampson:** Well, each air mass has its own characteristics. Some have cool and dry air, and that means they have high pressure. Areas with warmer, wetter air have lower pressure. **Mai:** How do they end up so different? **Ms. Sampson:** That's because of the uneven heating of Earth's surface. Here, let's take a look at a diagram to explain that.	**Mai:** And the map with highs and lows … I'm not sure what the highs and lows are showing. **Ms. Sampson:** Mai, I can add that to the "What do we need to know?" page. Good question! Does anyone else have more information about that? **David:** Well, down here it says something about high pressure. Warmer air is less dense, so it has lower pressure than cooler air. **Denise:** And dry air is denser than wet air. **Ms. Sampson:** OK, so it sounds like we're talking about high and low pressure, right? What else do you know about high- and low-pressure air? **Steven:** Hey, when there is a low coming toward us, they usually say it's going to rain or storm. **Marcus:** Yeah, those are the Hs and Ls on the weather map. But I'm not sure how air can have different pressures in different areas. Or even wetness or temperature. Won't the air all mix? **Denise:** Well, there's this other part of the story that I think is important here. It says that if an air mass stays in an area for long, it takes on the characteristics of the surface below. So I'm guessing if air is over a desert, it gets hot and dry. If it's over a big lake, it gets wetter. And it sounds like that tells what the pressure will be. **Mai:** Oh, so is that why we always get more rain and snow next to Lake Michigan? Does the air get wetter there?

understanding, students should be able to synthesize information by connecting ideas in the context of a real problem instead of repeating bits of disconnected facts. In the expert example, Ms. Sampson is hinting toward the concept of high- and low-pressure air masses, but we cannot tell if 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 cleared up some ideas about air masses, 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. Can we use temperature and air pressure to predict when a storm is going to happen? I think we can, but I'm not sure.

Ms. Sampson: Good question, Angie, but I think I hear a hypothesis in that statement. You're asking if temperature and pressure are good predictors, but if we reword that, can we make this 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 alright! 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 predict that temperature and air pressure are the …" Is that the way to state 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 we use when we're going to change a variable and see what the result is, Carlos, but that's a start. Who remembers what we use when we're observing events instead of changing a variable?

Alyssa: Isn't that when we use the "I think that …" kind of hypothesis?

Ms. Sampson: Yes, that's right, Alyssa! So, Angie, use that as a start. "I think that …"

Angie: OK. "I think that temperature and air pressure are the best data for predicting when a storm is going to happen."

Joseph: It needs a "because" statement.

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

Angie: Because it usually gets colder before a storm, and the weatherman said the air pressure drops before a storm.

Ms. Sampson: Good! That's our first hypothesis. Can you tell me more about what's going on with temperatures?

Andrea: OK, so a warm air mass moving over cold air creates a thunderstorm?

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 believe the best way to predict a storm is to look at wind speeds and air pressure. And colder air is denser than warm air, so I don't think cooler air means a low-pressure area is coming.

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

Carlos: How about this? "I believe wind speed and air pressure are the best ways to predict a storm, because the air pressure drops and the winds pick up right before a storm."

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 a student says, "I want to know if wind speed predicts storms, because it always seems to get windy just before it storms," 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" on 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 lessons. 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 you will do with students is 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, the teacher needs 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 the students 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: So we know there are different kinds of air masses, but I still don't know which of these are related to storms or severe weather or whatever they call it.

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: I think we need to find out if storms all have the same wind direction.

Jamal: We already have something about wind direction under "What do we need to know?"

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

(long pause)

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

(Multiple students): Yeah! We need more information.

Ms. Sampson: Alright 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 Devin reads Page 2 aloud.

Ms. Sampson: OK, good. 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: Well, we have five days of weather maps that can show how the highs and lows move.

Rose: And there are lines on the maps with arrows and half circles on them.

Marcus: Wait, I'm not sure what those are. I think we need to put those lines under "need to know."

David: Those are fronts. My dad told me about those once when I asked him about it when we were watching the weather. There are hot and cold fronts, and that's what the lines show.

Marcus: Yeah, but which one is which?

David: Umm … I can't remember. Ms. Sampson, which one has the arrows on the line?

Ms. Sampson: Good question! Let's put that under "need to know."

Tricia: Did you notice that wherever it rains, there's a front with the half circles? And there's an *H* on one side and an *L* on the other.

Jason: Does that relate to the hypotheses we wrote? Carlos said he thinks storms can be predicted by looking at pressure and wind.

Carlos: Yeah. That line shows where a high and a low meet. I think that's where storms happen.

Denise: We need to check that pattern. Put that under "What do we need to know?"

Vince: Yeah, but I think we can even look at some data about barometric pressure. We could build one in class and record data. I am pretty sure the air pressure will match temperatures. They both either go up or down together. I saw something the other day where it shows how to make a barometer to measure the air pressure. You get a U-shaped tube and put some liquid in it. And one end has to be open.

David: Cool! Can we build one? Maybe I can Google this and get the instructions. We can find some tubes in my grandpa's garage. He's got all kinds of junk we can use.

Ms. Sampson struggles to let the conversation work its course—they are getting off track and starting to talk about issues that are not important to the problem.

Alyssa: So maybe we just need to look at the map that shows winds. That's one of the maps we have to talk about. The weather map always has those arrows for the wind direction.

Mai: Yeah, that's the second part of Carlos's hypothesis. Is there a pattern that matches the weather?

Ms. Sampson: That's a good idea. If you think it's important, do you want to make that a hypothesis? Vince, we can add your hypothesis about the pattern with temperature and air pressure if you like.

Mai: Yeah! I believe air pressure and wind speeds tell the weather guy when air masses are going to … what's the word I want? Meet? It's like they crash into each other.

Sarah: Yeah, and on the maps, you can kind of see where the air masses are. And the fronts are usually on the edges.

Ms. Sampson: Let's put those under "need to know," Sarah. OK, I have that info recorded. Do we know any other new information?

Carmela: Yeah. The diagrams with the maps say that thunderstorms form when cold dry air pushes under warm, moist air and that the warm air rising is why a storm happens.

Angie: Wait, does that mean my hypothesis is wrong? I was thinking that cold air and low pressure go together.

Devin: Does that mean we cross out that hypothesis?

Ms. Sampson: We could, but can we just modify it with this new information?

Angie: Yeah, just switch what I said about warm and cold air, and we can keep it.

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 making a barometer, and 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 understandings. So you need to let students explore those ideas, even when your instincts tell you to steer them in a new direction. Teachers are likely to 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 it. She allowed the class to work through their ideas, and she included Vince's hypothesis in the list. You should avoid eliminating hypotheses for your class. Let students decide when an idea is rejected. That's a difficult thing for teachers to do, and it may take some practice, but it is important! In this case, Vince helped the process by introducing a new hypothesis to compete with Carlos's hypothesis. Including them both will allow students to compare them using evidence and information they collect. Eventually the students will have all the tools they need to decide which is the most viable hypothesis.

When you encounter this type of situation, be assured that it's normal in the PBL process. Each of the authors has experienced this, and we have felt the same internal conflict between providing content knowledge or 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.

But there are 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 types 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," 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 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. 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, the teacher has some choices that will determine what the next part of the lesson will include. Is there an inquiry-based lab or hands-on investigation that would 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 the teacher 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 "Weather" chapter (Chapter 7), the Northern Lights problem is an ideal situation in which to use a simple sundial or to have students build a Solar Motion Demonstrator to track the movement of the Sun through the sky in any given month. 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 inquiry-based investigations your students can conduct to learn or reinforce specific concepts. Astronomy problems like E.T. the Extra-Terrestrial (see Chapter 8) may be an opportunity to insert your favorite demonstration, model, or simulation of Moon phases. Problems from Chapter 5, "Earth's Landforms and Water," provide a context for doing a lab on water infiltration through different types of soil.

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 assess risks and take actions to minimize risks. Safety issues to be considered include the use of sharp objects, use and disposal of chemicals, and the presence of fire or burn hazards. Teachers are responsible for precautions such as wearing safety goggles or glasses, providing disposal containers for sharps and chemicals, and ensuring that students know where fire extinguishers and chemical showers are located.

Information Searches

Some 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 have analyzed 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: Beginning the Information Search

Ms. Sampson: Alright, class, you've created a good list of facts, hypotheses, and things we "need to know." Now we need to plan what information we'll look for next. 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 know about that Doppler radar question. Can we look for that?

Ms. Sampson puts Jamal's name next to "Doppler radar."

Ms. Sampson: You got it, Jamal! Your group can get started.

Denise: We'll look for information on fronts and air masses.

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

Jason: What about the air pressure idea? Is that part of one of those others?

Ms. Sampson: I don't think so. Do you three want to look that up?

Jason: Yeah, we'll take that topic.

Rose: What about wind speeds? We need to figure out how the wind arrows on the map match fronts and air masses. We can search for that.

Ms. Sampson: Good idea! If you'll volunteer, you can do that. Alright then, folks! You need to get started with the time we have left today, 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 the list with you tomorrow. Remember, when we're done, each group is responsible for sharing what you find with the entire class. Be organized!

Teacher-Selected Sources

For some classes, "searching" for information may require more assistance from the teacher. In these cases, the teacher 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 sources. 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 different groups. 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 Resources page (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 they need to solve the problem or build a complete solution to the challenge. But if they 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 the students created during the discussion of Page 1 and Page 2, especially the "What do we need to know?" and "Hypotheses" lists. The information search should address specific "need to know" items, and their findings should help in the evaluation and adjustment of some of the hypotheses as students apply what they have learned to the challenge presented in the story. Post the three lists 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 they 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 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. The teacher 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 they explored, what evidence they collected through research or experimentation, and how the evidence leads to a solution. The group then presents their 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 listed 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 them to vote on the one they prefer, or ask each student to write a short response or exit ticket with a prompt something like 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 "Responses 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 Leave It to the Masses problem we've been working on. As you present, remember that you need to describe the answers you found clearly, and you should be ready to tell us where you found them. 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 they found. Jamal, I'd like your group to start, if you don't mind.

Jamal: OK. We looked up how Doppler radar works. First of all, we found out that Doppler radar towers are the things that look like giant golf balls, like that one over by the old schoolhouse on State Road 13. I always wondered what that was. And it works like regular radar because it bounces radar waves off of objects to find out how far away they are. But the difference is that this kind of radar measures how fast and what direction an object is moving. If an object is moving away, the waves coming back from it get farther apart. If the waves are getting closer together, it's moving toward you. They call that the Doppler effect. So it can tell if clouds or rain or whatever is moving. It can also tell the difference between clouds, light rain or heavy rain, or hail. It can tell how hard it's raining by the size of the drops, I guess.

David: I thought the Doppler effect was what makes a train whistle change pitch when it goes past.

Ms. Sampson: It's the same idea, David. Radar uses radio waves, and the train whistle is sound waves. But in both cases, the distance between waves changes. In the train whistle example, you hear that as a change in pitch. OK, Jamal, that's a good start!

Denise, Angie, and Mai share information their groups found about fronts and air masses, including information about the symbols on the weather map for cold and warm fronts, and how they form when two different air masses meet.

Ms. Sampson: Good information, girls! We can use that as we look at the weather maps.

Jason: But how do we know whether a cold or warm front forms when the masses of air have different temperatures?

Carlos: Yeah, does the cold meet the warm, or the other way around?

Ms. Sampson: Good question. Let's look at the diagrams of cold and warm fronts on Page 2 of the story again.

Andrea: Can we put them up on the screen? I think we can see the answer in them.

Ms. Sampson: Sure, use the document camera.

Andrea: Look at the arrows on the bottom of the page. If the cold air moves toward a warm front, it's a cold front, and the warm, moist air rises and forms big storm clouds. If the warm air moves toward a cold air mass, it's a warm front, and the clouds are different.

David: You mean it's the direction the masses are moving?

Ms. Sampson: That's what our information shows, so yeah, it's the direction the air masses are moving. And if that's the case, can we find out what direction air masses are moving so we can use that for a prediction?

Jason: Well, yeah, we can. The wind map has arrows and lines that show what direction the wind is moving, so that's what we should use, right?

Rose: Are you sure? I thought our weather always moves from west to east, so I'm not sure wind direction causes that.

Ms. Sampson: Let's look at the data. Can you see air masses moving if you think of each day's map as part of an animated movie?

Marcus: Try putting two or three days of maps on the document camera and let's look.

Ms. Sampson: OK. Here are three days. Are there air masses that look like they are moving?

Mai: Kind of. I think they all do.

Ms. Sampson: OK, now let's look at the wind maps with these same days.

Angie: Oh yeah! The arrows match the movement of the masses.

Rose: Hmm … I guess it does. And there's a high-pressure mass moving from south to north, sort of. That makes it pretty easy to see how air masses move. But they don't always move just west to east.

Ms. Sampson: OK, so I think we have a better understanding. Let's look at the rest of the information you found.

The class looks at a few more pieces of information and agrees that using the maps of temperatures and air pressure helps identify air masses, and the wind maps help predict movement of the air masses to determine how the interactions may cause changes in the weather.

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 the teacher has identified as important learning goals.

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. When skillfully used, these kinds of questions can help students notice the problems with their claims. One of the most effective approaches is to have students compare a problematic claim to information they have listed under the "What do we know?" column of the analysis charts.

One of the strategies that can be very effective is to ask questions such as "Are there any 'what we know' statements that contradict this solution?" In the vignette, Ms. Sampson asked students to review the weather maps over three days to look for patterns in the movement. By asking students to compare their researched information with other facts and evidence, you can help them develop SEP 8: Obtaining, Evaluating, and Communicating Information. This is a critical practice in our world of abundant information. Students will be exposed 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 National Research Council 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 solution. As in the strategy above, this places students in the role of evaluators and requires comparison of solutions to evidence. 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. So the teacher needs 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' own thinking process, you may need to step in and present information that students need. If needed, 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 Doppler radar and a familiar example of the Doppler effect. This phenomenon is a key concept in understanding how Doppler radar is used to view weather data. Direct teaching has its place in the classroom, and your content expertise is important. If Ms. Sampson felt her students needed more information about the Doppler effect, she could use this opportunity to present a short lecture or demonstration about waves, wavelength, and frequency, with examples relating to light, sound, and radio waves.

Assessing Learning

When implementing a PBL lesson, the teacher/facilitator should respond to the learning needs of his or her students as they emerge. Flexibility is key, but to be flexible the teacher needs 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 provides for continuous assessment. The process of analysis using the PBL framework allows the teacher 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, the teacher sees 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 very helpful to implement informal assessment strategies like exit tickets. These are very 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 air masses take on the characteristics of the surface where they develop, but they should also recognize that the extreme low pressure and high winds of a hurricane are more likely to form when an air mass is positioned above very warm ocean water where the moisture can evaporate and be contained in a warming air mass. 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 are often used as a summative assessment, but they can also inform the choices the teacher makes about the next activities to include in a 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 the role of these assessments further 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

This is a simple and quick way to collect information about your students' understanding and issues that need to be resolved. Exit tickets (Cornelius 2013) 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 the teacher at the end of class. The next step is for the teacher 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 "one question you have about the Leave It to the Masses 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 don't understand why dry air is denser than moist air. 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 the connection between air pressure and the direction the winds move around a low-pressure area.

She explains that air is a fluid that moves like water and that the rotation of Earth helps create forces that push air around. As air moves, it is pushed toward a low-pressure zone by the higher pressure in other areas. She uses a 2-liter bottle of water to show how water moves more quickly if it swirls in a vortex as it drains out of the bottle when it is turned upside down. She relates the movement of air toward the low-pressure zone to the movement of the water, to help students visualize the concept.

Group Summaries

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

In this assessment, each group is 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, and 8). In the process of discussing and writing this summary, group members are able to solidify their understandings. 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

Ms. Sampson asked each group to write and turn in a summary of the solution they had developed on the second day of the lesson. In these summaries, she noticed an issue that needed to be explained. Her students wrote that cold fronts make rain, and warm fronts lead to sunny weather.

Ms. Sampson: Alright, kids, I saw in your solutions that many of you wrote that only a cold front creates rain and storms. And nobody mentioned what happens if two air masses move toward each other, and they both have the same "strength." Does anyone know what a stationary front is?

The students looked confused, so she asked them to view an online computer simulation that let them see animations of four different kinds of fronts. She gave groups time to try out each kind of front and take some notes.

Ms. Sampson: So what did you find out about fronts?

Sarah: This shows how each kind of front can make it rain.

Carlos: Yeah, and that stationary fronts make big storms.

Jeremy: So do occluded fronts. Did you see that big cloud that formed in that part of the simulation? I bet that makes a huge storm!

Mai: Yeah! My dad says that when a cloud makes that flat place on top, it's a really big thunderstorm.

Ms. Sampson: OK, those are some good observations. How do you think this relates to your weather maps?

Jason: It means we have to know about how strong an air mass is before we can predict the weather.

Angie: And it gives us a way to know if there is going to be a severe storm. We need to look at temperatures, and pressures, and winds, and patterns on the map. It's kind of complicated, but it's kind of important, too.

Ms. Sampson: That's a great comment! Now, let's go back to the computers and look at the simulation again. Let's see if we can use the shapes of clouds to identify what's happening in our weather right now.

Summary

Facilitating PBL requires a slightly different set of skills from direct teaching, 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 a 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 very 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 EARTH AND SPACE 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*

* * * * *

If you've ever asked yourself whether problem-based learning (PBL) can bring new life to both your teaching and your students' learning, here's your answer: Yes. This all-in-one guide will help you engage your students in scenarios that represent real-world science in all its messy, thought-provoking glory. The scenarios will prompt K–12 students to work collaboratively on analyzing problems, asking questions, posing hypotheses, and constructing solutions.

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Chapter 12

Landfill Recovery

OVERVIEW

In this chapter, students gather evidence by completing hands-on activities and reading texts to answer the question, *How can we reduce the volume of landfill waste?* Students learn about the volume of waste that ends up in landfills every year, investigate the feasibility of landfill mining, engage in a landfill mining simulation, and design a product made entirely of reused plastics. Students also construct an argument about the pros and cons of landfill mining using evidence they collect from a variety for sources.

This unit assumes that students know and can demonstrate that some of Earth's natural resources are limited and that recycling extends the life of nonrenewable natural resources. Additionally, this unit contributes to attainment of *Next Generation Science Standards* performance expectation ESS3-3: "Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment" (NGSS Lead States 2013).

OBJECTIVES

- Recognize that interventions can slow or stop the negative impact of human activities on the environment.
- Identify strategies for reusing natural resources.
- Investigate ways to reduce municipal solid waste.
- Draw conclusions that are based on evidence from multiple sources.
- Engage in a scientific argument.

STANDARDS ALIGNMENT

Next Generation Science Standards (NGSS Lead States 2013)

ESS3.C: HUMAN IMPACTS ON EARTH SYSTEMS

- Human activities have significantly altered the biosphere, sometimes damaging or destroying natural habitats and causing the extinction of other species. But changes to Earth's environments can have different impacts (negative and positive) for different living things. (MS-ESS3-3)
- Typically, as human populations and per-capita consumption of natural resources increase, so do the negative impacts on Earth unless the activities and technologies involved are engineered otherwise. (MS-ESS3-3 and MS-ESS3-4)

Common Core State Standards, English Language Arts **(NGAC and CCSSO 2010)**

GRADES 6–12 LITERACY IN HISTORY/SOCIAL STUDIES, SCIENCE, AND TECHNICAL SUBJECTS

- CCSS.ELA-LITERACY.WHST.6-8.1: Write arguments focused on discipline-specific content.
- CCSS.ELA-LITERACY.WHST.6-8.2: Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.
- CCSS.ELA-LITERACY.WHST.6-8.9: Draw evidence from informational texts to support analysis, reflection, and research.

TIME FRAME

- Seven to eight 45-minute class periods

SCIENTIFIC BACKGROUND INFORMATION

Humans have been using Earth's resources for millennia. From early humans' use of flint for tools to our present-day use of technologically advanced materials, humans have recognized that using Earth's resources enhances our survival and quality of life. As humans advanced to form civilizations and use agricultural practices, the use of natural resources increased. It increased again when humans learned how to extract natural resources from the ground. When we humans learned how to manipulate, alter, and produce marketable products, our use of natural resources increased to extraordinary levels. As we began to use natural resources at increased rates, we also increased the amount of waste produced. Production and disposal of marketable items generates significant amounts of waste, and all of that waste has to go somewhere. In modern history, humans have moved waste from the view of the public eye to landfills, where it is buried and never to be seen again.

In 2013, Americans generated 254.1 million tons of trash (National Geographic 2016). That's well over 508 billion pounds of trash! Between 1960 and 2000, the amount of trash generated each year increased from 88.1 million tons to 243.5 million tons. Since 2000, the rate of increase has leveled off for the most part. But, overall, it is still creeping upward. See Table 12.3 (p. 245) to discover what humans are throwing away.

Recycling has helped reduce the amount of trash that makes its way into landfills, and recycling has increased over the years. In 1960, people recycled 6.4% of their trash; in 2013, people recycled 34.3% of their trash (EPA 2016). Increasing the rate of recycling is a necessary, but insufficient step toward reducing the amount of trash and nonrenewable natural resources that ends up in landfills. Although recycling has helped reduce the amount of trash going into landfills, the Environmental Protection Agency has stated that reducing the amount of trash generated and reusing items rather than disposing of them are the most effective ways to reduce solid waste (EPA 2015).

Mining landfills to recover valuable natural resources is an option that has been gaining traction in recent years. Some of the benefits of landfill mining, beyond the recovery of natural resources, include extending landfill capacity, lowering landfill operating costs, producing energy by incinerating materials that cannot be recovered, reducing landfill closure costs, retrofitting liners to repair leaks and tears, removing hazardous wastes, and generating income from recovered materials (EPA 1997). Drawbacks include managing hazardous materials, release of landfill gases and odors, subsidence or landfill collapse, and increased wear on excavation equipment (EPA 1997).

Several examples of successful landfill mining in the United States and abroad suggest that landfill mining may be part of the solution to our dwindling natural resources. The anticipated recovery rates of some resources, according to available information, is 85–95% for soil, 70–90% for ferrous metals, and 50–75% for plastics. The purity of the recovered materials ranges from 90% to 95% for soil, from 80% to 95% for ferrous metals, and from 70% to 90% for plastics (Environmental Alternatives 2016). A Belgian waste management company presently mining a landfill near Brussels expects to reclaim 45% of the materials; the rest of the materials will be converted to electricity (Vijayaraghavan 2011).

Landfill mining is not without drawbacks, however. Technology to mine landfills efficiently and safely has not yet been developed. Using current technology requires multiple steps to excavate, separate, and clean the resources. An important economic and environmental consideration is that recovering some of the materials consumes more energy than would be used to make new materials. Additionally, the cost to recycle the reclaimed materials costs much more than the market value of the resources. For example, in 2009 it cost $4,000 to recycling 1 ton of plastic bags, but the resulting product had a value of only $32 (Clean Air Council 2016).

Each of these options, recycling, reducing waste, reusing items, and landfill mining, offer some hope for extending the life of natural resources. Alone, none of the options is sufficient to address the problem of diminishing natural resources. But in combination, the various options could make a meaningful difference.

MISCONCEPTIONS

Misconceptions about the availability of natural resources are based on fundamental misunderstandings about core Earth science principles. Most notably, some people think that humans depend on Earth for resources and that the activities of humans significantly alter Earth. Several of these misconceptions that are most closely related to this unit appear in Table 12.1 (p. 240).

TABLE 12.1. COMMON MISCONCEPTIONS ABOUT NATURAL RESOURCES AND THE IMPACT OF HUMAN ACTIVITIES

Common Misconception	Scientifically Accurate Concept
Earth's resources are not finite. There is an endless supply of water, petroleum, and mineral resources. All we have to do is explore to find them.	Earth's resources are finite, and we have a very good idea about where we can find and harvest existing resources. Earth scientists also know approximately how abundant or lacking various Earth materials are.
• "Man-made" materials do not come from mineral resources. • Few products we use everyday have anything to do with taking rocks and minerals from the ground.	All raw materials come from Earth. Products that are "man-made" (or human-made) are the result of processing raw materials through manufacturing. The plastics we use come from crude oil; all metals originate in ores mined from Earth; building materials, such as bricks, granite counter tops, and plasterboard, come from Earth materials.
Earth and its systems are too big to be affected by human actions.	Earth is a very large system, but scientists have accumulated overwhelming evidence that human activities alter Earth in irreparable ways. Earth's resources are limited and, in some cases, dwindling rapidly. Resources such as safe, potable water are difficult to access in some parts of the world. Human population now exceeds 7 billion people. As the population continues to grow, the strain on resources such as potable water will increase. Humans can and do affect Earth systems.
Technological fixes will save us from ruining our planetary environment.	Technology and science have limitations. It is true that technology and science can reverse or remedy some of the environmental damage that humans have caused. However, so far no one has developed technology to solve all of our environmental problems. It is unlikely that our current scientific knowledge and technology will ever generate more of the nonrenewable resources we take from Earth. Moreover, these advancements cannot solve current problems such as nuclear waste spills or toxic contamination such as that found at some Superfund sites.
Earth is both an endless supply of resources and a limitless sink for the waste products of our society.	We used to believe the adage that "the solution to pollution is dilution." We now know that such thinking not only is wrong but also threatens the health of Earth and the organisms that live on it. Even small concentrations or low doses of some toxic compounds can render soil or water unsafe for decades to come.

Source: The Math and Science Partnership Network 2016.

NONFICTION TEXTS

Heroes of the Environment: True Stories of People Who Are Helping to Protect Our Planet by Harriet Rohmer (San Francisco, CA: Chronicle Books, 2009); Flesch-Kincaid reading level 7.4, published Lexile level 1070L.

The stories of 12 people who are taking inspiring actions to protect the planet are shared in this engaging book. The stories range from removing industrial pollution from a river to protecting sea turtles and whales. The individuals portrayed are just as diverse as their actions.

One Plastic Bag: Isatou Ceesay and the Recycling Women of the Gambia by Miranda Paul (Minneapolis, MN: Millbrook Press, 2015); Flesch-Kincaid reading level 2.9, published Lexile level 480L.

This children's picture book carries a powerful message about the waste we generate, the impact it has, and the ways we might reduce it.

MATERIALS

For the Landfill Mixture

Note that you can substitute other materials. Choose materials according to the separation techniques needed. If working with salt or coffee grounds, be careful of items getting wet.

- Dry pasta
- Iron filings (see safety data sheet information in Appendix 4)
- Shredded paper
- Crayon shavings (made with a pencil sharpener)
- Mini-marshmallows
- Sand

For the Rest of the Investigation

- Magnets covered with plastic wrap
- Balloons (nonlatex)
- Tub or large bowl of water
- Pans or bowls for separating with water
- Beakers, cups, or bowls for the separated materials

- Heat source and container for melting (1 per group or 1 for the class, if done as a demonstration)
- Crayon mold
- String
- Bucket or gallon milk jug with an opening cut in the top that is large enough to add weight
- Masses, washers, sand, or water for testing
- Sufficient quantity of plastic grocery bags, empty water bottles, and K-cups (if you choose to use them) for the design challenge
- General supplies, such as scissors, tape, and glue
- Goggles (sanitized, indirectly vented chemical splash)
- Nonlatex gloves
- Aprons

SUPPORTING DOCUMENTS

- “Turning Waste Into Good Business and Good Jobs” graphic organizer
- “One Year of Solid Waste” cards
- “Municipal Solid Waste” cut outs
- “Landfill Mining: Brilliant Idea or Wishful Thinking?” essay and graphic organizer
- “Based on the Evidence … ” graphic organizer
- “Recovering Resources” planning and data sheet
- “Strength Test Data Sheet”
- “Recommendation to Style Barons” graphic organizer
- “Individual Recommendation to Style Barons” graphic organizer

SAFETY CONSIDERATIONS

- Have students wear goggles, gloves, and aprons during all phases of the investigation, including during setup and cleanup.
- Review safety procedures for dealing with heated materials, and supervise students carefully as they conduct the investigations.
- Review safety information in safety data sheets for chemicals (e.g., iron filings and plaster of paris) with students (see Appendix 4).
- Remind students to use caution in working with iron filings; they can be sharp and puncture skin.
- Tell students not to breathe in the dust from these filings.

- Make sure students have appropriate procedures for cleanup and disposal of iron filings.
- Remind students to use caution when heating or working with hot liquids or solids, which can seriously burn skin.
- Remind students to use caution with heating devices such as Bunsen burners and hot plates. Tell them not to touch the heating device until after it has cooled down.
- Use only GFI protected electrical outlets when working with hot plates or other electrical heating devices.
- Remind students to immediately wipe up any spilled water off the floor to prevent slip and fall hazards.
- Remind students not to eat any food used in lab investigations.
- Have students wash their hands with soap and water after completing the investigation.

LEARNING-CYCLE INQUIRY

Engage

In the Engage phase, students are introduced to the idea of reusing materials that are headed for a landfill. Students independently read "Turning Waste Into Good Business and Good Jobs," which is a chapter from *Heroes of the Environment.* As students read the chapter, they will discover that discarded items can be valuable and present opportunities for reuse.

Advance preparation: Make one copy of "Turning Waste Into Good Business and Good Jobs" for each student. Make one copy of the "One Year of Solid Waste" cards per group of three to four students. Cut the cards apart, and shuffle them before distributing a set to each group.

After preparations are made, begin the Engage phase. The steps are as follows:

1. Ask students to share something they do or something they know of that helps the planet. Then, introduce the book *Heroes of the Environment.* Describe the types of things the heroes of the book are doing to help keep the planet healthy.
2. Distribute a copy of "Turning Waste Into Good Business and Good Jobs" (Chapter 3 of *Heroes of the Environment*) and the accompanying graphic organizer. Tell students that they are now going to read about Omar Freilla from the Bronx in New York. As they read, students should be looking for the message of Omar's story. After they have finished reading, they should write what they think the message of Omar's story is in the appropriate space on the graphic organizer. Students should then add evidence that supports their thinking about the message of Omar's story.
3. After students have finished the reading, ask them to turn and talk to a neighbor about what they think Omar's message is. Then, ask several students to share what

they took away from the story. Make sure that the class has identified Omar's message: If something has a use, it is not waste.

4. Have students work in small groups to explore the amount of solid waste generated in the United States in one year.
   a. Begin by providing each group of students with one set of the "One Year of Solid Waste" cards.
   b. Ask students to work together to match the statistic card with the correct item.
   c. After 5–10 minutes, ask each group to share its results. As groups share, ask them to explain why they matched them up as they did.
   d. After all groups have shared, ask each group to review its initial matches and make changes that reflect the group's current thinking.
   e. When students are finished, reveal the correct matches shown in Table 12.2. Reinforce that these statistics represent one year of solid waste.

TABLE 12.2. ONE YEAR OF SOLID WASTE CARDS

Amount of trash generated by Americans in 2013	254 million tons of trash
Pounds of trash disposal per person	4.6 pounds
Percentage of trash from residences	65%
Percentage of trash buried in landfills	55%
Percentage of trash from schools and commercial locations	35%
Percentage of trash recycled	33%
Percentage of trash incinerated	12.5%
Number of solid-waste industry employees	368,000
Number of vehicles used to move trash to landfills	148,000
Number of communities with curbside recycling	8,660
Number of landfills	1,754
Number of recycled-materials sorting centers	545
Number of incinerators	87
Solid-waste industry annual revenue	$47 billion

Source: National Geographic 2016.

5. Engage students in a discussion about what they think they would find if they dug deep into a landfill. Students are likely to offer unspecific responses such as garbage,

trash, rotten stuff, and so on. Those answers are acceptable at this point. List the students' responses where all students can see them.

6. Students will now find out what is in landfills. Specifically, they will learn what percentage of municipal solid waste is paper, glass, metals, and so forth. For this activity, students will work in their groups.
   a. Give each group a copy of the "Municipal Solid Waste" page and a pair of scissors.
   b. Instruct students to cut categories at the bottom of the page apart and rank them, from highest to lowest, according to which ones they think make up the most or least amount of waste in a landfill.
   c. After students have ranked the categories of waste, they should match them to the appropriate section of the pie chart on the basis of their ranking.
   d. Ask groups to share where they placed each category on the pie chart and explain their reasoning.
   e. Compare and discuss groups' placements of the cards on the pie chart. After the discussion, ask groups to make any changes they want. This time, they should tape the cards in place.
   f. Reveal the correct percentages, using the information in Table 12.3.
7. Finish by introducing the question, *How can we reduce the volume of landfill waste?*

Assess this phase: Assessment of this phase is formative. Students are likely to reveal misconceptions about solid waste as they complete the "One Year of Solid Waste" and "Municipal Solid Waste" matching activities.

TABLE 12.3. MUNICIPAL SOLID WASTE

Category	Percent
Paper	27.0
Food	14.6
Yard trimmings	13.5
Plastics	12.8
Metals	9.1
Rubber, leather, and textiles	9.0
Wood	6.2
Glass	4.5
Other	3.3

Source: EPA 2016.

Explore

In this phase, students will continue working in groups to investigate the feasibility of mining landfills as a means to recover some discarded resources. They will also participate in a simulation in which they recover and test a nonrenewable resource.

PART I: MINING LANDFILLS

1. Provide each student with a copy of "Landfill Mining: Brilliant Idea or Wishful Thinking?" Instruct students to independently read the essay and complete the graphic organizer before returning to their groups.
2. After students return to their groups, distribute the "Based on the Evidence …" graphic organizer. Instruct students to discuss which company they think Style Barons should hire. Remind them that their decision must be based on evidence. Circulate around the room, asking guiding questions such as the following:
   - What evidence leads you to think Style Barons should choose this company?
   - How could you compare the materials available through traditional mining with materials recovered through landfill mining?
   - What additional evidence would help you make your decision?

PART II: COMPARING MATERIALS

Advance preparation: Collect old crayons for shaving. Remove the paper wrapping from the crayons, then use a manual pencil sharpener to make the shavings. Save some crayons to use when demonstrating how to melt the crayons and pour them into the mold. Combine the materials to make the landfill mixture. Bag and label the mixture. Make plaster of paris crayon molds.

After preparations are made, begin Part II of the Explore phase. The steps are as follows:

Separation

1. Before beginning, gather up separation tools and general materials. Put them in a central location where groups can easily access them during the separation activity.
2. Set the activity up with the following scenario:

   > *Each company has sent us some materials to test. Earth Materials R Us sent a pure sample of one of the materials they have available. Reclaiming the Past sent us a sample of items mined from their landfill. These items have gone through a washing process, so they are safe for us to handle. We have to sort the materials to recover what Style Barons needs. After we recover the materials, we must make a sample similar to the one Earth Materials R Us sent. I am expecting a mold from them to arrive any day.*

3. Give each group a bag of the landfill mixture. Provide each student with a copy of the "Recovering Resources" planning and data sheet.
4. You are playing the role of the lab manager. As groups work on designing and carrying out their separation process, circulate around the room to check on their designs and ask guiding questions.

5. After students have separated their materials, they will take turns melting the materials (crayon shavings) and pouring them into their molds.

Testing

1. Before you begin testing, reveal that the molds have arrived. Show the students the molds and demonstrate how they will be used.
    a. Show the students how to melt the crayons. Set up a single melting station that can be closely monitored. The crayons melt easily in a microwave, a candy melting pot, or in glass beakers that are in a hot-water bath. (An electric skillet works great for a hot-water bath.) It is helpful to melt the crayons in a container with a pour spout (e.g., a beaker or measuring cup). Doing so makes it much easier for students to accurately pour the melted crayons into the mold. While the crayons are melting, lubricate the mold by rubbing a drop of dishwashing detergent inside.
    b. Model how to handle the beaker with the melted crayons and how to pour the melted crayons into the mold. The melted crayons will rapidly start to harden again, so students should bring their molds to the melting station when they are ready to make their crayons. Once the melted crayons have been poured into the molds, groups can move them to a safe place for setting. Although they will set quickly, let the molds continue to set overnight so they are completely cooled before testing.
    c. Demonstrate how to remove the crayons from the molds by flipping the mold over. The crayon should fall out.
2. It is now time to test the strength of a pure crayon (the pure sample from Earth Materials R Us) and the one made from the reclaimed crayons. To contain the excitement and monitor testing, groups should test their crayons one at a time.
    a. Before beginning, separate two desks or tables by enough space so that the crayons span the opening with each end of the crayons securely on the desks. Give each student or group a "Strength Test Data Sheet."
    b. Mass the crayon to be tested.
    c. Slide the crayon to be tested through the handle of the loading device.
    d. Position the crayon so that it spans the gap in the desks.
    e. Slowly add mass (e.g., sand or marbles) to the loading device. Stop adding mass when the crayon breaks.
    f. Measure the amount of mass the crayon held before breaking.
3. Have students complete their data sheets and draw conclusions about which material is the better choice for Style Barons.

Assess this phase: The Explore phase for this learning-cycle inquiry can be formatively assessed. As students gather evidence from "Landfill Mining: Brilliant Idea or Wishful Thinking?" and from separating and testing the recovered materials (crayon shavings), they should be processing their thinking about the volume of waste that ends up in landfills and the possibility of solutions such as reducing waste and reclaiming resources found in landfills. Monitor their progress by listening carefully to their discussions as they work and by asking probing questions.

Explain

In this phase, students will use the data collected in the Explore phase to construct a scientific argument in response to the prompt, *Which company do you recommend that Style Barons use?*

1. Provide each student with a "Recommendation to Style Barons" graphic organizer.
2. Instruct students to work with their groups to review and list their evidence on the "Recommendation to Style Barons" sheet.
3. As groups work, walk around the room to ask guiding questions and provide assistance when needed.
4. When groups have finished their discussions, give each student an "Individual Recommendation to Style Barons" sheet. Tell students to work independently to construct an argument that supports their recommendation of either Earth Materials R Us or Reclaiming the Past.
5. Circulate around the room as students work independently, providing assistance and support when needed.

Assess this phase: In the Explain phase, each student's "Individual Recommendation to Style Barons" serves as a summative assessment.

Expand

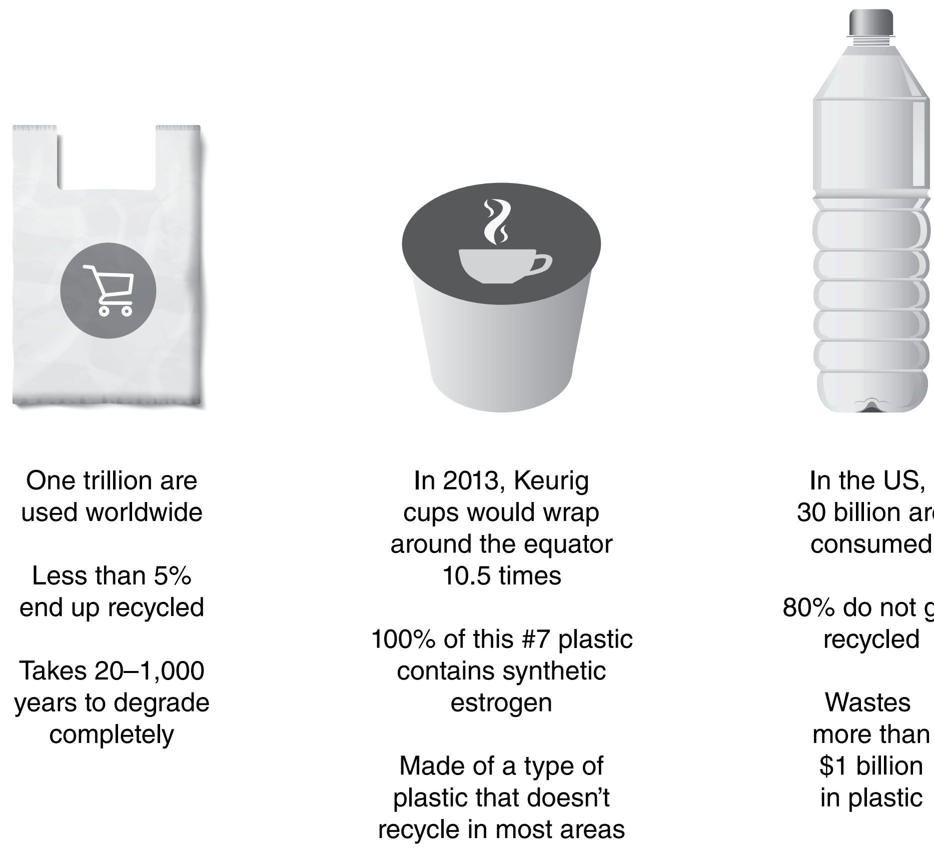
In this phase, students will design a product that is made entirely of recycled plastics.

Advance preparation: Collect plastic shopping bags, water bottles, and K-cups for students to use in their design challenge. Be aware that used coffee grounds, tea leaves, etc. will still be in the K-cups.

After preparations are made, begin the Expand phase. The steps are as follows:

1. Project the infographic "Sneaky Plastic Waste We're all Producing" shown in Figure 12.1. Discuss the volume of plastics going into landfills from just these three products. Talk about personal and observed use of these plastics.

FIGURE 12.1. SNEAKY PLASTIC WASTE WE'RE ALL PRODUCING



2. Read aloud *One Plastic Bag.* This is a children's book that is below grade level, but it is an inspiring story of how plastic shopping bags are being repurposed.
3. Discuss the benefits of keeping materials out of landfills and reusing them or repurposing them into other products.
4. Challenge students to design a product that could be made out of plastic shopping bags, water bottles, or K-cups. Students can use one material or any combination of these materials. Allow students to work independently, in pairs, or in small groups as they respond to the design challenge. Provide general supplies such as scissors, tape, and glue so students can construct, test, and modify their designs.
5. Finish the unit by asking students to reflect on what they have learned and answer the question, *How can we reduce the volume of landfill waste?* Students may record their answers as a bulleted list or in paragraph form.

Assess this phase: This phase uses both formative and summative assessment. As students work on the design challenge, ask them if their design is practical, who might be interested in the product, and how many of the recyclable items they are working with would be kept out of the landfill if they were to make 10, 100, or 1,000 of their designs. Use the final response to the question, *How can we reduce the volume of landfill waste?*, as a summative assessment.

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Name________________________________ Date____________________

Turning Waste Into Good Business and Good Jobs

What is the message of Omar's story?

Supporting evidence

Supporting evidence

Supporting evidence

Name________________________ Date________________

One Year of Solid Waste

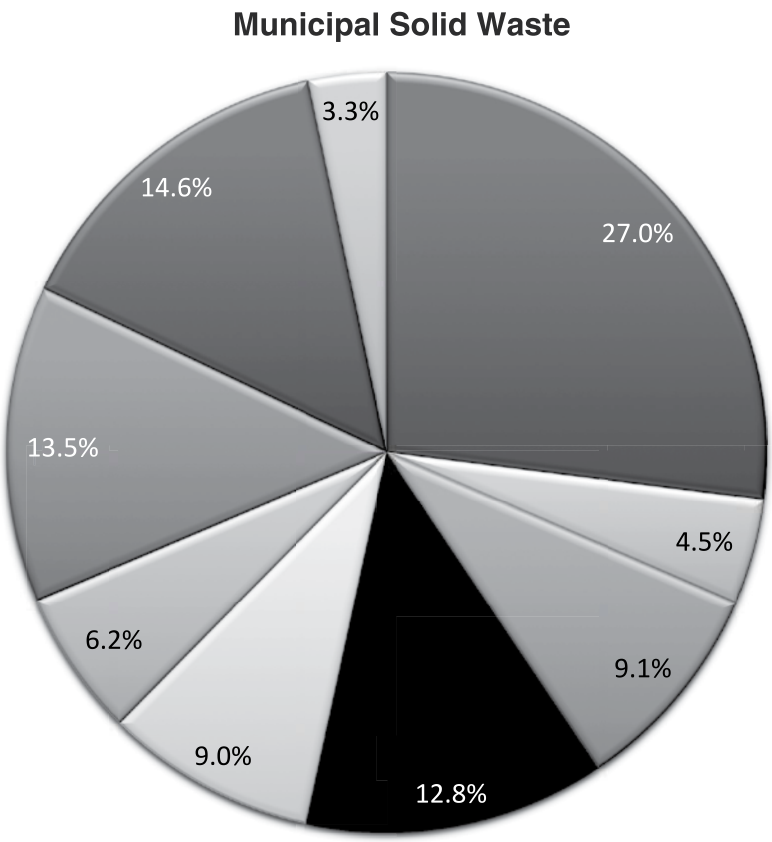
Cut out the cards below and provide one set to each group of students.

Amount of trash generated by Americans in 2013	254 million tons of trash
Pounds of trash disposal per person	4.6 pounds
Percentage of trash from residences	65%
Percentage of trash buried in landfills	55%
Percentage of trash from schools and commercial locations	35%
Percentage of trash recycled	33%
Percentage of trash incinerated	12.5%
Number of solid-waste industry employees	368,000
Number of vehicles used to move trash to landfills	148,000
Number of communities with curbside recycling	8,660
Number of landfills	1,754
Number of recycled-materials sorting centers	545
Number of incinerators	87
Solid-waste industry annual revenue	$47 billion

Name______________________________ Date____________________

Municipal Solid Waste

Cut the categories that appear at the bottom apart. Discuss each category with your team. Rank the categories from most to least amount of waste in landfills. According to your ranking, match the category cards with the percentage of municipal waste that makes sense to you. The category you think accounts for the greatest amount of solid waste in a landfill should be placed in the 27.0% section of the pie chart, and the category with the least goes in the 3.3% section.



Paper	Glass	Metals
Plastics	Rubber, leather, and textiles	Wood
Yard trimmings	Food	Other

Name____ Date________________________

Landfill Mining: Brilliant Idea or Wishful Thinking?

Style Barons is an environmentally friendly company that is about to start making a new line of fashion accessories. The accessories are made of colorful plastics and precious metals. They range from belts to backpacks to bags. The accessories are made of plastic and decorated with thin strands of gold, silver, and platinum. The decorations make interesting designs that are sure to attract attention! Style Barons is going for a look and feel that seem expensive, but it wants its products to still be sold at a reasonable price.

Style Barons must decide where it is going to buy the raw materials needed for the items. Earth Materials R Us is a company that mines raw materials from Earth. Reclaiming the Past is a company that mines landfills. Style Barons needs to think about the environmental and economic impacts of the company it chooses. Of course, Style Barons also wants to make some money when it sells the accessories!

EARTH MATERIALS R US

The upside of mining raw materials is that the new materials may be have a higher quality and have fewer impurities, and Earth Materials R Us knows where to mine. They also have an idea about how much of each raw material is available. The down side of mining raw materials is habitat destruction, hazardous waste that can pollute air and water, and dangerous working conditions.

RECLAIMING THE PAST

The up side of mining landfills is that the unwanted waste material can be used for electricity, the landfill will last longer, and many types of recyclable materials can be recovered. Reclaiming the Past has recovered precious metals and plastics, but it cannot say for sure where it will find them in a landfill. The company also doesn't know how much of each material it will find. The downsides to mining landfills include uncovering hazardous materials, releasing landfill gases and odors, and damaging the landfill.

Style Barons has several teams of scientists researching the options. The scientists have already collected some information. The next step is to look at the information and begin forming an evidence-based argument for mining raw materials or mining landfills to recover recyclables.

Name________________________ Date______________

Landfill Mining: Brilliant Idea or Wishful Thinking? (*continued*)

In the graphic organizer below, list the pros and cons of each of the companies Style Barons is researching below.

Earth Materials R Us	Pros	
	Cons	
Reclaiming the Past	Pros	
	Cons	

VOCABULARY

Word	What I think it means	Connection to essay
	Definition	
Word	What I think it means	Connection to essay
	Definition	
Word	What I think it means	Connection to essay
	Definition	

Questions I have

Name____ Date__________________________

Based on the Evidence ...

Style Barons has several teams of scientists researching the options. The scientists have already collected some information. The next step is to look at the information and begin forming an evidence-based argument for mining raw materials or mining landfills to recover recyclables. Table 1 shows some of the environmental and economic impacts for both options. Review and discuss this information with your group before considering which company to select.

TABLE 1. ENVIRONMENTAL AND ECONOMIC IMPACTS

Impact Type	Regular Mining (Earth Materials R Us)	Landfill Mining (Reclaiming the Past)
Environmental	• Habitat loss • Hazardous byproducts • Soil contamination • Water pollution	• Recovers recyclables • Reduces landfill area • Exposes hazardous materials • Releases landfill gases and odors
Economic	• May provide a variety of jobs such as geological engineers, mining technicians, equipment operators • Provides raw materials for industry	• Landfill lasts longer • Produces electricity • Landfills earn money selling recovered recyclables

According to the evidence you have from "Landfill Mining: Brilliant Idea or Wishful Thinking?" and Table 1, which company do you currently think Style Barons should select?

Evidence	Evidence
Company	
Evidence	Questions

Name____ Date________________________

Recovering Resources

The following memo arrived this morning:

> **S B** Style Barons
>
> TO: Earth and Environmental Scientists Research Group
> FROM: Harper Baron, Style Barons Director of Research and Development
> SUBJECT: Sample Materials
>
> The purpose of this memo is to let you know that we are ready to test materials from Earth Materials R Us and Reclaiming the Past.
>
> Earth Materials R Us has provided us with a pure sample of one of the materials we need. Reclaiming the Past has provided us with a sample of items mined from its landfill. These items have gone through a washing process, so they are safe for handling and testing. Develop a process for sorting the materials from the landfill. Sorting is the only way we can recover what we need. After the materials are recovered, perform a test to compare the two samples.
>
> Please complete the testing within the next couple of days. We are eager to start production on the new accessories line.
>
> ITEMS SHIPPED: Pure sample from Earth Materials R Us and landfill sample from Reclaiming the Past

In response to this memo, you must do the following:

1. Work with your team to design a process for separating the landfill sample to recover the needed material. The material is a waxy substance that can be easily melted and molded. The substance will be added to the plastic that will be used for Style Barons' new line of accessories. This material will make the plastic stronger.
2. Things to consider when designing the process include the
   a. properties of the materials in the mixture,
   b. available separating equipment,
   c. purity of the sample, and
   d. quantity of the sample.
3. Write your separation plan and share it with the lab manager. The separation plan must include
   a. a separation equipment list,

Name____ Date_______________________

Recovering Resources (*continued*)

   b. a step-by-step procedure for separating the materials,
   c. a data collection strategy to record the amount of each material recovered, and
   d. an explanation of how recovered materials that are not needed will be used.

4. After obtaining the lab manager's approval, proceed with the separation of the materials. You need 30 g of the material for testing.
5. Share the results of your separation with the lab manager.
6. Obtain the sample production and testing protocol from the lab manager. For the best results, follow the protocol exactly as directed.
7. Prepare a report for Harper Baron that explains the procedure and the results.

Name________________________________ Date____________________

Strength Test Data Sheet

Harper Baron is eagerly awaiting the test results. Conduct the tests as directed by the lab manager. Record all data below.

Criteria	Pure Sample From Earth Materials R Us	Reclaimed Sample From Reclaiming the Past
Mass of sample		
Test mass held		
Ratio of test mass held to mass of sample (divide the mass held by the mass of the sample)		

How do the ratios of the sample and the reclaimed sample compare?

Based on this test only, which sample should Style Barons add to the plastic to make it stronger?

Based on everything you have learned about the sample from testing and about the environmental and economic effects of traditional and landfill mining, what other factors should Style Barons consider?

Name______________________________ Date____________________

Recommendation to Style Barons

1. Working with your group, review the evidence you have gathered. Record the evidence in the table below.
2. Discuss the pros and cons of each company's mining processes and the quality of the materials that they can provide.
3. Talk about which company Style Barons should use. Write down notes during the discussion. This information could be helpful to you later.
4. Use the evidence you have gathered and meaningful information from the group discussion to make a recommendation to Style Barons.

Considerations	Earth Materials R Us	Reclaiming the Past
Environmental impact	Pros	Pros
	Cons	Cons
Economic impact	Pros	Pros
	Cons	Cons
Quality of materials	Pros	Pros
	Cons	Cons

Name____ Date____________________________

Individual Recommendation to Style Barons

Using all of the evidence you have gathered and discussed with your group, make a claim about which company Style Barons should use. Present your evidence, and share your reasoning.

Claim: Which company do you recommend?

Evidence	Evidence	Evidence

Reasoning (connect the evidence to the claim)

INQUIRING SCIENTISTS, INQUIRING READERS

IN MIDDLE SCHOOL

Using Nonfiction to Promote Science Literacy,

GRADES 6–8

Inquiring Scientists, Inquiring Readers in Middle School provides the guidance and information you need to tackle the challenge of integrating literacy into your science lessons. As authors Terry Shiverdecker and Jessica Fries-Gaither explain in the introduction, "Embedding nonfiction text and literacy activities into inquiry-based science honors the best practices of both disciplines." Research-based and classroom-tested, this book's lessons help you support student learning and maximize your time. Several unique features make this book a valuable resource:

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Grades 6–8

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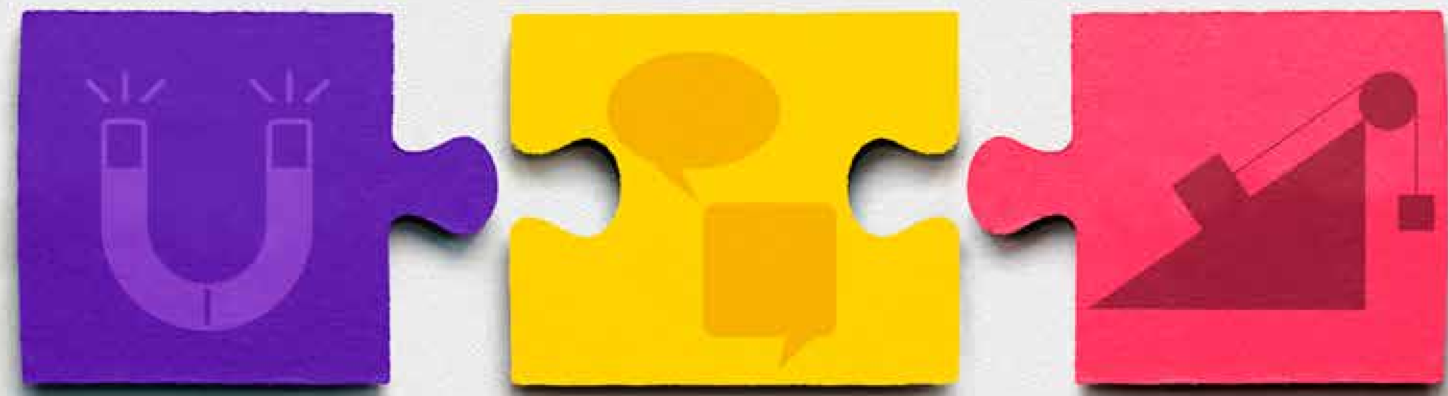

LAB INVESTIGATIONS for GRADES 6–8

Jonathon Grooms, Patrick J. Enderle,
Todd Hutner, Ashley Murphy, and Victor Sampson

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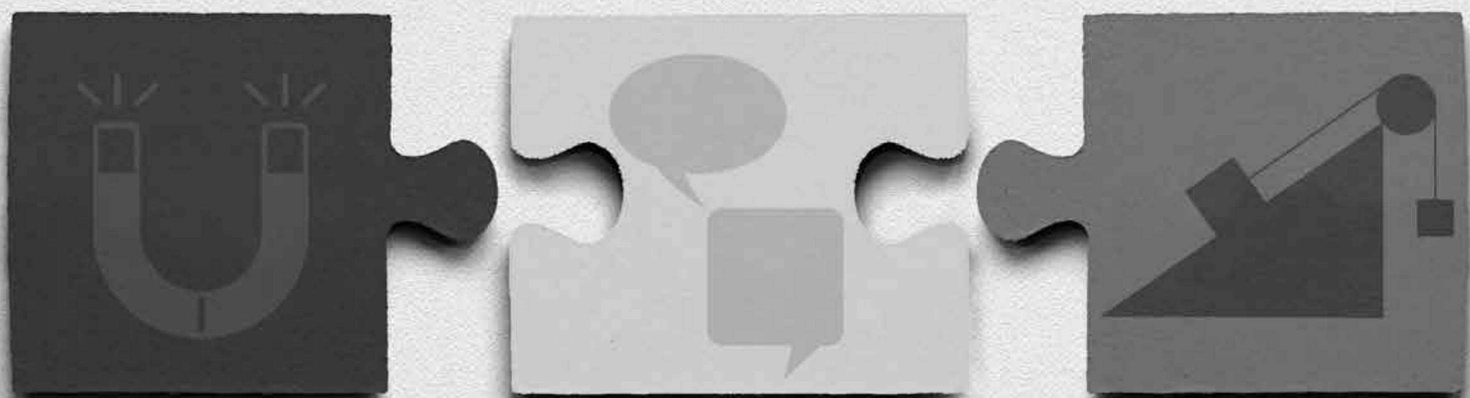

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APPLICATION LABS

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PREFACE

There is a push to change the way science is taught in the United States, arising from a different idea of what it means to know, understand, and be able to do in science. As described in *A Framework for K–12 Science Education* (National Research Council [NRC] 2012) and the *Next Generation Science Standards* (NGSS Lead States 2013), science education should be structured to emphasize ideas *and* practices to

> ensure that 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)

Instead of teaching with the goal of helping students learn facts and concepts, science teachers are now charged with helping their students become *proficient* in science by time they graduate from high school. To be considered proficient in science, the NRC (2012) suggests that students need to understand four core ideas in the physical sciences,[1] be aware of seven crosscutting concepts that span the various disciplines of science, and learn how to participate in eight fundamental scientific practices. These important practices, crosscutting concepts, and core ideas are summarized in Figure 1 (p. xii).

As described by the NRC (2012), new instructional approaches will be needed to assist students in developing these proficiencies. In answer to this call, this book provides 22 laboratory investigations designed using an innovative approach to lab instruction called argument-driven inquiry (ADI). This approach and the labs based on it are aligned with the content, crosscutting concepts, and scientific practices outlined in Figure 1. Because the ADI model calls for students to give presentations to their peers, respond to questions, and then write, evaluate, and revise reports as part of each lab, 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 (National Governors Association Center for Best Practices and Council of Chief State School Officers 2010). Use of these labs, as a result, can help teachers align their teaching with current recommendations for making physical science more meaningful for students and instruction more effective for teachers.

[1] Throughout this book, we use the term *physical sciences* when referring to the core ideas of the *Framework* (in this context the term refers to a broad collection of scientific fields), but we use the term *physical science* when referring to courses at the middle school level (as in the title of the book).

FIGURE 1

The three dimensions of the framework for the *Next Generation Science Standards*

Scientific Practices	Crosscutting Concepts
1. Asking questions and defining problems 2. Developing and using models 3. Planning and carrying out investigations 4. Analyzing and interpreting data 5. Using mathematics and computational thinking 6. Constructing explanations and designing solutions 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information	1. Patterns 2. Cause and effect: Mechanism and explanation 3. Scale, proportion, and quantity 4. Systems and system models 5. Energy and matter: Flows, cycles, and conservation 6. Structure and function 7. Stability and change
Physical Sciences Core Ideas • PS1: Matter and its interactions • PS2: Motion and stability: Forces and interactions • PS3: Energy • PS4: Waves and their applications in technologies for information transfer	

Source: Adapted from NRC 2012, p. 3.

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INTRODUCTION

The Importance of Helping Students Become Proficient in Science

The new aim of science education in the United States is for all students to become proficient in science by the time they finish high school. It is essential to recognize that science proficiency involves more than an understanding of important concepts, it also involves being able to *do* science. *Science proficiency,* as defined by Duschl, Schweingruber, and Shouse (2007), consists of four interrelated aspects. First, it requires an individual to know important scientific explanations about the natural world, be able to use these explanations to solve problems, and understand new explanations when they are introduced to the individual. Second, it requires an individual to be able to generate and evaluate scientific explanations and scientific arguments. Third, it requires an individual to understand the nature of scientific knowledge and how scientific knowledge develops over time. Finally, and perhaps most important, an individual who is proficient in science should be able to participate in scientific practices (such as designing and carrying out investigations and arguing from evidence) and communicate in a manner that is consistent with the norms of the scientific community.

In the past decade, however, the importance of learning how to participate in scientific practices has not been acknowledged in the standards of many states. Many states have also attempted to make their science standards more rigorous by adding more content to them or lowering the grade level at which content is introduced rather than emphasizing depth of understanding of core ideas and crosscutting concepts, as described by the National Research Council (NRC) in *A Framework for K–12 Science Education* (NRC 2012). The result of the increased number of content standards and the pressure to cover them to prepare students for high-stakes tests that target facts and definitions is that teachers have "alter[ed] their methods of instruction to conform to the assessment" (Owens, 2009, p. 50). Teachers, as a result, tend to move through the science curriculum quickly to ensure that they have introduced all the content found in the standards before the administration of the tests, which leads them to cover many topics in a shallow fashion rather than to delve into a smaller number of core ideas in a way that promotes a coherent and deep understanding. The unintended consequence of this approach has been a focus on content (learning facts) rather than on developing scientific habits of mind or learning how to use core ideas and the practices of science to explain natural phenomena.

Despite this focus on more content and high-stakes accountability for science learning, students do not seem to be gaining proficiency in science. According to *The Nation's Report Card: Science 2009* (National Center for Education Statistics 2011), only 21% of all 12th-grade students who took the National Assessment of Educational Progress in science scored at the proficient level. The performance of U.S. students on international assessments is even bleaker, as indicated by their scores on the science portion of the Programme for International Student Assessment (PISA). The Organisation for Economic Co-operation and Development (OECD) began administering the PISA in 1997 to assess and compare education systems. Since 1997, students in more than 70 countries have taken the PISA. The test is designed to assess reading, math, and science achievement and is given every three years. The mean score for students in the United States on the science portion of the PISA in 2012 was below the international mean (500), and there has been no significant change in the U.S. mean score since 2000; in fact, the U.S. mean score in 2012 was slightly less than it was in 2000 (OECD 2012; see Table 1). Students in many different countries, including China, Korea, Japan, and Finland, consistently score higher than students in the United States. These results suggest that U.S. students are not learning what they need to be considered proficient in science, even though teachers are covering a great deal of material and being held accountable for it.

TABLE 1

PISA scientific literacy performance for U.S. students

Year	U.S. mean score*	U.S. rank/ Number of countries assessed	Top-performing countries (score)		
			1	2	3
2000	499	14/27	Korea (552)	Japan (550)	Finland (538)
2003	491	22/41	Finland (548)	Japan (548)	Hong Kong–China (539)
2006	489	29/57	Finland (563)	Hong Kong–China (542)	Canada (534)
2009	499	15/43	Japan (552)	Korea (550)	Hong Kong–China (541)
2012	497	36/65	Shanghai-China (580)	Hong Kong–China (555)	Singapore (551)

*The mean score of the PISA is 500 across all years.

Source: OECD 2012.

Additional evidence of the consequences of emphasizing breadth over depth comes from empirical research in science education that supports the notion that broad, shallow coverage neglects the practices of science and hinders the development of science proficiency (Duschl, Schweingruber, and Shouse 2007; NRC 2005, 2008). As noted in the *Framework* (NRC 2012),

> K–12 science education in the United States fails to [promote the development of science proficiency], in part because it is not organized systematically across multiple years of school, emphasizes discrete facts with a focus on breadth over depth, and does not provide students with engaging opportunities to experience how science is actually done. (p. 1)

Based on their review of the available literature, the NRC recommends that science teachers delve more deeply into core ideas to help their students develop improved understanding and retention of science content. The NRC also calls for students to be given more experience participating in the practices of science, with the goal of enabling students to better engage in public discussions about scientific issues related to their everyday lives, be consumers of scientific information, and have the skills and abilities needed to enter science or science-related careers. We think the school science laboratory is the perfect place to focus on core ideas and engage students in the practices of science and, as a result, help them develop the knowledge and abilities needed to be proficient in science.

How School Science Laboratories Can Help Foster the Development of Science Proficiency

Investigators have shown that lab activities[1] have a standard format in U.S. secondary-school classrooms (Hofstein and Lunetta 2004; NRC 2005). This format begins with the teacher introducing students to a concept through direct instruction, usually a lecture and/or reading. Next, students complete a confirmatory laboratory activity, usually following a "cookbook recipe" in which the teacher provides a step-by-step procedure to follow and a data table to fill out. Finally, students are asked to answer a set of focused analysis questions to ensure that the lab has illustrated, confirmed, or otherwise verified the targeted concept(s). This type of approach does little to promote science proficiency because it often fails to help students think critically about the concepts, engage in important scientific practices (such as designing an investigation, constructing explanations, or arguing from evidence), or develop scientific habits of mind (Duschl, Schweingruber, and Shouse 2007; NRC 2005). Further, this approach does not do much to improve science-specific literacy skills.

Changing the focus of lab instruction can help address these challenges. To implement such a change, teachers will have to emphasize "how we know" in the physical sciences (i.e., how new knowledge is generated and validated) equally with "what we know" about behavior of matter on Earth (i.e., the theories, laws, and unifying

[1] We use the NRC's definition of a school science lab activity, which is "an opportunity for students to interact directly with the material world using the tools, data collection techniques, models, and theories of science" (NRC 2005, p. 3).

concepts). Because it is an essential practice of science, the NRC calls for *argumentation* (which we define as a process of proposing, supporting, evaluating, and refining claims on the basis of reason) to play a more central role in the teaching and learning of science. The NRC (2012) provides a good description of the role argumentation plays in science:

> Scientists and engineers use evidence-based argumentation to make the case for their ideas, whether involving new theories or designs, novel ways of collecting data, or interpretations of evidence. They and their peers then attempt to identify weaknesses and limitations in the argument, with the ultimate goal of refining and improving the explanation or design. (p. 46)

This means that the focus of teaching will have to shift more to scientific abilities and habits of mind so that students can learn to construct and support scientific knowledge claims through argument (NRC 2012). Students will also have to learn to evaluate the claims and arguments made by others.

A part of this change in instructional focus will need to be a change in the nature of lab activities (NRC 2012). Students will need to have more experiences engaging in scientific practices so that lab activities can become more authentic. This is a major shift away from labs driven by prescribed worksheets and data tables to be completed. These activities will have to be thoughtfully constructed so as to be educative and help students develop the required knowledge, skills, abilities, and habits of mind. This type of instruction will require that students receive feedback and learn from their mistakes; hence, teachers will need to develop more strategies to help students learn from their mistakes.

The argument-driven inquiry (ADI) instructional model (Sampson and Gleim 2009; Sampson, Grooms, and Walker 2009, 2011) was designed as a way to make lab activities more authentic and educative for students and thus help teachers promote and support the development of science proficiency. This instructional model reflects research about how people learn science (NRC 1999) and is also based on what is known about how to engage students in argumentation and other important scientific practices (Berland and Reiser 2009; Erduran and Jimenez-Aleixandre 2008; McNeill and Krajcik 2008; Osborne, Erduran, and Simon 2004; Sampson and Clark 2008).

Organization of This Book

The remainder of this book is divided into six sections. Section 1 includes two chapters: the first describes the ADI instructional model, and the second describes the development and components of the ADI lab investigations. Sections 2–5 contain the lab investigations, including notes for the teacher, student handouts, and checkout questions for students. Four appendixes contain standards alignment matrixes, timeline and proposal options for the investigations, and a peer-review guide and instructor rubric for assessing the investigation reports.

Safety Practices in the Science Laboratory

It is important for science teachers to make hands-on and inquiry-based lab activities safer for students and teachers. Teachers therefore need to have proper safety equipment in the classroom/laboratory in the form of engineering controls such as ventilation, fume hoods, fire extinguishers, eye wash, and showers. They also need to ensure that students use appropriate personal protective equipment (PPE; e.g., sanitized indirectly vented chemical-splash goggles meeting ANSI/ISEA Z87.1 standard, chemical-resistant aprons and nonlatex gloves) during all components of laboratory activities (i.e., setup, hands-on investigation, and takedown). Teachers also need to adopt legal safety standards and better professional practices and enforce them inside the classroom and/or laboratory. Finally, teachers must review and comply with all safety policies and procedures, including but not limited to appropriate chemical management, that have been established by their school district or school.

Throughout this book, safety precautions are provided for each investigation. Teachers should follow these safety precautions to provide a safer learning experience for students. The safety precautions associated with each activity are based, in part, on the use of the recommended materials and instructions, legal safety standards, and better professional safety practices. We also recommend that students review the National Science Teacher Association's document *Safety in the Science Classroom, Laboratory, or Field Sites* under the direction of the teacher before working in the laboratory for the first time. This document is available online at *www.nsta.org/docs/SafetyInTheScienceClassroomLabAndField.pdf.* The students and their parents or guardians should then sign the document to acknowledge that they understand the safety procedures that must be followed during a lab activity.

As a final note, remember that the lab activity is composed of three sections: the setup, the hands-on investigation, and takedown. PPE and safety procedures apply to all three sections!

Disclaimer: The safety precautions for 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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Teacher Notes

Lab 14. Potential Energy

How Can You Make an Action Figure Jump Higher?

Purpose

The purpose of this lab is to *introduce* students to the types of energy, specifically potential energy. Through this activity, students will have an opportunity to explore the crosscutting concepts of the importance of using and defining models to make sense of phenomena and how scientists focus on tracking the movement of energy through a system. Students will also learn about the difference between laws and theories and how scientists use multiple methods to investigate the natural world.

The Content

The *law of conservation of energy* states that within a given system the total amount of energy always stays the same. Essentially, this means that energy is neither created nor destroyed, but rather transferred from one type to another. Remember that scientific laws are used to describe specific relationships that exist in the natural world, whereas scientific theories provide broad-based explanations for different phenomena. In a more practical sense, laws tell us how things relate, while theories tell us why they do. In this case, the law of conservation of energy simply describes the relationship that exists among the many different types of energy present in the world.

There are several common forms of energy that exist in the world. Two of the most fundamental types of energy are potential and kinetic energy. When energy is stored in one form or another, it is called *potential energy*. Potential energy can be stored in the chemical bonds between atoms in a molecule and in the nuclei of atoms. Energy can also be stored based on the position of an object. Indeed, potential energy can be referred to as energy of position. The amount of potential energy an object has depends on the system being explored. In this use, a *system* refers to a specified collection of objects and their interactions. A ball on the floor has potential energy with respect to a desk in the same room, which can be called the ball-desk system. However, the potential energy of the ball is different if we are considering the ball-tree system, which includes a tree that exists outside of the room. Similarly, the amount of energy available and the different forms present will depend on the specific system that is being studied.

When potential energy is transformed into motion, it becomes *kinetic energy,* which can be detected when objects move. Kinetic energy is known as energy of motion. Kinetic energy is more obvious to identify, because it is the form of energy that does work on an object in a system. Other basic forms of energy include thermal energy (heat), chemical energy, electromagnetic energy, and nuclear energy. Some of these forms actually represent a mixture of potential and kinetic energies in more specific systems. More recognizable forms of energy, such as light and sound, also represent combinations of kinetic and potential energy.

As an example, think about climbing a hill. When you are at the bottom of a hill, you have low potential energy based on your position in the "hill-person" system. To increase your potential energy, you climb to the top of the hill. As you are climbing, you are moving, so you are using kinetic energy; you are transforming kinetic energy into increased potential energy; and you are changing position. Since you have climbed higher, you have greater potential energy. Now, you may wonder where the kinetic energy to climb the hill came from. That energy ultimately came from the energy stored in molecules that your body used to move your muscles.

Timeline

The instructional time needed to complete this lab investigation is 170–230 minutes. Appendix 2 (p. 411) provides options for implementing this lab investigation over several class periods. Option C (230 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 D (170 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 D, 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 14.1 (p. 252). The equipment can be purchased from a science supply company such as Carolina, Flinn Scientific, or Ward's Science. The clay and the action figures can be purchased at a toy store or general retail store.

We recommend that you use a set routine for distributing and collecting the materials during the lab investigation. For example, the equipment for each group can be set up at each group's lab station before class begins, or one member from each group can collect them from a table or a cart when needed during class.

TABLE 14.1

Materials list for Lab 14

Item	Quantity
Safety glasses or goggles	1 per student
Ruler	1 per group
Meterstick	1 per group
Electronic or triple beam balance	1 per group
Pencil	1 per group
Clay	100 g per group
Action figures	2–3 per group
Investigation Proposal C (optional)	1 per group
Whiteboard, 2' × 3'*	1 per group
Lab Handout	1 per student
Peer-review guide	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 and Laboratory Waste Disposal

Follow all normal lab safety rules. In addition, tell students to take the following safety precautions:

1. Wear sanitized safety glasses or goggles during lab setup, hands-on activity, and take down.
2. Sweep clay up off the floor to avoid a slip or fall hazard.
3. Do not allow the action figures to jump too far from the work area.
4. Remove any fragile items from the work area.
5. Wash hands with soap and water after completing the lab activity.

There is no laboratory waste associated with this activity. The materials for this laboratory investigation can be stored and reused.

Topics for the Explicit and Reflective Discussion

Concepts That Can Be Used to Justify the Evidence

To provide an adequate justification of their evidence, students must explain why they included the evidence in their arguments and make the assumptions underlying their analysis and interpretation of the data explicit. In this investigation, students can use the following concepts to help justify their evidence:

- Law of conservation of energy
- Potential energy
- Kinetic energy
- Transformation of energy

We recommend that you review these concepts during the explicit and reflective discussion to help students make this connection.

How 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 bias in their investigations. To help students be more reflective about the design of their investigation, you can ask the following questions:

1. What were some of the strengths of your investigation? What made it scientific?
2. What were some of the weaknesses of your investigation? What made it less scientific?
3. If you were to do this investigation again, what would you do to address the weaknesses in your investigation? What could you do to make it more scientific?

Crosscutting Concepts

This investigation is well aligned with two crosscutting concepts found in *A Framework for K–12 Science Education*, and you should review these concepts during the explicit and reflective discussion.

- *System and system models:* Defining a system under study and making a model of it are tools for developing a better understanding of natural phenomena in science. In this lab students will investigate a system that can be used to convert potential energy to kinetic energy.

- *Energy and matter: Flows, cycles, and conservation:* In science it is important to track how energy and matter move into, out of, and within systems. In this lab students will investigate the conversion of energy from one type to another.

The Nature of Science and the Nature of Scientific Inquiry

This investigation is well aligned with two important concepts related to the *nature of science* (NOS) and the *nature of scientific inquiry* (NOSI), and you should review these concepts during the explicit and reflective discussion.

- *The difference between laws and theories in science:* A scientific law describes the behavior of a natural phenomenon or a generalized relationship under certain conditions; a scientific theory is a well-substantiated explanation of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have an accompanying explanatory theory. It is also important for students to understand that scientists do not discover laws or theories; the scientific community develops them over time.
- *Methods used in scientific investigations*: Examples of methods include experiments, systematic observations of a phenomenon, literature reviews, and analysis of existing data sets; the choice of method depends on the objectives of the research. There is no universal step-by step scientific method that all scientists follow; rather, different scientific disciplines (e.g., chemistry vs. physics) and fields within a discipline (e.g., organic vs. physical chemistry) use different types of methods, use different core theories, and rely on different standards to develop scientific knowledge.

Hints for Implementing the Lab

- Allowing students to design their own procedures for collecting data gives students an opportunity to try, to fail, and to learn from their mistakes. However, you can scaffold students as they develop their procedure by having them fill out an investigation proposal. These proposals provide a way for you to offer students hints and suggestions without telling them how to do it. You can also check the proposals quickly during a class period. For this lab we suggest you use Investigation Proposal C.
- Suggest that students use a small amount of clay to stick the pencil to the ruler when they construct their teeterboard.
- Have students focus on changing one characteristic of the system at a time. They should not change the mass of the dropped clay while also changing the height they drop it from.

- Encourage students to think of a way they could mathematically represent the relationships they find in this investigation.
- Action figures should not be too large, so that they can actually be launched using the ruler apparatus. We have had success using small, plastic army action figures that can be purchased in large quantities. Be sure to test your action figures with the equipment to determine if they are appropriate.

Topic Connections

Table 14.2 provides an overview of the scientific practices, crosscutting concepts, disciplinary core ideas, and supporting ideas at the heart of this lab investigation. In addition, it lists the NOS and NOSI concepts for the explicit and reflective discussion. Finally, it lists literacy and mathematics skills (*CCSS ELA* and *CCSS Mathematics*) that are addressed during the investigation.

TABLE 14.2

Lab 14 alignment with standards

Scientific practices	• Asking questions and defining problems • Planning and carrying out investigations • Analyzing and interpreting data • Using mathematics and computational thinking • Constructing explanations and designing solutions • Engaging in argument from evidence • Obtaining, evaluating, and communicating information
Crosscutting concepts	• Systems and system models • Energy and matter
Core ideas	• PS3.A: Definitions of energy • PS3.B: Conservation of energy and energy transfer
Supporting ideas	• Law of conservation of energy • Potential energy • Kinetic energy • Transformation of energy
NOS and NOSI concepts	• Scientific laws and theories • Methods used in scientific investigations
Literacy connections (*CCSS ELA*)	• *Reading*: Key ideas and details, craft and structure, integration of knowledge and ideas • *Writing*: Text types and purposes, production and distribution of writing, research to build and present knowledge, range of writing • *Speaking and listening*: Comprehension and collaboration, presentation of knowledge and ideas
Mathematics connections (*CCSS Mathematics*)	• Reason abstractly and quantitatively • Construct viable arguments and critique the reasoning of others • Use appropriate tools strategically • Attend to precision

Lab Handout

Lab 14. Potential Energy

How Can You Make an Action Figure Jump Higher?

Introduction

Teeterboards are typical pieces of equipment found on many playgrounds around the country. They are often used in shows that focus on gymnastic tricks. The picture in Figure L14.1 shows a circus act involving a performer launching another performer high into the air. It is easy to observe how the activity of a teeterboard involves objects' motion. However, that activity also involves energy shifting between forms.

FIGURE L14.1

Circus performers on a teeterboard

The law of conservation of energy states that within a given system the total amount of energy always stays the same—it is neither created nor destroyed; instead, energy is transformed from one form to another. When energy is stored in one form or another, it is called potential energy. Potential energy can be stored in the chemical bonds between atoms in a molecule and in the nuclei of atoms. Energy can also be stored based on the position of an object. Indeed, potential energy can be referred to as energy of position. When potential energy is transformed into motion, it becomes kinetic energy. Kinetic energy can be detected when objects move. Kinetic energy is known as energy of motion.

For an example, think about climbing a hill. When you are at the bottom of a hill, you have low potential energy based on your position. To increase your potential energy, you climb to the top of the hill. As you are climbing, you are moving, so you are using kinetic energy; you are transforming kinetic energy into increased potential energy; and you are changing position. Since you have climbed higher, you have greater potential energy. In this investigation you will explore the relationship between potential energy and kinetic energy as you try to make an action figure jump using a teeterboard.

The Task

Use what you know about the conservation of energy and models to design and carry out an investigation that will allow you to develop a rule that explains how an action figure can be made to jump lower or higher on a teeterboard.

The guiding question of this investigation is, **How can you make an action figure jump higher?**

Materials

You may use any of the following materials during your investigation:

- Ruler
- Meterstick
- Electronic or triple beam balance
- Pencil
- Clay (100 g)
- Action figures
- Safety glasses or goggles

Safety Precautions

Follow all normal lab safety rules. In addition, take the following safety precautions:

1. Wear sanitized safety glasses or goggles during lab setup, hands-on activity, and takedown.
2. Sweep clay up off the floor to avoid a slip or fall hazard.
3. Do not allow the action figure to jump too far from your work area.
4. Remove any fragile items from the work area.
5. Wash hands with soap and water after completing the lab activity.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

To answer the guiding question, you will need to design and conduct an investigation that explores changing the potential energy of an action figure. To accomplish this task, you must determine what type of data you need to collect, how you will collect it, and how you will analyze it.

To determine *what type of data you need to collect,* think about the following questions:

- How will you test the ability to make the action figure jump higher?
- How will you measure the height of the jump?
- What type of measurements or observations will you need to record during your investigation?

To determine *how you will collect your data,* think about the following questions:

- How often will you collect data and when will you do it?

- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of the data you collect and how will you organize it?

To determine *how you will analyze your data,* think about the following questions:

- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

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

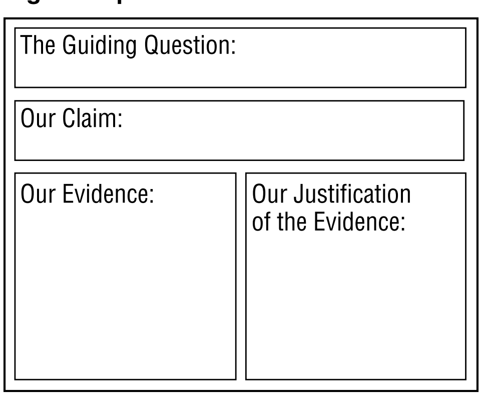
- how defining systems and models provides tools for understanding and testing of ideas;
- why it is important to track how energy and matter flows into, out of, and within a system;
- the difference between laws and theories in science; and
- the different forms of scientific investigation, including experiments, systematic observations, and analysis of data sets.

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 L14.2.

FIGURE L14.2

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member 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 arguments developed by their classmates. This is similar to how scientists present their arguments to other scientists at conferences. If you are responsible for critiquing your classmates' arguments, your goal is to look for mistakes so these mistakes can be fixed and they can make their argument better. The argumentation session is also a good time to think about ways you can make your initial argument better. Scientists must share and critique arguments like this to develop new ideas.

To critique an argument, you might need more information than what is included on the whiteboard. You will therefore need to ask the presenter lots of questions. Here are some good questions to ask:

- How did you collect your data? Why did you use that method? Why did you collect those data?
- What did you do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- How did your group analyze the data? Why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your analysis? How do you know that your interpretation of your analysis is appropriate?
- Why did your group decide to present your evidence in that way?
- What other claims did your group discuss before you decided on that one? Why did your group abandon those alternative ideas?
- How confident are you that your claim is valid? What could you do to increase your confidence?

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 most acceptable and valid answer to the research question!

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 to 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. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable and valid!

Checkout Questions

Lab 14. Potential Energy

How Can You Make an Action Figure Jump Higher?

1. What is potential energy?

2. What is kinetic energy?

3. A student is trying to get a cart to reach the wall at the end of the system pictured below. He uses a ramp to get the cart some energy to cover that distance. However, as shown below, using the ramp as constructed, he was not able to reach the wall.

   a. What can the student change to get the cart to reach the wall?

   b. How do you know?

4. The law of conservation of energy describes how energy exists in physical systems but not why it acts in certain ways.

   a. I agree with this statement.

   b. I disagree with this statement.

   Explain your answer, using an example from your investigation about potential energy.

5. Science only relies on experiments to understand the physical world.

   a. I agree with this statement.

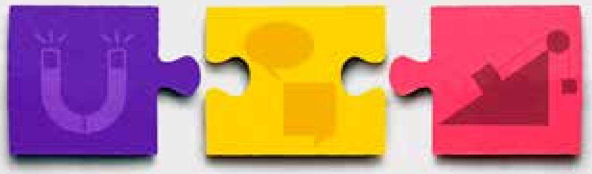
   b. I disagree with this statement.

   Explain your answer, using an example from your investigation about potential energy.

6. Scientists often have to define the boundaries of physical systems and use them to create models to test ideas. Explain why defining systems and models is important in science, using an example from your investigation about potential energy.

7. It is important to track how energy flows into, out of, and within a system during an investigation. Explain why it is important to keep track of energy when studying a system, using an example from your investigation about potential energy.

Argument-Driven Inquiry in PHYSICAL SCIENCE



LAB INVESTIGATIONS for GRADES 6–8

Are you interested in using argument-driven inquiry for middle school lab instruction but just aren't sure how to do it? *Argument-Driven Inquiry in Physical Science* will provide you with both 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 physical science students work the way scientists do.

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1. **An introduction to the stages of argument-driven inquiry**—from question identification, data analysis, and argument development and evaluation to double-blind peer review and report revision.
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This book is part of NSTA's bestselling series about argument-driven inquiry, which includes books for middle school life science and high school chemistry and biology. Like its predecessors, the collection is designed to be easy to use, with reproducible student pages, teacher notes, and checkout questions. The labs support today's standards and will help your students learn the core ideas, crosscutting concepts, and scientific practices found in the *Next Generation Science Standards*. In addition, the authors offer ways for students to develop the disciplinary skills outlined in the *Common Core State Standards*.

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GRADES 6–8

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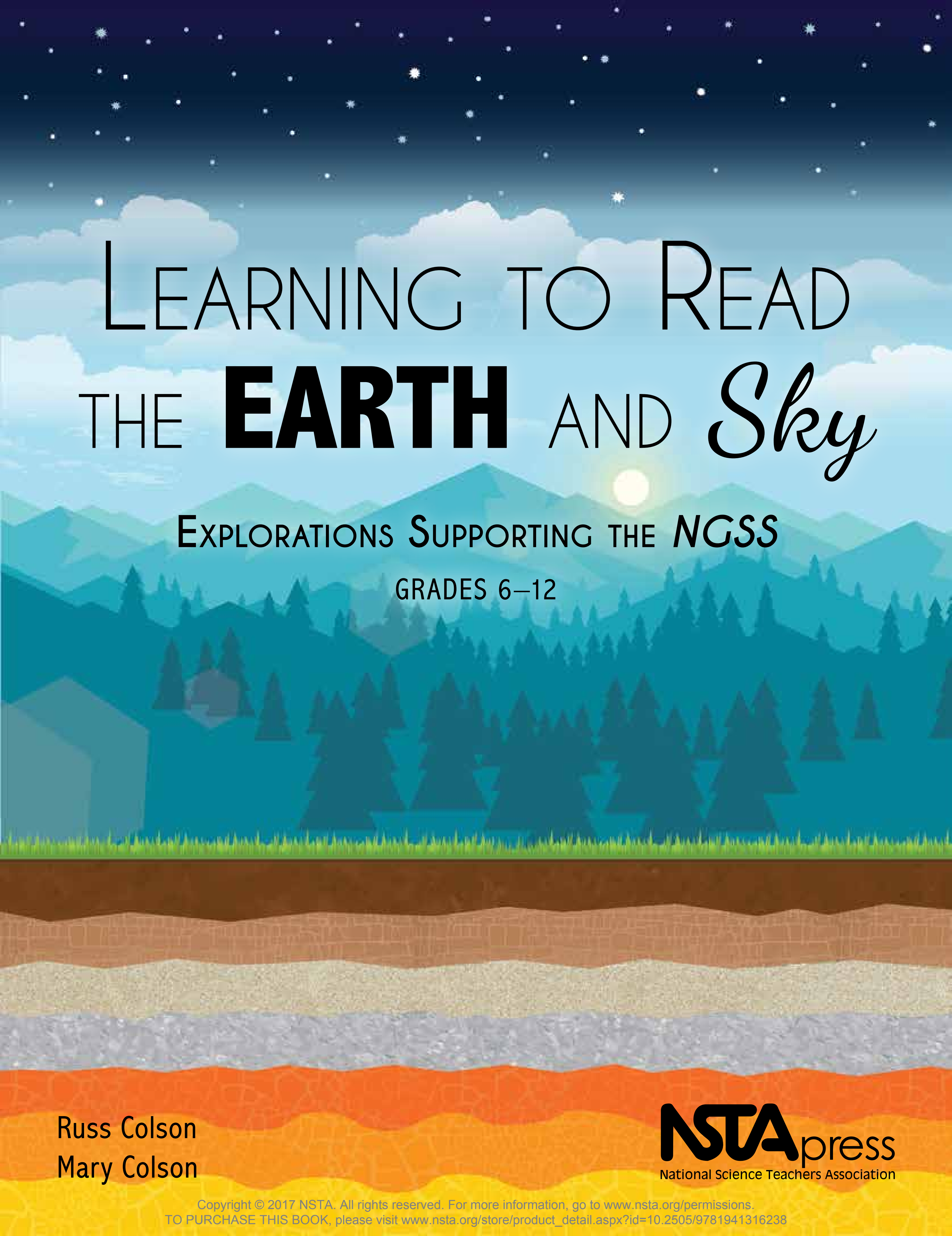

Learning to Read the EARTH and Sky

Explorations Supporting the *NGSS*

GRADES 6–12

Russ Colson
Mary Colson

NSTApress
National Science Teachers Association

Learning to Read the EARTH and Sky

Explorations Supporting the *NGSS*

GRADES 6–12

Russ Colson
Mary Colson

NSTApress
National Science Teachers Association
Arlington, Virginia

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ACKNOWLEDGMENTS

We are indebted to more people than we can list here, but we would like to mention several groups of people whose contributions to this book were profound. We thank the many, many colleagues, friends, and mentors who have helped shape our thoughts on science and science teaching, especially those who read and commented on earlier drafts of this book. Among this group we include our students, who in learning with us have also often taught us. We thank our parents, who first inspired us to notice the world around us and to wonder and explore. We thank our children, who explored the world with us on many family adventures and expanded our understanding of it. We thank the editorial team and staff at NSTA Press, whose support and work have made this book possible. Thanks also go to Patricia Freedman for her meticulous editorial work and to Ken Roy for his contribution of the safety tips and text throughout the book.

ABOUT THE AUTHORS

Russ Colson and Mary Colson have spent much of their careers at the intersection between scientific research and science teaching. They have coauthored papers in peer-reviewed journals on topics ranging from the mysterious death of hadrosaurs in South Dakota to the nature of chromium dimers in silicate melts. They have applied those research insights to classroom investigation, publishing activities for teachers and giving multiple workshops on authentic science in the classroom. Many of the insights and activities in this book come from conversations and arguments on the nature of science, research, and teaching shared during field trips and lunchtime discussions. Through this experience, they have come to truly believe that science in the classroom and science in the research lab need not differ in their core approach.

Russ Colson has worked for more than 20 years as a professor of geology, planetary science, and meteorology at Minnesota State University Moorhead (MSUM). He has engaged hundreds of future teachers in field trips and laboratory science, including opportunities for many undergraduates to present research at national conferences. He founded two successful new programs at MSUM—Earth Science Teaching and Geosciences—and served as director for two education grant programs—Transforming Teacher Education at MSUM and Research Experiences for Teachers. He was a member of the team for the Minnesota earth science teacher licensure standards. In 2010, he was selected by the Carnegie Foundation and the Council for Advancement and Support of Education as one of four national winners of the U.S. Professors of the Year award.

Russ's research experience includes work as an experimental geochemist at the Johnson Space Center in Houston, Texas, and at Washington University in St. Louis, Missouri, where, among other things, he studied how a lunar colony might mine oxygen from the local rock. He put together an experimental petrology laboratory at MSUM with funding from the NASA and the donation of an electron microprobe from Corning. He twice received the university's top award for research involving undergraduates.

Russ has published 18 science fiction stories and articles and enjoys landscaping and gardening at his rural Minnesota home.

Mary Colson teaches eighth-grade earth science at Horizon Middle School in Moorhead, Minnesota, having taught previously in Texas and Tennessee. Her teaching is characterized

by investigation-based curriculum, which she creates herself and changes regularly. She has developed field-based projects, including grant-funded work at a local city park and a water quality research project on local wetland. She was named the middle school recipient of the 2008 Medtronic Foundation's Science Teaching Award presented by the Minnesota Science Teachers Association.

She served on the Minnesota Science Teachers Association Board of Directors for eight years, including a term as president, and then served as the elected District IX director for the National Science Teachers Association Council. She worked as a member of the *Next Generation Science Standards (NGSS)* writing team and was subsequently an educational consultant with Achieve Inc. to develop sample evidence statements and science/math tasks for the middle school and high school *NGSS* for Earth and Space Sciences performance expectations.

Mary holds a master's degree in geological sciences and earned her teaching licensure through the University of Tennessee Lyndhurst Fellowship Program, a competitive paid graduate program designed to recruit teachers from the ranks of trained scientists.

Mary is an avid outdoors person, explaining her wide-ranging field experiences, but also enjoys making a good quilt on a winter evening.

ABOUT THIS BOOK

Learning to Read the Earth and Sky is filled with informative visuals that enhance the book's content. We have provided an online Extras page to host full-color versions of many of the book's images. Feel free to print those images, as needed, for classroom instruction. You can access the Extras page at *www.nsta.org/learningtoread.* Throughout the book, images that are available on the Extras page are marked with the following icon: .

You will also notice that this book differs from other NSTA Press books in its use of *earth* and *Earth.* Whereas other NSTA Press publications use *earth* to refer only to soil and *Earth* in all other instances, we have chosen to strictly reserve *Earth* for references to the planet—including not capitalizing *earth science* as a discipline. This style convention is very important to us and at the heart of what we perceive as a long-standing misconception of what earth science is about. You can read more about our usage decision in "The Language of the Earth" section of the introduction (p. xx).

Bringing the universe into the classroom on a scale that students can investigate and discover

Inspiring teachers to reach beyond prepared curricula and explore science with their students

INTRODUCTION

In 1997, a group of college students, a pickax, and I (Russ) were scrambling along a rural gravel road in western North Dakota. The brisk wind cut through our thin jackets as the Sun fell behind a bank of clouds on the horizon. After six weeks of lectures in Geology in the National Parks, students at last had a chance to discover geology for themselves. They gathered around the young woman with the pickax, eyes drifting from the soft yellows and browns in the nearby buttes to the deepening hole in the grey rock. About a foot below the surface, the pickax began to dredge up crisp, black imprints of willow leaves. Eyes widened and interest quickened. "How could it be wet enough for willow trees to live here on the dry plains?" "How did they get into the rock?" "How long ago was it?" Suddenly, science became something to figure out, not just something to know.[C1]

And that's exactly what science should be, something to figure out, not just something to know. Telling stories to children does not teach them how to read a book, and telling facts, laws, or principles does not teach students to read the stories written in the earth and sky. *Learning to Read the Earth and Sky* explores the *doing* of earth science—how we read the stories written in the earth by applying the practices of science.

Appropriately, the *Next Generation Science Standards* (*NGSS;* NGSS Lead States 2013) emphasize science as a practice, not as a body of knowledge. Science is not about what we know, or think we know, so much as it is about how we know it. It is the person who *knows how we know* that participates in science. Only that person can reasonably discuss whether our understanding of the world is true or false. Anyone else must either accept or reject an idea based on their faith in the person who told them.

Along with science as practice, the *NGSS* emphasize the Earth as a complex, interacting system. In the natural world, everything is connected. John Muir recognized this interacting connectivity when he said "When we try to pick out anything by itself, we find it hitched to everything else in the Universe" (Muir 1911, p. 110).

So, the *NGSS* encourage both doing science in the classroom—the science and engineering practices—and learning the complex interplay of systems over the whole Earth and space beyond—the disciplinary core ideas (DCIs). The problem is that *you can't bring an all-encompassing supersystem into the classroom even if middle or high school students were able to understand it.* In fact, trying to capture the whole sweep of everything at once is contrary to the historical practice of scientific research—scientists break complex problems into bite-size, solvable chunks. In discussing the solution to a complex, interconnected problem in his book *A Brief History of Time,* Stephen Hawking (1996) notes that "it might be impossible to get close to a full solution by investigating parts of the problem in isolation. Nevertheless, it is certainly the way that we have made progress in the past" (p. 12). *Learning to Read the Earth and Sky* offers ways to break the immensity into small chunks that we can bring into the classroom.

Teachers might be concerned that the all-encompassing DCIs of the *NGSS* cut the link to more familiar big ideas of earth science. For example, the *NGSS* do not specifically identify classic ideas such as telling stories from rocks and strata (the wellspring of nearly everything we know about Earth's past), the movement of cyclones and fronts (the traditional foundation for understanding weather), or the processes that shape planetary surfaces (one of the primary new discoveries of the last half century). Instead, the *NGSS* DCIs emphasize interactions and cycles within Earth and space systems. Thus, for example, one of the components of the *NGSS* DCIs becomes this ESS2.A grade band endpoint for grade 8:

> *The planet's systems interact over scales that range from microscopic to global in size, and they operate over fractions of a second to billions of years. These interactions have shaped Earth's history and will determine its future. (NRC 2012, p. 181)*

Another component becomes this ESS2.C grade band endpoint for grade 8:

> *Water continually cycles among land, oceans, and atmosphere via transpiration, evaporation, condensation and crystallization, and precipitation, as well as downhill flows on land. (NRC 2012, p. 185)*

Does this mean that the traditional big ideas are no longer a part of the standards put forth for teaching earth science? No, of course not. They are all in there (along with, no doubt, the kitchen sink). The *NGSS* DCIs are less a limitation on what factual information all students should learn than they are a philosophical proposal that whatever students learn about earth and space processes, they should learn within the context of how that component fits into a bigger picture of a system of interacting subsystems.

FOUR PREMISES OF THIS BOOK

Our goal in writing this book is to provide concrete examples of classroom exploration that meet the ambitious goals of the *NGSS* to both teach science as a practice and reach toward an understanding of how all the small parts fit into a greater whole. We offer some of our own experience in bringing the entire universe into the classroom on a scale that students can test and discover, and we break down the sweeping DCIs into specific examples that students can see, touch, and experience.

We start with the four premises that are described in the following sections:

1. Earth science should engage students with the world they know.
2. Teacher and student are colleagues and fellow scholars.
3. Doing earth science requires breaking big concepts into smaller chunks.
4. The purpose of experimental and observational activities in the classroom is to practice doing science, and not to convey factual information in an active and "hands-on" way.

Engaging Students With the World They Know

Nicolas Desmarest was an influential figure in a heated 18th-century controversy over how rocks form. Did they form by cooling of volcanic lava or by crystallization and settling from seawater? Through careful fieldwork in which he mapped the connection between volcanic rocks and volcanoes, he showed an undeniable link between basaltic rocks and the volcanoes of central France, a contribution that swung the verdict to the belief that some rocks form from volcanic lava. When asked in his old age about the "truth" of the matter, rather than reassert his own views, he responded simply "Go and see!"

Thus, Desmarest reminds us that science doesn't begin with theoretical ideas or facts but rather with the belief that we can understand our universe through observation. Like science research, effective science teaching begins with what students can see, feel, and explore, not with theoretical ideas. Earth science in particular deals with phenomena that people can see and experience all around them—rocks, rivers, clouds, and wind. To improve teaching in the classroom, the DCIs of the *NGSS* must be reduced to a scale that students can "go and see."

Seeing alone is not enough. To do science, students and teachers must understand what they see and what it tells us about how the world works. Earth science is not about knowing the laws of nature, or even knowing the stories of Earth's past. Earth science is about *reading* the stories written in the earth and sky, the *practice* of science.

Addressing aspects of our universe that students see and experience, and teaching students to read those stories on their own, gives them ownership in the process of discovery. They realize that science is not something they are told, coming from high oracles of the mysterious science world. Science becomes something that people *do,* something that *they* can do.

This book is not just a "rule book" of science. It is a book of practice, showing how to dribble, how to pass, and how to shoot in the game of earth science. It provides ways for teachers and students to practice the game together, remembering that science is what we do, not just what we know.[C1]

Teacher and Student as Colleagues and Fellow Scholars

In a brand-new science room in 2003, I (Mary) engaged my eighth graders with an old geology activity—crystallizing thymol in a petri dish. Like magma, thymol produces large crystals when cooled slowly and small crystals when cooled fast, illustrating the foundation for one of the key stories told by igneous rocks. But this time, something wasn't working for one of my groups. No crystals formed in their slow-cooled sample, and when crystals finally did grow, they were small. One student in the group looked at me with disappointment. "What did we do wrong?" he asked.

"I don't know," I said. "We'll have to figure it out."

The teacher doesn't know? She has to figure it out?

Postures shifted. Eyes brightened. We started asking questions. "It's cold, so why isn't it solid?" "What did the other groups do different?" "What can we try new?" The students hunched over the lab bench with renewed interest. Suddenly, the lab no longer dealt with getting the "right" answer from the teacher's key. Now the lab dealt with how they could figure out something that the teacher didn't know. In the accident of the lab "not working," it had become real science.

Some comparisons and experimentation led them to the conclusion that, if they melted the thymol entirely, crystallization was delayed because of an absence of "seed" crystals. When it finally did crystallize from a supercooled state, it did so rapidly, producing small crystals. But the real discovery of the activity was that science is about figuring things out, not waiting for the teacher to hand out the answers.

We believe that the authentic teacher engages in discovery with her students, asking her own questions, developing her own exploratory activities, analyzing and interpreting results that don't always seem to make sense. Sometimes labs developed in this way may not be completely polished, and the results not completely certain, but the challenges that arise are not a problem to be avoided. The challenges and uncertainties are the whole point of the activity. In taking up those challenges, the teacher gives students the valuable learning experience of seeing her doing science, not just assigning activities and following recipes that someone else developed. Not only do the students realize that the teacher values true exploration, but they see and learn from the way the teacher asks questions and tests ideas.

Early in my (Russ's) career at Minnesota State University Moorhead, an older faculty member in the education department characterized a teacher as a pipeline through which knowledge flows to the student. This image didn't work for me. Doing science is no more about passive knowledge than playing basketball is about knowing the rule book. The teacher is better characterized as coach, illustrating good science reasoning skills—by sometimes allowing himself to get stumped and having to figure out a puzzle in front of the students—and then giving students the chance to practice solving their own puzzles.

Teachers often look for polished and well-tested activities to do with their students. This is fine to do on occasion—the teacher only has so much time, and the next class period is already pressing. But the point of teaching is not to make it easy on the teacher or the student. *Easy* is giving students a recipe lab where they follow the simple instructions to the inevitable outcome. *Good* is crafting situations where students struggle to figure out what to do, grapple with concepts, and have to ask lots of questions. Some labs should be of this latter type. And some should be of the teacher's own making.

This book provides some activities that we have tested and find useful for cultivating student reasoning and discourse in the classroom. More important, it provides insight into the process of doing science that can help us all be more authentic teachers, developing our own activities and providing the foundation so we can truly say, "My students and I do science together."

Breaking Big Concepts Into Smaller Chunks

Back in the 1980s, a humorous list of test questions circulated among PhD candidates preparing for their preliminary exams. Each of the questions captured the expectation that candidates should provide comprehensive, detailed answers for vaguely worded, abstract, and far-reaching questions. One of the questions was something like "Explain the universe. Give three examples."

The *NGSS* propose that a key outcome of education should be that every student understands Earth's complex systems and how they interact— that students understand Earth's place in time and space and how human actions impact broad planetary processes in complex ways. Although this is an important goal, it may be seen as vague, abstract, and far-reaching. In our view, it's difficult to get to these big-scale understandings without first engaging in much smaller-scale science exploration. The good news is that the "big-picture" goals of the *NGSS* do not limit the small-scale science that the teacher can bring into the classroom. All of earth science, its core discoveries, its methods of investigation, and its stories of past and present, fit comfortably within the broad learning outcomes of the *NGSS*. That's not to say that all of earth science should be brought into the classroom. Trying to cover "all the material" causes a class to devolve into a listing of facts and concepts without time for the actual practice of science exploration. However, the big-picture *NGSS* goals can be reached through a doable subset of classroom-size science explorations.

In real research, scientists might be studying the chemical evolution of the Moon, but their work will focus on a small subcomponent of how that evolution works. Likewise, students might examine how "water continually cycles among land, ocean, and atmosphere," but in the classroom they will look at how water condenses out of air. The job of the teacher is to make choices that limit the scope of the topic, allowing time for students to truly explore some subset of a larger system, while tying what the students are doing into an understanding of that system. The small-scale classroom work helps students understand *how things work and how we know,* while the bigger picture gives them a conceptual understanding of the elegant workings of our world and universe.

New teachers fresh out of college often feel like they have lots of material to cover. For example, they might have ideas about atmospheric circulation and climate, seasons, movement of energy, ocean currents, and how they all work together. But how do you pare that down to something that middle and high school students can do in the classroom? Maintaining a sense of the big picture without getting lost in the sea of details, while still giving students a real experience in science exploration, depends, like real research, on breaking the big picture down into small, solvable components.

Although teachers need to limit what they bring into the classroom, we should not limit the scope of the discipline by predefining a subset of material that every class must encompass. Rather, we should limit the number of examples we use to illustrate the bigger ideas while maintaining the full scope of the discipline as fair game for learning. This book offers examples of specific, small-scale activities that you can do in the classroom, along with connections to the big-picture ideas of the *NGSS* to which the activity applies.

Using Experimental and Observational Activities in the Classroom to Practice Doing Science

Fads are common in teaching. Some of these fads are of lasting importance, while others fade away, yet each one is portrayed as revolutionary and the "final word" at the time. Some fads introduce important new ideas that may not be fully understood until later. A couple of decades ago, "inquiry-based science" was the big thing, raised to importance by *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996). Its intention was not unlike the science and engineering practices proposed by the *NGSS,* and thus of lasting importance, but in application the pursuit of inquiry often became confused with the use of activities to convey factual information. For example, instead of a teacher telling students about the thicknesses and character of Earth's core, mantle, and crust, the students might color, cut out, and assemble a premade model of Earth's interior—a pedagogically sound activity for learning a concept but not one that engages students in the scientific process.

Thus, inquiry-based science, intended to prompt teachers to do science with their students, sometimes became an alternative avenue for conveying science knowledge. Why? Because doing real science is a lot harder than conveying information. It's hard to create activities. It's hard to interpret the results. It's hard to interact one-on-one instead of as a whole class. And it's especially hard to re-create in the classroom the sense of science discovery that in real life took thousands of scientists hundreds of years.

Teachers don't have hundreds of years in the classroom, and yet they want to give students a sense of the exploration and discovery inherent in science. The secret is to limit the options that students need to consider. Without sufficient limitations, the classroom lab devolves into random experiments that provide little or no insight into the science. With limitations set too tight, students have no real creative or analytical input and the lab becomes a "lecture by activity" in which the goal is to reinforce the content knowledge or derive the "correct answer."

It is helpful to have specific examples of how to apply limits to classroom investigations. Those limits depend on the ability level of the students and on the materials and time available. It is also helpful to have examples of obstacles that students are likely to encounter and misunderstandings they are likely to entertain. This book offers example activities and stories from the classroom that can help guide the teacher in setting those limitations while still providing a meaningful experience in science discovery.

ORGANIZATION OF THIS BOOK

The main part of this book is organized into three sections: "The Practices of Science," "The Language of the Earth," and "YOU Can Do It!" These sections are described in the pages that follow. After these sections are the afterword and three appendixes. The afterword includes a brief discussion of some aspects of teaching that we did not cover in depth in the main sections. Appendix A lists chapter activities and anecdotes related to *NGSS* performance expectations. Appendix B lists chapter activities and anecdotes related to *NGSS* science and engineering practices, DCIs, crosscutting concepts, and performance expectations. Appendix C provides illustrative quotes for selected ideas presented in the introduction and individual chapters. The quotes highlight a few of the significant ideas in science education that have been explored by teachers and researchers. Throughout the book, discussions corresponding to selected ideas in Appendix C are noted by a superscript *C*, followed by the note number.

The Practices of Science

Science is something we do, not something we know. The *NGSS* emphasize teaching science as a practice. *Learning to Read the Earth and Sky* devotes nine chapters to examining the practices of science, offering sample earth science activities for the classroom and anecdotes that illustrate student challenges and misunderstandings. Our goal is to help students and teachers understand the basic tools and language of science: how to propose and investigate a question that can be answered through science, how to analyze and interpret data, how to create and use a scientific model, and how to explain and communicate a scientific theory. We explore how an experiment differs from a learning activity, how to use graphs and maps, what scientific modeling means, and how to reason from evidence to theory.

The Language of the Earth

More than any other science, earth science is about stories: stories of Earth's past, stories of how things work, stories of how we know. Most of the great discoveries of geology are hinged on learning how to read those stories. The key "content" is not the conclusions of scientific studies—models, theories, and natural "laws." Rather, the key content is an understanding of how we read the stories. Many of these story-reading skills are unique to earth science—the place where it is set apart from chemistry, physics, and biology.

Learning to Read the Earth and Sky devotes five chapters to methods we use to read the stories written in the earth. Although the *NGSS* embeds these story-reading skills (the grammar of the earth, if you will) within the DCIs, we think there is a need, when applying these story-reading ideas in the classroom, to break them out. Without an understanding of these earth-reading concepts, any effort to examine Earth systems becomes an exercise in accepting the "facts" that someone gives without any real understanding of the underlying science. We consider in particular (1) how we read the story of Earth's past as written in earth—the soil, sediments, and layers of rock that make up our planet; (2) how we figure out the nature of places we can never visit, such as distant stars and the Earth's core; and (3) how we track down the movement of elements through the complex cycles and systems of the Earth.

Earth science emerged as people learned to read the stories of Earth's past and present written in its lithosphere, hydrosphere, atmosphere, and biosphere. Today, we apply these same language skills to reading the stories of other worlds written in their own "earthy" materials. In this book, we leave the first "e" in earth science lowercase to remind ourselves that the skills and practices of earth science now apply to more than planet Earth alone.

YOU Can Do It!

We believe that teachers should do science with their students. *Learning to Read the Earth and Sky* devotes three chapters to examining the teacher's role in this collaboration: teacher as curriculum narrator; teacher as guide in starting where you and your students are; and teacher as mentor, practitioner, and scholar.

The teacher, as *curriculum narrator,* can tie spontaneous and small-scale classroom exploration to the big ideas of science. The DCIs of the *NGSS*—and John Muir—tie everything in the universe to everything else, focusing our attention on the elegant way that the universe works in great systems and cycles.

Teachers can engage students *where they are.* We propose that students are most engaged with discovery when they investigate events and places that they know.

Teachers can be *mentors* and *practitioners of science.* We argue that students should be neither rigidly directed by the curriculum nor allowed to flounder with too little guidance. Instead, students should be provided a middle road where they make real choices in what investigations to pursue and how to pursue them, under the guidance of an expert mentor and practitioner of science—the teacher.

Scientists are sailors on the ship, not passengers, and understanding science is about understanding how to sail the ship. If we as teachers don't do a bit of the sailing with our students, then neither we nor they can ever really understand what science is all about.

Safety Practices in the Science Laboratory and Field

Both inquiry-based classroom and laboratory/field activities that immerse students in the practices of science can be effective and exciting. To ensure the success of these activities, teachers must address potential safety issues relative to engineering controls (ventilation, eye wash, fire extinguishers, showers, etc.), administrative procedures and safety operating procedures, and use of appropriate personal protective equipment (indirectly vented chemical-splash goggles meeting ANSI/ISEA Z87.1 standard, chemical-resistant aprons and nonlatex gloves, etc.). When personal protective equipment is indicated for use in an activity's safety notes, it is required for all phases of the activity, including setup, hands-on investigation, and takedown. Teachers can make it safer for students and themselves by adopting, implementing, and enforcing legal safety standards and better professional safety practices in the science classroom and laboratory/field. Throughout this book, safety notes are provided for activities and need to be adopted and enforced in efforts to provide for a safer learning/teaching experience.

Teachers should also review and follow local policies and protocols used within their school district and/or school, such as a chemical hygiene plan and Board of Education safety policies. Additional applicable standard operating procedures can be found in the National Science Teachers Association's (NSTA) *Safety in the Science Classroom, Laboratory, or Field Sites (www.nsta.org/docs/SafetyInTheScienceClassroomLabAndField.pdf).* Students should be required to review this document or one similar to it under the direction of the teacher. Each student and parent/guardian should then sign the document to acknowledge that they understand the procedures that must be followed for a safer working/learning experience in the laboratory. An additional reference is available for teachers to further explore field trip safety considerations: *Field Trip Safety* by the NSTA Safety Advisory Board *(www.nsta.org/docs/FieldTripSafety.pdf).*

Disclaimer: The safety precautions for 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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ANALYZING AND INTERPRETING DATA, PART 1

GRAPHING

To understand a graph, it's important to remember that graphs represent real-world observations. Graphing is a language that turns an initially puzzling blizzard of real-world data into a coherent story.

Back before stories went viral on Twitter, anonymous jokes circulated by e-mail. I (Russ) received one such e-mail on March 20, 1999, that illustrated the complexity of crunching through a large body of observations to reach a synthesizing conclusion.

> *Sherlock Holmes and Dr. Watson went on a camping trip. After a good meal and a bottle of wine they lay down for the night, and went to sleep. Some hours later, Holmes awoke and nudged his faithful friend.*
>
> *"Watson, look up at the sky and tell me what you see."*
>
> *Watson replied, "I see millions and millions of stars."*
>
> *"What does that tell you?" says Holmes.*
>
> *Watson pondered for a minute. "Astronomically, it tells me that there are millions of galaxies and potentially billions of planets. Astrologically, I observe that Saturn is in Leo. Horologically, I deduce that the time is approximately a quarter past three. Theologically, I can see that God is all powerful and that we are small and insignificant. Meteorologically, I suspect that we will have a beautiful day tomorrow. What does it tell you, Holmes?"*
>
> *Holmes was silent for a minute, then spoke.*
>
> *"Watson, you idiot. Someone has stolen our tent."*

With the last sentence, obscure elements, such as why Holmes woke him up and how a unique solution to the question is possible, become clear. There is a point in an investigation when new observations are no longer bewildering but fit neatly into a growing understanding. At that point, we gain the ability to predict future observations.

ORGANIZING THE BEWILDERING

Graphs bring large numbers of bewildering observations together in a single, coherent picture. They provide a means to explain how variables are related to each other and can be a starting point for evaluating possible cause-and-effect relationships. They provide a way to make predictions based on correlations between variables, which can be used to test whether the correlations are causative or not. To develop those explanations and make those predictions, we need to understand the language of the graph.

In this chapter, we offer a quick journey through reading a graph. As you review the case study and the subsequent sections on working with graphs, pay attention to the habits of mind that you use and think about how you might guide students in developing those habits.[C10]

Considerations in Learning the Language of the Graph

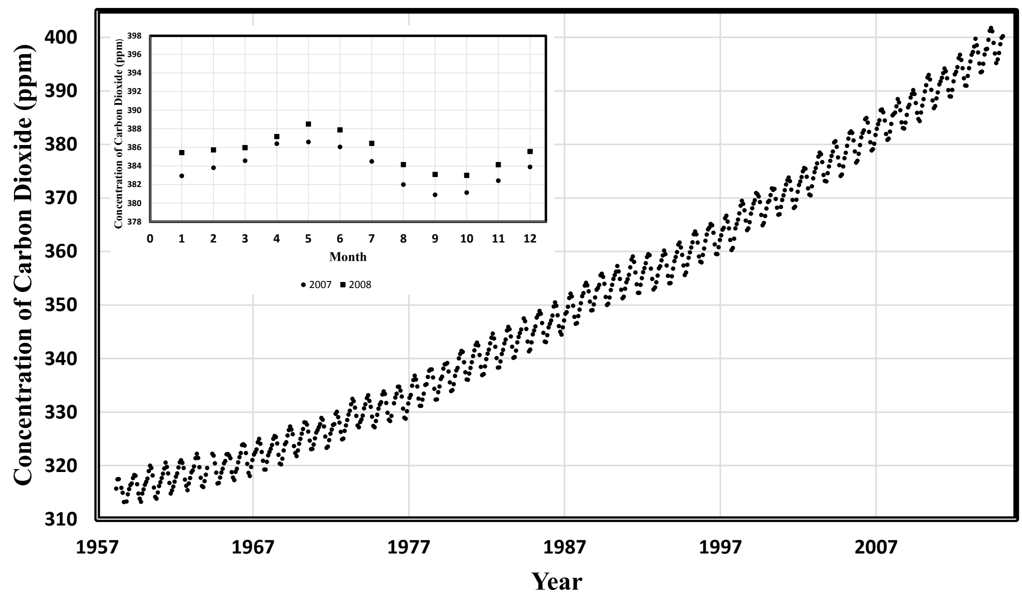
- Does this graph plot variation in one parameter against another? Most graphs used in experimental science do, but bar graphs don't.
- What are the labels on the axes? How do the values apply to the real world? Do you need students to explore any aspect of the labels? For example, on the Keeling Curve discussed in this chapter, would your students understand the idea of *concentration in ppm?*
- Is there a correlation or not?
- If there is a correlation, is the relationship linear or not linear? What does that mean in terms of real-world behavior?
- Is the slope positive or negative? What does that mean in the real world?
- What is the value of the slope? What does that mean in the real world?
- If there is a correlation, is there a causal relationship? What is your evidence? What predictions can we make from that causal relationship?
- If there appears to be a correlation, is it real—that is, is it greater than the uncertainty in the measurements? Is the scatter in the data around a correlation trend smaller than the change in value due to the correlation?

A CASE STUDY IN GRAPH READING

Let's consider a classic graph from the earth sciences that continues to have a significant impact on national policy. The Keeling Curve shown in Figure 4.1 is a record of the concentration of carbon dioxide (CO_2) measured at the top of Mauna Loa since 1958.

Figure 4.1

The Keeling Curve charting the measured change in carbon dioxide in the atmosphere at the summit of Mauna Loa in Hawaii



Note: ppm = parts per million.

Sources: Based on data from *ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt.* Carbon dioxide data were collected by David Keeling of the Scripps Institution of Oceanography (SIO) before 1974 and by both the SIO and the Earth System Research Laboratory at the National Oceanic and Atmospheric Administration since then.

What does this graph tell us? We see that the amount of CO_2, in parts per million (ppm), is plotted on the y-axis and time is plotted on the x-axis. The concentration of CO_2 since 1958 is not constant but increases to the right, telling us that the concentration of CO_2 is increasing with time.

We can see that the trend is not linear, but rather the slope of the trend becomes steeper with time—notice that you can't draw a single straight line through data for all years. This means that the rate of increase in CO_2 has itself been increasing, which is consistent with humans burning more fossil fuels and making more cement in the 2000s than in the 1960s (although this correlation does not prove that human activity is the only cause of this increase). We can see that the trend in the data does not intersect the y-axis at zero on the left-hand side of the graph, meaning that some CO_2 was already present in the atmosphere in 1958.

We also notice a peculiar sawtooth pattern to the variation in CO_2 concentration. From the inset on the graph, we see that each rise and fall is exactly one year long. Each year, the concentration increases from about October (month 10) to May (month 5) and decreases from about May to October. Like Sherlock's missing tent, this observation makes sense when we realize that from May to October, plants in the Northern Hemisphere are consuming CO_2 during their growing season. The zigzag pattern of the Keeling Curve proves a strong *correlation* between variations in CO_2 and time of year. When combined with other evidence for seasonal variations in CO_2 due to plant respiration, this correlation provides a strong case that the zigzag variations are *caused by* seasonal variations in plant growth.

Discovery of the Carbon Dioxide Annual Cycle

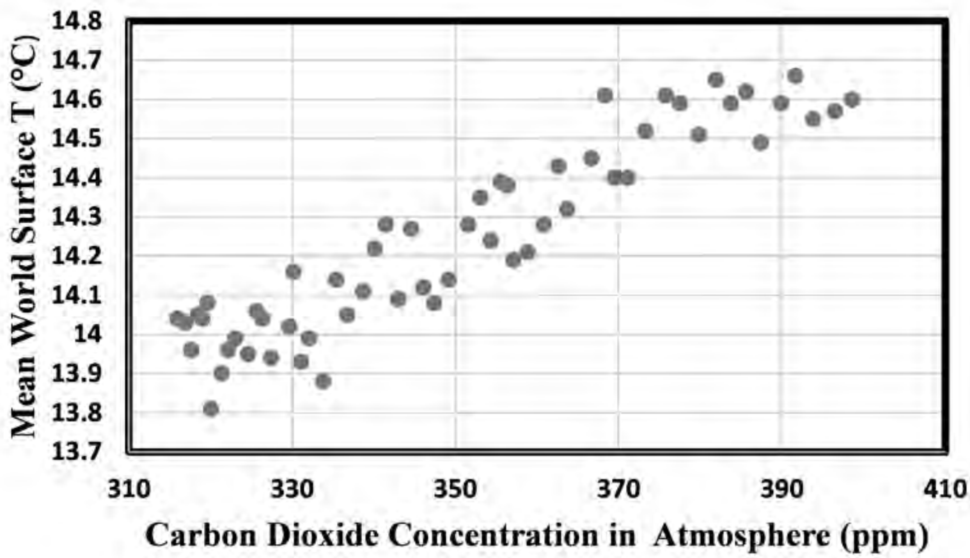
In the mid-1950s, Charles David Keeling developed a system for measuring the carbon dioxide (CO_2) concentration in air. As a postdoctoral fellow at the California Institute of Technology, he measured the CO_2 concentration in forests and grasslands, places where the air would be more affected by natural biological activity than by human activity. He discovered that air impacted by the forests and grasslands showed a regular daily cycle in CO_2. He was able to relate the cycle to respiring plants giving off CO_2 at night.

In March 1958, Keeling and his team began making CO_2 measurements on Mauna Loa. Unexpectedly, he found that the concentration of CO_2 at Mauna Loa rose from March until May and then declined until October. The same pattern repeated in 1959. In Keeling's own words: "We were witnessing for the first time nature's withdrawing CO_2 from the air for plant growth during summer and returning it each succeeding winter" (Scripps Institution of Oceanography 2016a, 2016b).

The Keeling Curve is often combined with measurements of world air temperature to show a correlation between CO_2 concentration and average global temperature (see Figure 4.2). In this graph, we see a strong positive correlation between CO_2 and temperature. A positive correlation means that they are both increasing together. We might jump to the conclusion that the increase in CO_2 is *causing* the increase in temperature. However, since these data come from field measurements and not from a controlled experiment in which only one variable is changed and another variable responds, the correlation does not necessarily imply causation.

The distinction between *correlation* and *causation* is an important one for students to consider. I (Russ) often present the difference this way: "Every morning I get up, and also

Figure 4.2
Correlation between the average annual concentration of carbon dioxide measured at the summit of Mauna Loa and average annual world surface air temperatures (T)



Sources: Based on data from *http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A2.txt* (for temperature) and *ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_annmean_mlo.txt* (for carbon dioxide). Carbon dioxide data were collected by David Keeling of the Scripps Institution of Oceanography (SIO) before 1974 and by both the SIO and the Earth System Research Laboratory at the National Oceanic and Atmospheric Administration since then.

every morning the Sun rises. Every morning! A clear correlation. Wow. I must cause the Sun to rise!"

Correlation simply means that two things happen together. However, a correlation does present the possibility that one change causes the other. The possibility that I cause the sunrise can be tested by making a prediction and seeing if the prediction is born out: If my getting up in the morning causes the sunrise, then we predict that if I get up at different times of the day the sunrise should follow (I have tried this, and, disappointingly, it doesn't work).

For the correlation shown in Figure 4.2, the case for causation is strengthened by other experiments showing that CO_2 absorbs infrared radiation—radiation that might otherwise escape into space—and so *could cause* the temperature of Earth to rise. Testing for causation by making a prediction such as we did with me and the sunrise would require that we produce different amounts of CO_2 over long periods of time and see how it affects world temperature. This is an experiment which, for better or worse, we are in the process of carrying out.

From Figure 4.2, we can also get a feel for uncertainty in the data and how that uncertainty affects our confidence in the correlation between temperature and CO_2. *Uncertainty* is one of the most important ideas of science. It's important for students to understand that correlations are never perfect, both because no measurement is ever exact and because real variation that is not explained by our correlation model might exist in natural data. Uncertainty is an estimate of how imperfect our measurements or correlation models might be.

As simplified in the following text, a graphical analysis of uncertainty can be done by students even without doing a lot of math. Although graphical statistics don't have the rigor of mathematical analysis, students get a feel for what uncertainty means and how it can be inferred from data.

Notice that values for temperature in Figure 4.2 vary from 13.8°C to 14.7°C and CO_2 concentrations vary from about 315 ppm to nearly 400 ppm. Although the variations in temperature and CO_2 are correlated, they are not perfectly correlated—that is, we can't draw a single smooth line or curve that passes through all the data points. We can think of the total variation as being the sum of the variation that goes along with the correlation trend (the variation explained by a curve through the data), plus any "extra" scatter around that trend (the amount of variation from the curve). This "extra" variation can be caused by many factors such as imprecisions in our measurements or real variation in the data that are correlated with other, unidentified causes. This extra variation gives us a feel for the uncertainty in the data.

You might have students consider the magnitude of the variation that is "explained" by the correlation and compare it with the magnitude of the remaining scatter around the trend. The smaller the magnitude of the scatter compared with the variation explained by the correlation, the more confidence we have that the correlation is real and not a random artifact of data variations. For example, in Figure 4.2 the total variation is a bit less than a degree, whereas the scatter is about 0.2 degrees. You might also have students draw a "maximum reasonable slope" line and a "minimum reasonable slope" line through the data. From these two trends, students can get a feel for how much the uncertainty might affect the slope of the trend.

NOT JUST A TECHNIQUE

Although students need to develop a number of technical skills to make graphs, such as proper scaling and proper plotting, the mechanics of drawing a graph are not the main point of data analysis, interpretation, and graphing as proposed by the *Next Generation Science Standards (NGSS).* For example, science and engineering practice 4 matrix for grades 6–8 in Appendix F of the *NGSS* includes this element: "Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships" (NGSS Lead States 2013).

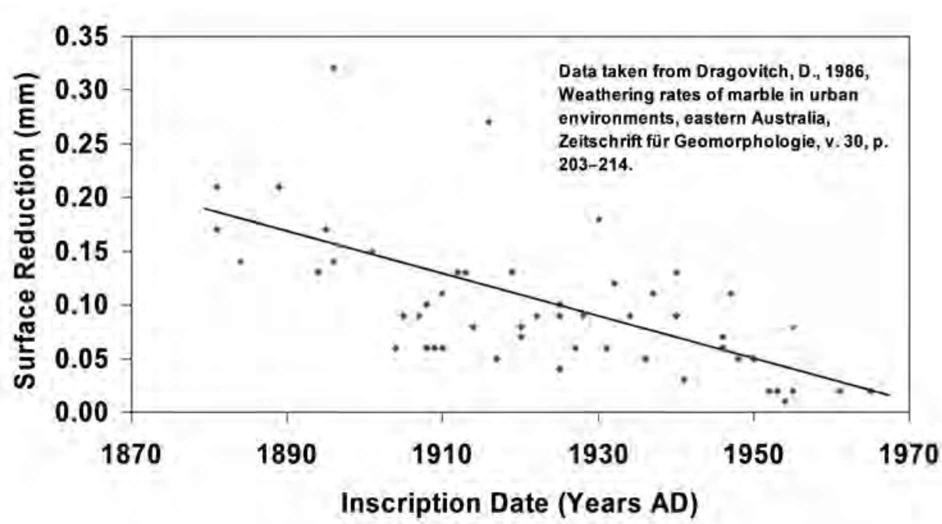
Nor do the technical mechanics of drawing a graph address the *NGSS* crosscutting concept of Cause and Effect: Mechanism and Explanation, as described in *NGSS* Appendix G for grades 9–12: "students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects."

In our experience, students are much better at plotting graphs than at understanding what the graphs mean. This struggle that students experience in connecting graphical data to lab and field observation has been reported by teachers and education researchers for many years, as pointed out, for example, by Robert Beichner in his 1994 paper "Testing Student Interpretation of Kinematics Graphs." Yet, deriving meaning from the graph is the main point of the graph. What does the slope represent? What does the y-intercept mean? How does the information on the graph relate to the natural system under study?

In 2014, I (Mary) had my students study graphs showing the rate of weathering of tombstones in Sydney, Australia (see Figure 4.3). I began with simple exercises such as considering whether the slope was positive or negative and what that might mean in terms of the rock changing through time. Then, I had students calculate the slope (millimeters per year). For technical reasons, some students ran into difficulties in calculating slope. In math, students sometimes determine slope by counting squares in a grid; some

Figure 4.3

Weathering rate of marble tombstones in Sydney, Australia



Source: Graph and activity developed by Rebecca Teed and published as "How Fast Do Materials Weather" in *Starting Point: Teaching Entry Level Geoscience*, available at *http://serc.carleton.edu/introgeo/interactive/examples/weatrate.html.*

students couldn't find slope because there was no grid on the graph. Other students tried to measure the rise and run with a ruler—not realizing that the scales of the two axes were quite different and plotted different types of values (millimeters vs. years). In science, graphs rarely plot dimensionless numbers against each other. To transfer math graphing skills to the science classroom, students need guidance in thinking about labels and scales on the axes.

Our conclusion is that students need to practice reading scientific graphs even if they know the mechanics for creating them. Students need practice thinking of numbers not as dimensionless values but as values connected to real-world measurements such as mass, temperature, and solubility. Students need practice relating trends on graphs to real-world processes and relationships.

We view reading a graph as a language skill, like learning to read a book, rather than a technical skill, like learning to write the letters of the alphabet. In the following section, we offer some ways to practice that language skill.

GRAPH-READING CHALLENGES

In learning to read and write in the language of the graph, students might practice translating graphs into real-world understanding or translating real-world data into graphs.[C11]

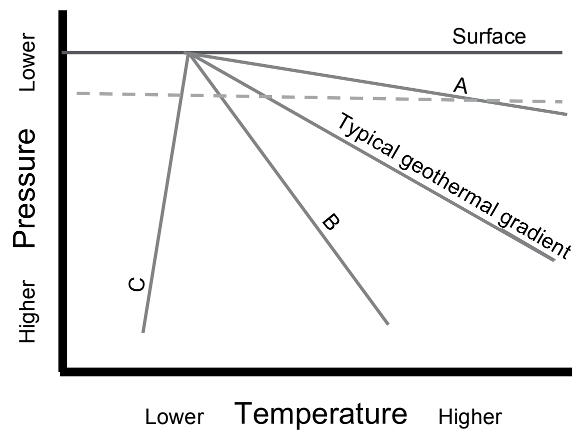
For example, in the activity with the tombstones, after students calculated the slope and associated that slope with a rate of weathering (about 2 mm/100 years), one student commented that it didn't seem like a very fast weathering rate. I (Mary) asked if the tombstone would still be there in a million years. That question launched the class into a calculation of how long it would take to weather the tombstone away completely, an activity that engaged them in translating the graphical information into a real-world application.

One way to practice going the other direction—translating observational data into a graph—is through the use of short graphing puzzles. I (Russ) often engage students in conceptual analysis of what observational data imply about the slope on a graph, or whether the observational data are most consistent with a positive or negative slope—basic concepts of graph reading that students often struggle with most. These puzzles are easy for teachers to create and adapt to a variety of lessons and topics.

For example, most students understand that the Earth gets hotter as one goes deeper. This increase in temperature with depth is called *geothermal gradient.* However, not all locations have the same geothermal gradient. Yellowstone National Park has magma near the surface, resulting in a higher geothermal gradient in that area. With a graphing puzzle such as that presented in Figure 4.4, you might prompt your students by asking which trend represents the geothermal gradient at Yellowstone (the one that's hottest close to the surface). For follow-up, you might ask, "What would be the temperature at the point the different trends converge?" and "What would be the physical meaning of the other trends?"

Figure 4.4

Conceptual graphing puzzle on the geothermal gradient at Yellowstone National Park



Prompt questions you might use with students include the following: Which line most closely portrays the high geothermal gradient present at Yellowstone National Park? What value for temperature or pressure do you expect where the lines converge? What is the real-world meaning of the other trends? Note that pressure is plotted on the *y*-axis—as you go deeper into the Earth, there is more rock above you and therefore greater pressure. The dashed line shows one particular depth, which can guide students in determining which trend shows the highest temperature at that depth.

When Experience Contradicts Learning

Many students have visited caves, usually on summer vacations with their families, and noticed that the air temperature *decreases* as they descend into the earth. It's cold in the cave, especially in contrast to the hot summer weather. And especially if one ignores the signs that say "Cave is cold, bring a coat!"

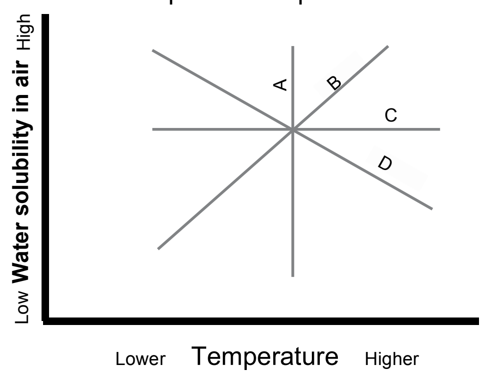
Students often ask how the Earth can get hotter with depth if caves are colder. Yeah. What's going on here? Which is it? Hotter or colder as you go down into the Earth?

Cave temperatures are often close to the average annual temperature outside the cave. They will indeed be cooler than the outside air in summer. But they are warmer in winter.

In Chapter 2, "The Controlled Experiment," we reported experiments for measuring the solubility of water vapor in air as a function of temperature. Suppose that you're working on a similar unit. You might prompt your students with the following puzzle (see Figure 4.5, p. 62): "Consider the observation that on a hot, muggy day, water condenses on a cold can of pop when you take it from the cooler out at the lake. If the water forms on the can of pop when the water condenses from the air, which trend line would represent how solubility of water vapor changes with temperature?" You might then ask these follow-up questions: "What would be the physical meaning of the other lines?" "Does a vertical line even make sense?" "Why or why not?"

Figure 4.5

Conceptual graphing puzzle on the temperature dependence of water vapor solubility in air



Prompt questions you might use with students include the following: Which of the lines best portrays the trend of solubility with temperature, given that water condenses on a cold can of pop on a hot, muggy day? What is the real-world meaning of the other trends (none of which actually occur in our dimensional reality)?

The vertical line (line A in Figure 4.5) doesn't make sense because it implies that only one temperature is possible and, at that temperature, water solubility in air simultaneously takes on all possible values. The horizontal line (line C in Figure 4.5) means that the water solubility does not change with temperature. Line D in Figure 4.5 implies that water vapor becomes more soluble with decreasing temperature, the opposite of the relationship observed.

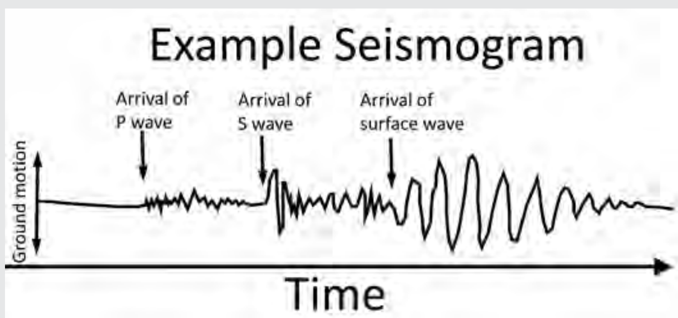
PAYING ATTENTION TO AXIS LABELS

You can't know what a graph is telling you if you don't know what's been plotted on it. Students often automatically and wrongly assume that the axis labels will correspond to whatever data they are given in a classroom problem.

For example, finding the location of an earthquake epicenter is a common classroom activity in which data from the seismogram and the graph axis labels don't match up. The input data are typically arrival times—the times when the P and S waves arrived at a seismograph—but the graph plots travel times—time elapsed between earthquake and arrival of the seismic wave at the seismograph.

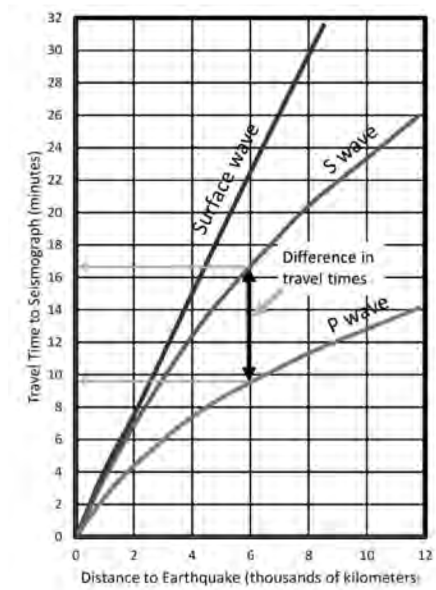
Seismic Travel Time Analogy

Measuring seismic arrival times is like noting that you saw a flash of lightning at 2:00 p.m. (the P wave) and then heard the sound of thunder at 2:00:25 p.m. (the S wave). To figure the distance to the lightning bolt, you use the difference in the arrival times of the light and the sound. Given that sound travels at about one-fifth mile per second through our atmosphere (1 mile every five seconds), the hypothetical lightning bolt was 5 miles away. From this, you can calculate the time of the lightning strike (because the speed of light is so fast, this is essentially the same as the arrival time of the flash, about 2:00 p.m.). The travel time for the thunder was thus about 25 seconds.



To determine how far each seismograph is from an earthquake, students need to figure out how the arrival times at three seismograph stations can be applied to a graph that plots travel time versus distance from earthquake (Figure 4.6, p. 64). They then draw a circle on a map around each of the three seismograph stations with the radius determined from the graph. The epicenter is located at the point where the circles intersect. Younger students might use a graph that plots the difference in P and S arrival times instead of the travel times, making for a simpler problem. However, in either case, the values in the data sets given to the students (arrival times) do not directly correspond to what's plotted on the graph (either travel time or difference in travel times). When students try to chart the arrival times on the axis labeled "travel time" (or "difference in travel times"), they get nonsensical results, which forces them to go back and rethink what the graph means.

Figure 4.6 ✪
Graph of seismic wave travel times versus surface travel distance



Seismograph data provide arrival times for P and S waves from an earthquake. In figuring out how far each seismograph was from the earthquake, students need to realize that this graph does not plot arrival times, and adjust their strategy accordingly. They also need to realize that the difference in the travel times for the P and S waves and the difference in arrival times will be the same value.

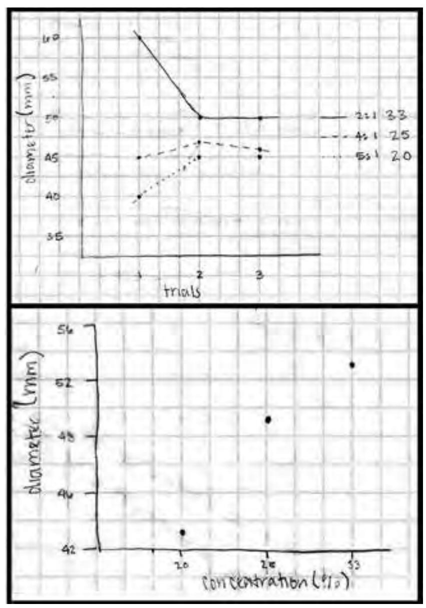
Another way to give students a chance to think about axis labels is to let them choose how to plot their own data. Unless specifically directed otherwise, students tend to gravitate toward histograms, rather than the *x-y* scatter plots that show the correlations between two experimental variables. Not specifically telling students what kind of graph to use can introduce an opportunity to talk about different kinds of graphs.

One year, I (Russ) had college students measure the effect of viscosity and eruption rate on the slope and diameter of sugar-water volcanoes on the distant (imaginary) planet of Lollipop. Students were asked to determine the relationship between volcano diameter and one of the following: composition of sugar water, eruption rate, or temperature.

Several groups chose to study the effect of melt composition (sugar acting as the proxy for silica concentration, which influences the viscosity of lava in volcanoes on Earth). Despite knowing the goal of the experiment, several groups didn't initially include with their report an *x-y* graph showing the variation in diameter with composition. One group plotted volcano diameter versus the trial number for three different trials of each of three compositions, making a line graph as in Figure 4.7. This graph provided useful information, just not the relationship between the dependent and independent variables the way a scatter plot would. For example, the graph showed the reproducibility of their results, giving a feel for experimental uncertainty, and offered a way to consider if there were any unexpected trends with time in their measurements. The freedom to plot a variety of graphs gave us the opportunity to talk about the value of different types of graphs.

Figure 4.7

Student graphs from an experimental investigation of the relationships between melt composition and volcano diameter (at fixed flow volumes, flow rates, and melt temperature) on the imaginary world of Lollipop



The results are reported for three melt compositions (by mass): 20% water and 80% sugar, 25% water and 75% sugar, and 33% water and 67% sugar. Volcano diameter was plotted against trial number in the upper graph—a type of line graph—rather than plotting melt composition versus diameter in an *x-y* scatter plot. This provided an opportunity to talk about the value of different types of graphs. After discussing, students plotted the average diameter against melt composition (lower graph), but the lower graph plots categorical data along the *x* axis, ordered by time of experiment, making it no different in concept from a histogram—notice that there is no meaningful scale on this graph; rather, the data are simply plotted against the three different compositions.

FINAL THOUGHTS

Reading a graph requires paying attention to the details of the graph, including what variables are plotted against each other, whether the variables are correlated, and the slope of that correlation. Most important, reading a graph requires paying attention to what the graph means in the real world. In science, graphs are not simply abstract numerical constructs. Graphs represent real phenomena, and understanding a graph requires visualizing the real-world meaning of it.

R. T. Rybak, a former mayor of Minneapolis, gave a presentation for the Minnesota Science Teachers Association in 2015. He recalled a story told by a colleague whose daughter taught math first in Los Angeles and then in Minnesota. She was surprised to find that her Minnesota students understood negative numbers much faster than her California students. Rybak associated that difference with Minnesota's cold winters, and the corresponding mental image Minnesota kids have of a thermometer scale that goes both above and below zero. In fair disclosure, we Minnesotans are always on the lookout for reasons to think well of our winters, so maybe we should take the story with a grain of salt, but the value in associating numbers with life experience remains sound.

We might call this life connection to numbers *experiential meaning.* Reading and constructing graphs requires that we connect the content of the graphs to experiential meaning. We need to think about how the graph—its slope, its values—relates to the world around us. We need to help our students do that.

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EXAMPLE ACTIVITY DESIGN

THE IMPACT-CRATERING EXPERIMENT

What to Graph, How to Graph It, and How to Make Predictions

The graphing activity we present here is a continuation of the experimental activity begun in Chapter 2. In Chapter 2, students identified questions to address, developed their experimental methods, made measurements, and organized their results into a table. Here we walk through how to coach students in analyzing and interpreting their experimental data using graphs.[C12]

TEACHER PREPARATION AND PLANNING

Look over the data your students derived from their cratering experiments. Make a graph or two of your own. Which are the independent and dependent variables? On which axes should they be plotted? Would it be better to combine some results onto a single plot? For example, you might plot drop height versus crater size for a variety of different masses or impactor size. Think about how you can encourage and guide your students as they construct their graphs without telling them exactly what to do. Think about any peculiarities in the students' data so you are ready to facilitate discussion when they discover differences between groups.

EXAMPLE PROMPTS AND LIMITING OPTIONS

Taking a Look at the Data

You might get students started analyzing results by asking them to look at their data, still in table form. For example, you might give the following prompts:

- Can you spot any consistent trends?
- What variables appear to affect crater size and in what way?
- Do the trends appear linear or nonlinear?
- Are the results reproducible within each group, meaning are data similar for multiple trials of the same variable?
- Are the results reproducible between the groups that tested the same variable?
- Are the results what you expected?

- Do the data make sense given the experimental observations and conditions?
- If there are differences in results between groups, can you identify possible reasons? For example, did someone measure in different units?

Preparing to Graph the Data

Talk about types of graphs and the kinds of data that are best plotted on them. In particular, talk about the difference between a bar graph (good for data that can be counted and put in bins) versus an *x-y* scatter plot (good for seeing correlations between two numerical variables). If students need a refresher on the mechanics of graphing, you can go through some simple examples. For example, you might ask students the following questions:

- Which axis do you want to plot the variables on?
- Do you want to do one graph with all your data, or more than one graph?
- What scale do you want to choose for each axis?

Note: We don't recommend using computer graphing routines, which choose the scales behind the scenes and make setting up the graph seem like magic, but if your goal is to also teach students how to use graphing software and you can spare the large upfront time to learn the technology, go for it.

Graphing the Data

Have students graph their own results first, then perhaps graph the data from another group that measured the same variables, plotting it on their own graph. This can help bring home the value of clear data table formulation that other people have to read. It also gives students an opportunity to recognize any differences in results between groups. You might also have groups plot the results for other variables measured by other groups. At this point, it's not necessary for students to draw any lines or "connect any dots" on their graphs.

Analyzing the Results

Remind students how to look for trends in their data. For example, you might ask the following questions:

- Does it make the most sense to "connect the dots" of the data, or does drawing a smooth line (or curve) of best fit through the data make the most sense?

- If you were to draw a line or curve through your data, would it be linear or nonlinear?
- Can you explain the meaning of the trends you see?
- What does the trend tell you about the relationship between crater size and the variables that affect it?

Help students explore the difference between one group's results and the results from another group who experimented with the same variables. Can they identify causes of the differences? Group members often respond to this kind of question by saying "we measured wrong." Encourage students to think beyond this simplistic response. Let groups show one another how they arrived at their measurements. Prompt students' discussions with these questions:

- Might someone have inadvertently introduced a new variable?
- Might differences in results be due to the coarseness of your measuring tools or differences in the way groups chose to do their measurements?

Help students develop a feel for the experimental uncertainty in their measurements. You might prompt them with these questions:

- Based on the scatter in your data, how reproducible are your results?
- Would a line or curve of best fit go exactly through each point, or would the line or curve take a path between points?
- What does this mean about the measured values?
- If there is a large amount of scatter compared with the overall trend, what does that mean for your confidence in the trend?
- If there is a lot of scatter in the data around a trend, what does that mean for your confidence in the exactness of the measured values?

The Big Challenge—Making a Prediction

Valid science makes predictions that can be shown to be either true or false. Discuss the idea that if their experiments show a causative relationship between variables, then they should be able to predict an outcome that was not directly tested in the experiments.

Tell students you are going to drop a ball of mass *X* from height *Y*. Give groups enough time to consider their graphs and data table and to write down their predictions for how big the new crater will be. You can do this for several different masses and drop heights.

We suggest considering only one variable at a time for any one prediction. For example, if a group varied the mass of impactors, not drop height, you would choose an impactor with a mass that is different from the ones the students used, but the same drop height. If a group varied drop height, but not mass, then choose a drop height different from their experimental ones but using the same mass. Maybe for one prediction you could mix it up by changing multiple variables and having them interpolate.

After each prediction, do the experiment two or three times and measure the crater diameter for each. Perhaps measure the crater diameter in two directions for each experiment. Calculate an average of the multiple measurements so students understand the idea that repeated measurements decrease uncertainty. Tell the students the results and direct them to compare the measured value with their predicted value. Discuss how close the predicted value needs to be to the measured value to still be counted as "right." For predictions that are way off, discuss possible explanations for the difference.

For scoring and grading, you might choose the "right" answer to be anything within 10% or even 20% of the predicted value. No one will ever predict the crater size exactly (you can't even measure it exactly). This provides another chance to discuss experimental uncertainty if you choose. You can give credit for the accuracy of their prediction, giving higher scores to those who are closer, say in increments of 10%, which gives the students some "skin in the game" when they make their predictions.

EXAMPLE INTERACTION

Student question: When I draw the line on the graph do I just connect the dots?

Teacher prompt: Do the dots fall exactly along a perfect line or curve?

Student observation: Well, sort of, but they kind of bounce around a bit. The dots don't really line up.

Teacher prompt: Do you think the not lining up reflects how velocity really affects the size of the crater?

Student interpretation: I think the bouncing around is probably because we didn't measure it exactly right.

Teacher prompt: Why do you think that?

Student reasoning: Well, we redid this one experiment and one measurement is higher and the other measurement is lower, so it doesn't seem like it's a real difference.

Teacher prompt: So do you think that connecting the dots gives you a better measure of how the real world behaves, or would a smooth curve do that?

Student conclusion: Probably the smooth curve.

SUMMARY CHECKLIST FOR TEACHER AS PRACTITIONER OF SCIENCE

- Plan time for students to discuss the meaning of their data *before* they start graphing.
- Review types of graphs and talk about how and what to plot, depending on students' background knowledge.
- After students graph their own data, plan for discussions on what the graphs and data mean in terms of what students experienced and observed during their experiments.
- Have students use graphed data to predict new impact crater sizes.
- Find some way to give students some skin in the game—for example, through grading or class challenges.

TEACHER REFLECTION

Consider ways to use your students' newly exercised graphing skills in future units and lessons. For example, you might have students sketch conceptual graphs given a basic understanding of natural variations. How will air volume change as the temperature of air increases; what will the graph look like, in concept? Or you might take graphical data from real research or something in the news and have students interpret what the graphed data are telling us.

Tie your students' experimental research to the big ideas and driving questions on which your curriculum is based. In what ways can your students' experimental analyses help them make sense of natural phenomena? For example, this cratering research project ties to our big idea that planets have a history of change; it also ties to the *NGSS* disciplinary core idea ESS1.C that we can learn about the history of our solar system by looking at asteroids, meteorites, and the cratered surfaces of other planetary bodies.

Learning to Read the EARTH and Sky

Explorations Supporting the *NGSS*

GRADES 6–12

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Grades 6–12

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DIVE IN!

IMMERSION IN SCIENCE PRACTICES FOR HIGH SCHOOL STUDENTS

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Contents

PREFACE

The Graduate STEM Fellows in K–12 Education Program was initiated in 1999 by the National Science Foundation as part of an "effort to renew the Nation's science, mathematics, and engineering workforce" and to create a bridge between K–12 education and colleges and universities (AAAS 2011, p. 7). The Partnerships for Research Opportunities to Benefit Education (PROBE) project at the University of New Hampshire (NSF GK-12 0338277), funded in 2004, was one of some 299 projects supported over the program's more than a decade of funding. PROBE began as a program to help advance inquiry-based teaching strategies at the secondary level. The goals for the program were based on the national recommendations at the time as set forth in such documents as the *National Science Education Standards* (NRC 1996) and *Inquiry and the National Science Education Standards* (NRC 2000). At that time, although state and national standards were calling for the integration of inquiry-based teaching, it was not clear to teachers how these methods could or should be implemented in the classroom. The PROBE project took this as an important premise and identified that one of the primary issues was that most secondary science teachers had not had authentic research experiences. Thus, the teacher–scientist partnership was born, aligning teachers with graduate student scientists to assist in the growth and enrichment of science teachers with very little scientific research in their educational backgrounds. At the same time, the graduate students, as future faculty, were learning how to become better communicators of their science and skills critical for effective teaching. The graduate students represented a variety of STEM disciplines and the corresponding investigative practices inherent in those areas. The collaborations further deepened the teachers' experiences and added to the stories of how the partnerships developed their science teaching strategies over time.

Although the PROBE project took place almost a decade before the release of the *Next Generation Science Standards* (*NGSS*), we feel that the experiences of the graduate student and teacher participants are being replayed in many classrooms across the United States today. Science teachers are working hard to develop more authentic strategies for students to learn science by coupling science practices and crosscutting concepts with high-leverage content in pursuit of a multidimensional approach to science learning. Teachers are learning to turn the classroom environment into an active learning lab for their students by releasing more ownership of that learning to the students. This is a difficult dilemma for teachers who may have been accustomed to fully controlling the teaching environment and carefully releasing the concepts to students in an orderly fashion. Many teachers wonder if they will be successful in making the change: Will the change be worth it, will they be able to cover the same amount of material, will they lose control of the classroom, how will they assess this type of learning, and what will colleagues think? Control of the teaching paradigm was how teachers typically learned from their own precollege and university faculty. As students, they experienced many content-based lectures and carefully planned labs with specific directions that assisted them in validating concepts and examinations that required a great deal of recall. It was not until graduate school that these teachers might have had the opportunity to ask their own questions, design their own experiments, and conduct the necessary analysis to arrive at an outcome. The type of teaching advocated by the *NGSS* still requires control of the environment and safety diligence; however, it emphasizes that the discovery of the conceptual ideas can be accomplished in multiple ways.

The examples and stories provided here have the potential to assist the current transformations toward the *NGSS* with descriptions of real classrooms and real challenges that are likely to occur. The data collected during the PROBE project were not focused on assessing student knowledge. Rather, the data reflected in this volume tell the story of the teachers' growth and their perceptions of changes in student attitudes toward and engagement with science. We hope the vignettes assist both new and more seasoned teachers with tactics to advance learning and reflect about how students are likely to respond. The stories within these chapters are real. They are not perfect renditions of the *NGSS*. They are a view into the start of some very dedicated teachers diving into a new and complex educational concept where teachers and students are learning and practicing science together.

The PROBE project reaffirms the potential of relationships between teachers and practicing scientists to be constructive and generative in the advancement of students as scientific learners. Perhaps most significantly, it documents the importance of inviting both teachers and high school students to engage in science learning actively, from the inside, and not just as observers of what has already been done. We encourage you to *Dive In!*

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We would be remiss if we did not also extend our gratitude to the other Partnerships for Research Opportunities to Benefit Education (PROBE) graduate student scientists, secondary science teachers, and University of New Hampshire (UNH) undergraduates who may not have written a specific lesson or vignette but contributed to the stories and lessons learned and described throughout this book by being actively engaged in the project and committed to the improvement of the learning and teaching of science for all students. We appreciate your dedication and the generosity of your schools and students throughout this process (see list of names and schools on p. x). You are amazing educators and it has been a privilege to work with all of you!

UNH faculty served as project co-principal investigators, as PROBE steering-committee members, and as research advisers to the PROBE graduate students. Other faculty opened their labs and classrooms to the PROBE teachers and students during the course of the project. We particularly appreciate the time and dedication given by the steering committee members, Drs. Eleanor Abrams, Christopher Bauer, Sonia Hristovitch, Brad Kinsey, Dawn Meredith, Subhash Minocha, Barrett Rock, and Charles Warren. Your enthusiasm for science and commitment to outreach contributed to the success of the project, and you served as excellent role models for all participants.

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We have learned an incredible amount throughout this process and are thankful for the opportunity. We hope that readers will find the experiences helpful as we work to improve science education for all students.

Sincerely,

Karen J. Graham

Lara M. Gengarelly

Barbara A. Hopkins

Melissa A. Lombard

PROBE Partner Schools

Goffstown High School
Goffstown, NH

Nashua North High School
Nashua, NH

Newmarket High School
Newmarket, NH

Nute High School
Milford, NH

Pittsfield High School
Pittsfield, NH

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Raymond, NH

Salem High School
Salem, NH

Sanborn Regional High School
Kingston, NH

Somersworth High School
Somersworth, NH

Spaulding High School
Rochester, NH

Timberlane Regional High School
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Matt Endrizzi

Sue Garabedian

Pat Gaudet

Michelle Gibson

Chrisse Henner

Michelle Holland

Tom Koch

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Lara M. Gengarelly, PhD, was one of the science education researchers on the Partnerships for Research Opportunities to Benefit Education (PROBE) project and the coordinator of the manuscript-writing "project" that forms the basis of this book. Dr. Gengarelly is currently a science literacy state specialist with the University of New Hampshire (UNH) Cooperative Extension and an affiliate associate professor with the UNH Joan and James Leitzel Center for Mathematics, Science, and Engineering Education. She has taught science in both elementary and secondary schools. Dr. Gengarelly was a faculty member in the UNH Education Department from 2004 to 2014, where she taught and supervised undergraduate and graduate preservice teachers. She works on science education projects that involve partnerships between scientists and K–12 teachers, such as the GLOBE (Global Learning and Observations to Benefit the Environment) Carbon Cycle Project; provides professional development for teachers; and designs curriculum, such as for the Student Climate Data Project. Dr. Gengarelly's current research investigates the underlying factors of professional development that can help educators create learning experiences that ultimately improve learners' science literacy and attitudes toward STEM disciplines. She is particularly interested in studying how to increase the integration of authentic scientific research practices in K–12 formal and informal settings.

Barbara A. Hopkins, MEd, CAGS, was the project director for the PROBE project. She is the director of science education for the state of New Hampshire. In her former position, she was the assistant superintendent for multiple school districts (K–12), where she focused on advancing curriculum, instruction, and assessment. She taught chemistry for several decades and developed the Advancing Science instrumentation program as her Christa McAuliffe Sabbatical project. Ms. Hopkins received a Presidential Award for Secondary Science Teaching and the first New Hampshire Distinguished Educator Award. She was the director of the UNH IMPACT Center, which transformed into the Joan and James Leitzel Center for Mathematics, Science, and Engineering Education, where she served as the associate director. She co-authored the National Institutes of Health–funded BRIN (Biomedical Research Infrastructure Network) project, advancing the science research pipeline in New Hampshire and other grants supporting inquiry science teaching practices. Ms. Hopkins served on the 2009 National Assessment of Educational Progress Science Framework Planning Committee and developed an engineering curriculum for elementary students known as KEEPERS. In 2016, she received the New Hampshire Outstanding Service Award for her leadership and work in public education. She recently completed her course work as a doctoral student in the UNH Education Department's Policy and Leadership program.

Melissa A. Lombard, PhD, was one of the lead graduate-student scientists (GK–12 Fellows) for the PROBE project. Dr. Lombard is currently a lecturer in the Department of Earth Sciences at the University of New Hampshire and a licensed professional geologist in the state of New Hampshire. As a graduate student, she was a PROBE fellow and TESSE (Transforming Earth System Science Education) fellow (NSF GEO-Teach 0631377), working with high school and middle school science teachers to develop and implement lessons incorporating the science practices. She has taught geology to undergraduate students for several years and previously worked as a geologist in the environmental industry. Her primary research interests are characterizing contaminants in groundwater and the atmosphere. She remains interested and active in working with K–12 science educators.

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2

A GRASSROOTS EFFORT

COLLABORATIONS TO ENHANCE SECONDARY SCHOOL STUDENTS' ENGAGEMENT WITH THE SCIENCE PRACTICES

The purpose of this chapter is to introduce you to a variety of collaborations that help secondary school teachers with science practice integration (SPI). Each vignette included in this chapter illustrates different ways collaborating partners work to support science teachers, all of which are feasible for science teachers working to incorporate authentic science investigations and *Next Generation Science Standards* (*NGSS*) science practices in their courses (NGSS Lead States 2013).

Given that instruction focused on SPI is often a new experience and takes teachers outside of their comfort zone, teacher collaboration can support this shift to an innovative way of teaching science (Anderson 2007; Duschl, Schweingruber, and Shouse 2007; Ermeling and Yarbo 2016; NRC 2012). Research indicates that "when teachers are given the time and tools to collaborate they become life-long learners, their instructional practice improves, and they are ultimately able to increase student achievement far beyond what any of them could accomplish alone" (Carroll, Fulton, and Doerr 2010, p. 10).

The following vignettes describe a range of collaborations, some of which originated from the Partnerships for Research Opportunities to Benefit Education (PROBE) project (i.e., teacher–scientist [TS] partnerships) and others generated by high school science teachers, to support implementation of SPI in the high school science classroom.

- An Earth science teacher describes the benefits of her collaboration with a graduate-level scientist and with university faculty that supported her ability to facilitate her students' use of science practices ("Why I Love Teaching Science Investigations With the Support of Others: A Medley of Collaborations That Bring Science Practices to Life").
- An Earth science graduate-level scientist discusses her partnership with an Earth science teacher and other colleagues that resulted in an engaging geology activity that explored one role of minerals in society ("Making Paint With Minerals in a Geology Classroom: How Collaboration Links Science Learning and Society").

- A physical science teacher shares his collaborative teaching approach that includes other colleagues in his high school and graduate-level STEM lessons ("An Interdisciplinary Collaboration: Physical Science and Mathematics").
- A biology teacher illustrates her multidimensional collaboration among colleagues at various high schools, university faculty, and graduate-level scientists ("Worm Watch: Partnering With a University Lab to Engage Students in Science Practices").
- A faculty scientist who has been partnered with K–12 teachers since the 1980s discusses his graduate student's collaboration with a high school teacher and the benefits of TS collaborations ("TS Partnerships: A UNH Faculty Perspective").

All the vignettes in this chapter highlight the importance and feasibility of collaborations that support the teachers' use of SPI in the secondary science classroom. These collaborations are mutually beneficial to the parties involved, which helps sustain partnerships for extended time periods. One way of developing these collaborations originates from university faculty who conduct grant-funded, science-related research that includes outreach opportunities, such as partnerships with local high school teachers. Another source of these collaborations consists of secondary school community teams that address best practices of teaching science through professional development opportunities. The possibilities for collaboration among educators are diverse and vary depending on the needs of each party involved.

It is our hope that these vignettes will introduce you to what is possible and motivate you to form your own collaborations within or outside of your local school community to enhance opportunities for SPI in your learning community. Whereas some types of collaborations are supported by external funding (e.g., grants), others use existing resources. This chapter includes recommendations that are feasible in most school settings for forming your own collaboration, many of which do not require external funding. To generate some dialogue about this topic, we also include questions for reflection and discussion. In addition, potential resources, including national organizations that promote and facilitate TS collaborations, are integrated throughout the chapter and are listed in the suggested resources in Appendix A (p. 275).

VIGNETTE 1

Why I Love Teaching Science Investigations With the Support of Others: A Medley of Collaborations That Bring Science Practices to Life

MS. PRESTON, EARTH SCIENCE TEACHER

Many years ago I read an article in which university professors questioned what high school teachers were teaching their students. The university professors claimed that when students came to the university, they had to be remediated in almost every subject area. At the time, I was a brand-spanking-new science teacher at a public high school. I vowed that if I ever had a chance to work hand in hand with a university or college, as a high school teacher, I would make the connection and work hard so that both sides would benefit. I had that chance a few years ago when I decided to join the PROBE program during its second year at my high school.

I had watched a colleague of mine, Ms. Bursaw, succeed in bringing scientific practices into her classroom with the assistance of a PROBE graduate-level scientist for one year, and I felt like my participation was truly something that would benefit my science students and me. I filled out the necessary paperwork and committed to spending time learning about science practices, working with a graduate student "fellow," and thinking a bit out of the box. The experience was extremely rewarding for all parties. In fact, that year I had a student literally rise up out of his seat and proclaim, "I want to do THAT!" when a graduate-level scientist presented his magnetic research on the Sun. Coincidentally, the same student happened to be in a Saturday morning detention a few weeks later, and what do you think he was reading? *Astronomy* magazine! I knew we had succeeded.

The experience of working in the unknown, of teaching by doing science with my students, did not come easy. I was fortunate enough to work with a patient, kind, and enthusiastic graduate-level scientist, Melissa. You see, graduate students are very accustomed to working in the unknown of scientific research! I considered Melissa my equal in the classroom and more of an authority on components of the content and science investigation process we were teaching. We met during an intensive weeklong summer institute and further developed our partnership over the school year while Melissa worked part time in my classroom. Both of us wanted a successful outcome, and we respected each other's points of view. I believe these characteristics helped with the transformation toward greater use of authentic science practices in the classroom.

Melissa came to our class with new ideas, and she knew where to locate information that would help us create engaging lessons for the students. A simple example is one lesson in which the students were charged with debating aspects of the big bang theory. Since I was not well versed in debate rules and execution, Melissa quickly found a template we could model in our classroom. The students took the lesson seriously. At the end of the debate lesson, we surveyed the class and asked the students to rate our success on this lesson. This was particularly daunting to me, because the students had an opportunity to "grade" us! I was pleasantly surprised to find out that, overall, the students felt they had learned a lot about the origin of the universe. They also enjoyed the opportunity to think like scientists and defend their ideas with evidence to make persuasive arguments.

Another key point that Melissa's research experience helped us with was appropriately referencing resources. Melissa approached our librarian to discuss which citation format was recommended for our students. She shared with our students a popular format that our English teachers require. We encouraged students to use the format in any situation in which they were researching outside sources and communicating their findings. By focusing on this one issue, we helped my students understand that proper citing of references is generally expected in the real world. I keep this in mind to this day, and I feel that this is one way my original intent of partnering with a university has been fulfilled.

Week to week, Melissa was invaluable as we navigated through SPI. One particular lesson is described in the vignette, "Making Paint With Minerals in a Geology Classroom." During this lesson, Melissa encouraged the students to ask questions and pursue their own research topics. She acted as a role-model scientist for our students, who were implementing science practices for maybe the first time!

In addition to my partnership with a graduate-level scientist, two other opportunities came about because of my participation with the PROBE program and relationship with a university. First, a professor of geochemistry invited me on a sea expedition to the East Pacific Rise. I was particularly interested in this research cruise because I am a former geologist. It is my understanding that when researchers submit grant proposals for funding, they have to include an outreach component. Oftentimes, having public school teachers involved provides the researcher with an advantage in getting funding from federal agencies. In other words, if you are an adventurous teacher, there are opportunities out there for you! In fact, one of my peers is currently applying for a summer ocean adventure. The second opportunity that originated from my relationship with a university was the chance to participate in a summer institute called Advancing Science. This was a weeklong summer course in which we learned how to use some very expensive and technical equipment to help us analyze samples in the classroom. In turn, we were allowed to borrow the equipment from the university for a few weeks at a time to give our students an idea of how science might be accomplished in a real lab.

At the time of the invitation to the real cruise, I was teaching an astronomy class, and we were beginning a unit on spectroscopy. This can be a fairly high-level topic that requires students to analyze the way in which matter emits and absorbs radiation. Exposure to ultraviolet (UV) radiation as a cause of skin cancer is a real-life challenge that sunscreen companies research daily to produce the best product for consumers. These companies use a spectrophotometer in their labs to test their products. Because of my affiliation, the University of New Hampshire (UNH) Advancing Science program, I was able to borrow a UV-Vis spectrophotometer. This instrument measures the absorption and transmittance of UV energy in solutions very quickly and at a high resolution.

Since we were conducting a unit on spectroscopy and I was headed on a research cruise 70 miles off the coast of Costa Rica, I thought it might be useful to ask my students to investigate the effectiveness of a range of sunscreens. Given my students' prior knowledge about radiation and their competency in designing and carrying out investigations, I figured that they would be the best "scientists" for the job. I had several brands, SPFs, and ages of sunscreen available for testing. My students took to the investigation quickly, with great interest in helping to keep their teacher safe in the sun! By creating liquid solutions of the various sunscreen samples and using the UV-Vis spectrophotometer to safely expose the solutions to UV energy, they were able to gather enough data to reach the conclusion that I should use a one-year-old, 45-SPF, "sports" variety sunscreen. Do you know that I was the only person to *not* get sunburned!

Now, you may be wondering how you might also pull off a trip or at least a science investigation like this one. For example, how would you re-create the lesson if you did not have any relationship with a university or college? Well, because educators are extremely resourceful, we realize that there are many ways to solve a problem. You may not have a UV-Vis spectrophotometer, but inexpensive UV beads (beads that are white indoors and react to UV radiation by changing color, because they have a special nontoxic chemical within them) are available through science catalogs. You can use the beads to get an idea of which sunscreens are better at blocking UV rays by slathering different sunscreens on the beads in petri dishes and exposing them to the sunlight for various periods of time.

Finally, there is a great benefit to collaborations with universities or colleges. Having access to graduate-student scientists, equipment, and partnerships with researchers has allowed me to create interesting lessons with the science practices as a foundation. The PROBE project gave me the opportunity to create a bond with some fantastic professors with whom I can continue to learn and have meaningful dialogue about my subject matter. It is fortuitous that we, as teachers, have recently become valuable partners to our local colleges and universities, and because of this relationship, we are encouraged to create genuine science in our classrooms. When we get to be part of the experience at the university level, our students benefit because we bring opportunities to them in the classroom and, ideally, prepare them for a university science course if they choose that direction. As an added bonus, our students realize that their teachers not only inspire but also bring alive learning through the doing of science. As a result of these collaborations, we become something more than "just a teacher," and our students recognize that others in our community find our profession vital.

The collaborations described by Ms. Preston yielded several opportunities for her secondary school Earth science students to engage in science practices. The debate that focused on the big bang theory is an example of students engaging in argument from evidence. Engaging in argument is one of the new emphases of the *NGSS* science practices (NRC 2012). This kind of critical discourse is essential in the science classroom because "one of the hallmarks of the scientist is critical, rational skepticism" (Osborne 2010, p. 463). As a result, the big bang debate, Ms. Preston's students were developing their reasoning skills and ability to produce scientific arguments.

Beyond the additional science practices that were enacted in Ms. Preston's classroom, the collaboration with university labs and scientists illustrated aspects of the nature of science. For instance, students had the opportunity to learn that scientists frequently rely on technology to support the gathering of data (NGSS Lead States 2013). The UV-Vis spectrophotometer, while not absolutely necessary, was used to facilitate the students' investigation to identify the most effective sunscreen. Also, this sunscreen investigation made a connection to a real-world example, as discussed further in the next vignette, which focuses on mineral resources in our society.

Reflection Questions

1. What collaborations already exist in your school, department, or organization?

2. How can you leverage existing collaborations to bring SPI to your students?

VIGNETTE 2

Making Paint With Minerals in a Geology Classroom: How Collaboration Links Science Learning and Society

DR. LOMBARD, EARTH SCIENTIST[1]

At the conclusion of a geology unit on rocks and minerals, the secondary school science teacher with whom I worked, Ms. Preston, and I decided to conduct a student-directed science activity where the students could apply the concepts learned throughout the unit. Our expectation was that by the end of the unit, the students would have the ability to ask meaningful and interesting questions to build on their recently acquired knowledge and to apply science practices. The unit began with the standard mineral identification labs using color, streak, luster, and hardness to examine differences between minerals. Pulling everything together, we wanted to emphasize the use of minerals in everyday objects. Ms. Preston had the idea of using minerals to make paint, so we explored the possibility of doing this in the classroom.

Ms. Preston had proposed this creative idea, but we didn't know if it was possible to implement this activity in the classroom. Before conducting the lesson with the class, we collected some background information. Initially, we did not even know what materials were necessary. We began by searching for any existing lesson plans about making paint and found nothing in geology textbooks and very little on the internet. In general, there were scant resources on the topic, but we did not give up. We decided to use the expertise of other members of the faculty to gain some background knowledge. I talked with an art teacher at the high school, Ms. Stuart, who had an interest in combining science with art. She proved extremely helpful in planning this experience. Based on Ms. Stuart's input, we decided to use as the binding agents linseed oil for oil-based paint and gum arabic for water-based paint. In addition to the classroom minerals we were planning to use for this project, she provided us with powdered mineral pottery glazes such as red iron oxide and copper carbonate. She also provided us with paintbrushes and reminded us that pictures painted with the oil-based paint required a special paper so that the oil would not soak through the paper.

Before we implemented this activity, I experimented with making the gum arabic to the proper consistency and also mixed some of the pottery glazes with the different binding

1 At the time of the PROBE project, Melissa A. Lombard was a doctoral candidate. She now has her PhD (see Contributors, p. xv).

agents to determine approximate amounts of the ingredients to make paint. Having determined that it was possible to make paint using the available supplies, we were ready to try this activity in the classroom.

We decided to present this lesson to our geology class. Our ultimate goal was to guide the students to the idea that they could make paint using minerals. We did not want to present it as a cookbook type of lab with step-by-step directions. Instead, we provided our students with the opportunity to ask questions, explore, develop a procedure, and draw conclusions on their own. The approach we took to introducing the lesson was to do a "fishbowl" activity. Basically, we recruited a few fellow teachers—Ms. Bursaw and Mr. Lee (an automotive technology teacher)—and performed a short skit in front of the classroom. The skit was a fishbowl activity, in the sense that it was designed to look like a casual conversation among the teachers and the graduate-level scientist in front of the classroom. We were acting as though class had not begun, although the bell had rung and the students were in their seats. Of course, we had no idea if the students would pay any attention to what we were saying, but we gave it a try. As the students watched, we enacted the skit using the following dialogue:

> [Ms. Bursaw and Ms. Preston walk into the class just as the bell rings, talking loudly enough for all students to hear.]
>
> **Ms. Preston:** So, I was talking with the art teacher, Ms. Stuart, about enamels in jewelry. She teaches a class this quarter on how to make them, and yesterday I noticed she had on this *beautiful* necklace that was nautilus shaped. I wonder how she came up with the earthy colors?
>
> **Ms. Bursaw:** Well, I have actually made a lot of jewelry in the past, but I have never made enamels. I think it's pretty tough to do. I know that in the past ancient people made colored paints out of berries and bugs.
>
> **Ms. Preston:** Oh yeah! They also used minerals to make different colors. I was online the other day and ran across a website that had pictures of clay sketchings where the people used certain minerals that were soft enough to grind, and they had more vibrant colors than just white, black, and gray. They drew on cave walls, and the pictures are still there today.
>
> [Dr. Lombard walks in with Mr. Lee.]
>
> **Ms. Preston:** (*to Dr. Lombard*) Hey! Where have you been?
>
> **Dr. Lombard:** I was in auto tech because my car is getting pretty old and I need to have a bunch of work done on it. Mr. Lee was explaining to me everything that I needed to have done. Believe it or not, everything I need involves minerals, so I brought him here because we're talking about that in geology!

Mr. Lee: Yeah, a lot of the parts that Miss Lombard needs are made out of minerals. Her car needs new brake pads, which are made with asbestos; she needs some new shocks, which are filled with mica; and she needs some new spark plugs, which use clays and tungsten. Her car is in pretty rough shape—a new windshield because there is a crack in it … . The glass that is used is made out of quartz, just like sand. She also needs some paint where things are starting to rust.

Ms. Bursaw: Wow, that's cool! We were just talking about how to make paint, and I didn't realize all that stuff in your car used minerals, too.

Ms. Preston: No joke?!

Dr. Lombard: Wow, I didn't know paint was made out of minerals!

Ms. Preston: Yup, that's how people made paint a long time ago …

Dr. Lombard: Oh, cool! Do you think we could try to make paint in geology class using minerals?

Ms. Preston: Well … we could … try. I wonder if my class would be up to it? What am I saying? My students are *always* up for a challenge!

[Ms. Bursaw and Mr. Lee start to leave the room.]

Ms. Bursaw: Hey, guys, have fun!

Mr. Lee: Miss Lombard? Call me later on the car.

Dr. Lombard: I will. Thanks so much for your help!

This skit seemed to work in terms of grabbing the students' attention and interest. In fact, later in the day some students asked me about my car because they thought that it really needed all of that work!

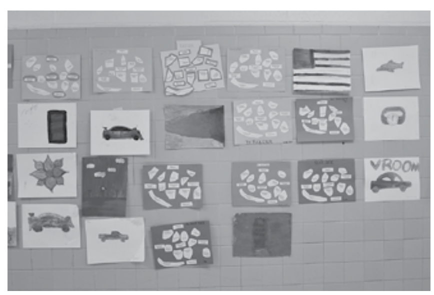
At the conclusion of this skit, we facilitated a brainstorming session in which students shared questions they had about how to make paint with minerals. These questions were listed on the board in the front of the classroom and included the following:

- What kinds of minerals can be used to make paint?
- What minerals produce different colors—red, blue, yellow, and so on?
- How much of a mineral is needed?
- What should we mix to make a liquid (use as a binder)?
- How much money might this cost?

- Where can we get the minerals?
- Are there any safety issues we should be concerned about?
- What elements are in the minerals we can use to make paint?

Following the brainstorming session, the students were directed to work in groups, and each group was responsible for finding answers to one question. We had reserved a classroom set of laptop computers with internet access for the day, and students were allowed to go to the library to obtain and evaluate information. This concluded the first 90-minute-block class spent on this lesson. Students could continue their research that evening and were given more time at the beginning of the next day's class. Then, midway through the second class, each group was responsible for communicating their findings to their classmates. We did this informally and had one or two people from each group give a brief synopsis of their findings, which were written on the board. After each group gave a brief report, Ms. Preston and I also shared our findings. For instance, the group that was responsible for finding information on the binding agents found information about using milk; however, we wanted to avoid this agent because of the potential for bad odors. So we provided information about using the linseed oil and gum arabic as binding agents, and also showed the students the mineral pottery glazes that they could use.

With many, but not all, of their questions answered, the students were given the task to make paint in different colors with the materials we had in the classroom. Their final project was to use the paint to create a picture of an everyday object made from minerals.



Samples of students' paintings using their own mineral-derived paints

The students worked in small groups and became very absorbed in the task of making paint. Students spoke to each other about what minerals or glazes they would try and the colors they thought would result. They planned and carried out their procedures. The really exciting part for us was that our students were applying the concepts about minerals we had previously discussed. Discussions arose about a mineral's streak versus its exterior color and which color would be imparted to the paint if the two differed. A contest erupted over who could grind the mineral with the highest hardness. One student was very determined to use hematite (hardness of 5.5–6.5) and a mortar was cracked, but the paint was made. After the two class periods, most of the paints had been made and were sitting overnight to thicken. On the following day, the students used their own paints to illustrate objects derived from minerals. Groups collaborated and shared their different paints so that everyone could use a wide array of colors. Paintings included pictures of jewelry, a battery, a car, and even an airplane.

Ms. Stuart, the art teacher who had offered advice and supplies, stopped by to see the final products. She offered to hang some of the class paintings in the art display case in the school entrance hallway, and several students agreed to have their paintings displayed.

The "Making Paint With Minerals" lesson plan associated with this vignette is included in Chapter 4, p. 132.

At the conclusion of this lesson, we were very impressed with the overall results and the involvement of the students. We really had no idea how the students would react to the fishbowl introduction or the activity of making paint. The geology class was made up of students of different ages and levels of motivation. We did this activity within the first few weeks of the course, and everyone cooperated and seemed excited about participating.

It was very rewarding to see and hear students applying their knowledge and discussing the characteristics of minerals we had previously gone over in class with no prompting from the teacher or graduate-level scientist. The students were encouraged to discover and explore on their own, and they embraced the opportunity to be scientists and do science. The students were really engaged in this lesson and valued the paints they produced. They were truly interested in the project and not just completing it for a grade. One of our students vividly remembered this lesson almost three years afterward.

Collaborating with other teachers in the school not only served as a means of valuable information but also made the fishbowl introduction possible. We were fortunate to be working in a school where the teachers are very supportive of one another and willing to help each other. We wanted to involve the automotive technology teacher to spark the interest of some of the boys in the class. Mr. Lee was happy to spend five minutes with our class at the beginning of the block. Ms. Bursaw happened to have a free block during our class time and was also very willing to assist us in our skit, as she shared our enthusiasm about the lesson. Ms. Stuart offered advice and supplies and was also very interested in the lesson's outcome. Because teachers from other disciplines became involved in the lesson, students were able to conduct a science activity that applied several science practices and showed them that minerals and their uses are widespread. It reinforced the idea that minerals are used in many everyday objects.

In the "Making Paint" vignette, secondary school students' investigation questions arose from both prior knowledge and direct observation of mineral resources in the classroom. Their questions spurred their curiosity and approach to producing paint from raw materials. In this way, the students drove the learning experience and took some ownership for the direction of the investigation.

During the activity, students worked in small groups to accomplish the task of making paint. This use of teamwork in a science classroom resonates with the way professional scientists work. "Studies … show science is fundamentally a social enterprise. Scientists talk frequently with their colleagues, both formally and informally. Science is mainly conducted by large groups or widespread networks of scientists" (Michaels, Shouse, and Schweingruber 2008, p. 4).

What is probably most important, however, is that as a result of the "Making Paint" collaboration these students had a chance to work with a real-world example in their science classroom and understand that science is part of society. One of the guiding principles of the *Framework* is a linkage of science learning to students' interests and experience (NRC 2012). According to the *Framework*, "in order for students to develop a sustained attraction to science and for them to appreciate the many ways in which it is pertinent to their daily lives, classroom learning experiences in science need to connect with their own interests and experiences" (NRC 2012, p. 28). Dr. Lombard describes in "Making Paint" the students' strong motivation when making sense of information to produce paint and when explaining how common materials in our society are derived from mineral resources.

Reflection Questions

1. What are some potential collaborators or types of collaboration in your community available to you (e.g., local science museums, Cooperative Extension scientists, National Park naturalists, state agencies, citizen science projects; see "Suggested Resources")?

2. Keeping in mind your available resources, in what way can you generate a mutually beneficial, ongoing partnership that supports your goals as a science educator?

VIGNETTE 3

An Interdisciplinary Collaboration: Physical Science and Mathematics

MR. O'REILLY, PHYSICAL SCIENCE TEACHER

Have you ever thought about doing some of your science teaching in collaboration with others? Maybe you could work with a music teacher when teaching sound or with an art teacher when teaching color. How about the chemistry of art? Wouldn't it be great if you could obtain some help from outside your school? One of the benefits of the PROBE program was that it allowed me to work closely with a graduate-level scientist, Dan Seaton, from a local university and occasionally with a graduate-level mathematician from the same university. As I progressed through my first year of SPI with Dan's collaborative support, I shared these new methods with any fellow physical science teachers who also wanted to be involved.

My school had block scheduling, which consisted of four 90-minute classes per day. Physical science was a half-year course of two quarters. One of my goals as a science teacher was to create an integrated Algebra 1/physical science class. This would be a full year's endeavor where a block's time would be split, with about 22 students switching between each of the two classes. A challenge was given to the guidance department to find enough students whose schedules were compatible with this new arrangement. We were fortunate to identify 44 students for this new course.

The mathematics colleague with whom I partnered for the integrated class had suggested this idea a few years earlier, but there never seemed to be enough time to do the actual planning. The PROBE initiative afforded both assistance and motivation to implement this integrated course. The four of us (myself, the mathematics instructor, the graduate-level scientist, and the graduate-level mathematician) not only collaborated to enhance the investigations included in our classrooms but also worked together to co-create a schedule for physical science and Algebra 1 that maximized the commonalities of each curriculum. From the physical science perspective, we looked at when the students would be taught specific mathematical skills. If necessary, I rescheduled some labs to coincide with the mathematics curriculum. One specific example was an investigation that required students to calculate the density of certain materials using the slope of a graph. With many classes, I had to stop and explain how this was calculated mathematically. In my integrated class, the mathematical skills were already in place, which saved me time. It also showed the students that there were practical uses for the mathematics they were learning. The mathematics teacher and I met frequently to plan our upcoming schedules. If either of us needed a full 90 minutes for a specific day, the other would plan accordingly. For a lab about motion, we combined the two classes and both facilitated the lesson. There were many benefits to this integrated class. In the end, I was able to cover just as much curriculum with greater depth and understanding.

Universities today recognize the need to inspire local students in the area of science and mathematics. As a result, universities and colleges often have outreach programs and grants to support and partner with local and regional schools in the area of science and mathematics instruction. The same could be said of many industries that may provide materials, funds (some actually include this type of funding in their budgets), and technical personnel. I encourage you to discover the community resources available to you to enhance your science curriculum. You may form an ongoing partnership. I continued corresponding about scientific investigation ideas with my graduate-level scientist, Dan, long after we finished our year working together.

For ideas for potential collaborators or sources of collaboration see the suggested resources in Appendix A, p. 275.

Mr. O'Reilly illustrates an interdisciplinary collaboration between his physical science class and a colleague's mathematics class. The new vision for science education put forth by the *Framework* emphasizes the importance of using mathematics and computational thinking in the context of science content (NRC 2012). Vignette 3, "Interdisciplinary Collaboration," shows one such example that was feasible in a public high school in New Hampshire. This example reminds us to consider working with a peer outside our own discipline, including colleagues teaching other STEM disciplines and others such as English language arts teachers.

Reflection Questions

1. Support from school administrators helps collaborative teams achieve their goals. Identify the key school leadership members and ways you could elicit their support for the collaborative efforts you have initiated.

2. Professional learning communities (PLCs), are groups of teachers and administrators in a school who meet on a regular basis to share, discuss, and reflect on new strategies or current ideas implemented in the classroom. In what way could you use the PLC model to promote more collaboration among STEM teachers interested in SPI?

VIGNETTE 4

Worm Watch: Partnering With a University Lab to Engage Students in Science Practices

MS. BURSAW, BIOLOGY TEACHER

The Worm Watch project began at the request of a teacher colleague who wanted her biology students to study nematodes (*Caenorhabditis elegans*). These particular species of nematode are tiny and best viewed through a dissecting scope. To begin developing our Worm Watch project, we investigated who was conducting nematode research at our local university and who would be willing to help. This is how we were introduced to Dr. Charles Warren and his lab at UNH. Dr. Warren's lab was working with RNA interference (RNAi) to turn genes off to determine what the genes controlled. Shortly after initial introductions, a workshop was organized for teachers who were interested in working with nematodes and RNAi. There was much interest among my colleagues. In the end, a core group of teachers formed.

The primary challenges to implementing this new scientific research into the classroom, for me at least, were time and understanding. RNAi and care of *C. elegans* were totally new. This meant that I needed to learn about how RNAi worked and how *C. elegans* were to be maintained. This seemed rather daunting, as there were specific procedures to follow with time constraints regarding the daily maintenance of the worms. Additionally, the media they grew on were much more complex than the nutrient agar for growing bacteria with which I was familiar. I carved out time to learn about RNAi and *C. elegans* as well as to learn about the materials and protocols regarding the care of the worms.

Many teachers do not realize how willing many college professors are to help high school teachers and students. They just need to be asked. Dr. Warren was terrific. He invited us to his lab for lessons on how to make the media and how to handle the worms. We learned the importance of

> It is important to keep in mind that some research scientists include K–12 outreach efforts in their scholarship and are a better fit as a collaborator than others. Finding the right fit is key. There are university and professional organizations designed to assist teachers in locating the right fit (see Appendix A).

handling the worms correctly. We also learned how to make worm selections so we could show our students how to do the same. He assigned one of his graduate students to be our liaison for materials and questions when we could not reach him.

Some of the teachers in the group were also lucky enough to have a PROBE graduate-level scientist working with them in the classroom. I was lucky to have Michelle as a graduate-level scientist, whose knowledge and lab skills in this area far surpassed mine. Ms. Foster, a teacher from a nearby high school, had the assistance of Mike, another graduate-level scientist.

One of the more daunting parts of the project was preparing the media that the worms needed. There were several components that needed to be added to the agar. High school teachers always need to be frugal with their budgets. We ordered materials in larger quantities as a group to stick to our classroom budgets. Then, a colleague figured out a way to distribute all the materials among the teachers and suggested that we have a "cocktail party" where we would all meet and divide up the supplies. So, on a Friday afternoon, four colleagues and I went to the high school where Ms. Foster teaches. Mike and Ms. Foster had planned things out ahead of time. Some materials just had to be weighed and apportioned into containers. For others, solutions had to be made before being divided up. Mike had done all of the calculations for the amounts we would need. We each claimed a chemical and got busy. Dr. Warren stopped in to see how we were doing and to answer any questions we had. While this was a major endeavor, it was much less time consuming than it would have been for any one of us to do individually.

Worm Watch was a long-term project in the classroom. The goal was to try to silence genes in the nematodes using RNAi. The RNAi would be introduced to the worms via the bacteria that they use for food. Dr. Warren's lab provided us with a library of bacteria, which contained the RNAi that would interfere with the transcription of certain genes. The result of this would be similar to a mutation in the DNA. Each group of students needed to culture the bacteria with RNAi, and then feed it to their worms. Then we would see if the expected change occurred and/or whether any other abnormalities developed. This provided the students with a wonderful opportunity to learn about RNAi, culture *C. elegans,* and develop their lab techniques while doing real scientific research. Any unusual finding we would report to Dr. Warren's lab.

Throughout the project, we made sure the students engaged in SPI. For instance, the students prepared the media that they were going to use. This was an important part of carrying out an investigation for two reasons. First, it saved a lot of prep time after school. Second, and more important, it gave the students the experience of following a scientific protocol with accuracy to produce media. This gave them ownership. At least one or more students commented in their evaluations of the project that they really felt like a scientist because they had done everything from start to finish, including making their own media and pouring their own petri dishes.

The value of teaching a project such as this one is that it was a great learning experience for both the teachers and the students. The workshops and training sessions counted as professional development hours toward recertification. The students participated in an authentic science investigation, which was very motivating for them. This is also the type of experience that students can mention in their college essays if they are planning to major in science. Since very little was done ahead of time for the students, they were empowered by the experience. Confidence comes from meeting a challenge. Also, they knew that Michelle and I were looking for their feedback. They knew that what they said would be taken seriously and would be shared with teachers at other schools and research scientists at UNH. It was a true partnership.

The moral of the story is that because doing something new is time consuming, you should (1) ask for help at the university level, (2) try to find some like-minded colleagues, and (3) have the students do as much of the scientific work as they are capable of doing.

This vignette is dedicated to the memory of the late Dr. Charles Warren, without whose assistance Worm Watch would never have been successfully undertaken.

Similar to previous vignettes, the "Worm Watch" vignette describes a collaboration among secondary school teachers and scientists that facilitated high school students' engagement with the science practices. In the case of "Worm Watch," a university research lab provided scientific protocols that students had an opportunity to use within their classroom setting. The students also had a chance to share their results with the university lab. Both the use of authentic lab techniques and the communication exchange between the students and research lab were motivating for these high school students. Students were immersed in science practices because they were applying them in context.

One way to locate research scientists who are committed to education outreach and student investigations is through the Global Learning and Observations to Benefit the Environment (GLOBE) program (*www.globe.gov*). The GLOBE International STEM Network (*www.globe.gov/web/globe-international-stem-network*) is an international network of scientists who work with GLOBE students around the world conducting science. Scientists mentor students and teachers, present scientific ideas, and collaborate on scientific research. Furthermore, dozens of scientific protocols for measuring and reporting soil characteristics, biological change, atmosphere and weather, and water quality are available on the GLOBE website, along with online tutorials for their use in the classroom. These are publicly available resources designed for science teachers.

Reflection Questions

1. More recently, online opportunities have multiplied for science educators that connect professional scientists and K–12 educators. For example, GLOBE

provides teachers with the opportunity to use science protocols developed by scientists as well as to report data to the GLOBE website (*www.globe.gov*) to further science research. How can the GLOBE website support your use of *NGSS* science practices and scientific investigations?

2. What are additional online resources for teachers that align with the recent science standards, your teaching goals, and your students' learning goals (see Appendix A)? How could you and your students benefit from these online resources?

VIGNETTE 5

TS Partnerships: A UNH Faculty Perspective

DR. ROCK, PROFESSOR EMERITUS

Ryan Huntley participated in the PROBE program as a graduate-level scientist during the school year while conducting his master's thesis research on the Yucatán Peninsula of Mexico. His research centered on characterizing the spectral properties of jungle vegetation associated with cenotes—sources of water for the ancient Maya—using both field measurements and satellite-based remote sensing data. His PROBE assignment was to assist in teaching a general biology class at a local high school.

As Ryan's faculty adviser, I was fully supportive of his involvement in the PROBE program. Much of my own career has been devoted to developing K–12/16 science outreach efforts at UNH, including Forest Watch (*www.forestwatch.sr.unh.edu*), GLOBE (*www.globe.gov*), Project SMART (Science and Mathematics Achievements Through Research Training; *www.smart.unh.edu*) and Watershed Watch (*http://nia.ecsu.edu/ww/ww.html*). Ryan had been involved in Forest Watch, as both an undergraduate and graduate student, so he had lots of direct experience working with precollege students and was great at working with K–12 students over many years. PROBE added a new dimension to his experience—working with high school students directly in their classroom.

During his PROBE year, Ryan was able to incorporate much of his forestry and remote sensing research experiences into classroom and laboratory activities for the students. Examples of this integration of authentic science into the high school biology class include the use of handheld spectrometers, which allowed students to collect spectral data from foliage during the fall season. He also introduced his students to the use of a pressure gauge to measure changes in water potential in the foliage being studied with the spectrometers. He was also able to bring many Forest Watch activities into the biology curriculum as well. While conducting his own research in the jungles of Mexico, he spoke via Skype to his New Hampshire students, showing and describing field hazards such as scorpions, tarantulas, and ant-plants (small tropical shrubs housing thousands of fiercely biting ants—plants you do not want to come in contact with!). Upon his return from Mexico, he found that his students had developed a new appreciation for their real-life Indiana Jones!

In addition to providing a year of graduate funding, the PROBE program provided Ryan with many benefits, such as representing authentic science at the high school level, gaining self-confidence by working with a wide range of student interests and abilities, improving his self-image by being seen as a "real scientist," and helping his students learn science by doing it. As a graduate-level scientist, doing exciting research, Ryan brought the excitement of discovering new ways to use satellites to hunt for ancient Mayan ruins (the Maya always built the city and temple complexes adjacent to cenotes). Ryan was also working with another of my graduate students, Sam Meacham, who was an adventuresome cave diver involved in mapping flooded underground caves that connected adjacent cenotes. Both Sam's and Ryan's areas of research represent real examples of authentic and exciting science.

One of the challenges Ryan experienced was finding that some of the students coming into general biology were not really interested in the subject matter (or at least didn't want to show interest around their friends). Introducing scorpions, tarantulas, biting ants, and the hunt for ancient Mayan ruins to the classroom seemed to help break through to those simply interested in just getting a grade. Being seen as an Indiana Jones does have its advantages.

Participating in the PROBE program was an introduction to the real world of teaching at the high school level. Ryan was expected to commit to being in the high school classroom and labs two full days per week, a significant time commitment. This level of commitment also presented a challenge from the PROBE student's point of view. Two full days out of each week placed a limit on the amount of time available for Ryan to do his own research, thus lengthening his research program. As Ryan's graduate adviser, I felt that the benefits to the graduate student far outweighed this concern, and that the off-campus time spent in the high school classroom increased his self-confidence and self-worth, resulting in a more mature student who would be more capable of representing UNH once he graduated.

It is important to recognize that making the right match between K–12 teachers and their students and a collaborating scientist can be a challenge for teachers. Oftentimes teachers may be reluctant to seek university research scientists as partners in such a collaborative effort. However, in today's highly competitive federal grant programs (e.g., NSF, NASA, NOAA), research scientists are strongly encouraged (and often required) to include a significant "Broader Impacts" component in proposals seeking grant support for research funding. Including a proposed collaboration with either a K–12 or citizen science effort as an example of such broader impact can often mean the difference between success and failure of the proposal. University researchers may actually seek opportunities to develop such collaborative programs, and today's universities likely have campus programs designed to connect teachers seeking an authentic science experience for their students with researchers interested in developing such a collaboration. At UNH, the Joan and James Leitzel Center for Mathematics, Science, and Engineering Education (*http://leitzelcenter.unh.edu/index.html*) performs this function.

It must also be recognized that not all research scientists can be effective in K–12 collaborations. It has been said that asking a scientist to speak plain English is like asking a cat to bark. Campus centers such as the Leitzel Center can be very helpful in facilitating the right match between interested teachers and effective research scientists. It may be necessary to have help finding barking cats, so that students have a positive experience.

High school science teachers participating in a field-based professional development workshop series hosted by the University of New Hampshire

Based on my own experiences, I know the very positive impact an active scientist can have as a participant in the K–12/16 learning process. Both Forest Watch and GLOBE are examples of such a positive impact. In both programs, active research scientists have become a central part of engaging future generations of K–12 teachers and their students in a regional or global learning community, and they represent a new paradigm for future STEM education efforts.

In my more than 25 years of working directly with K–12 teachers, beginning in 1987, I have been not only privileged to gain a better understanding how they are engaged daily in the process of educating their students, but also inspired by their excitement and enthusiasm resulting from learning new concepts and research-based scientific information to relay to their students. Together, the teachers, along with my graduate students and myself, have become a community of scholars, each learning from the other. I see scientist and teacher partnerships as a two-way learning opportunity that benefits both the scientist and the teacher. I have learned as much from the teachers in Forest Watch and GLOBE about effective teaching methods as they have learned science and its processes from me. Such partnerships are a win-win experience.

Dr. Rock shares the perspective of a research scientist who includes K–12 outreach projects as part of his scholarship and promotes partnerships with K–12 educators to support students' science literacy. While there are numerous examples of TS partnerships, it is important that you identify the scientist and/or program that is the best fit for you and your students. Finding the right fit is key to leveraging a collaboration to achieve SPI.

In our work with various science, engineering, and mathematics departments and professors, we have learned that many, if not most, are very willing to share their expertise. This includes scientists associated with local industries, community and technical colleges, and retired or emeritus deans and professors. Teachers just need to ask! There were countless times when we heard that professors had visited a school or presented at a state science conference, but no one ever followed up with them. This was disappointing to the scientists (professors) and indicated to them that either teachers were too busy or that they lacked the confidence to engage further. We share this to empower teachers to advocate for their needs. Building relationships with scientists does not have to be through a large program or the result of a large grant.

Every year, teachers host parents' nights, and that is a perfect opportunity to ask about their backgrounds. Cities and towns have Chambers of Commerce, Rotary Clubs, or other professional organizations where teachers can go, join, and develop relationships with business and industry representatives. Colleges and universities are everywhere and are very accessible electronically. We also have scientists for neighbors! Why not invite scientists or their graduate students to visit or Skype with your class? Perhaps invite scientists to share their work with students as in a Science Café and then follow up with them. Share your ideas and ask them for their ideas and recommendations. Through these relationships, everyone learns and grows. Most important, you are not doing it alone. And as you continue to learn and be challenged, so will your students!

Reflection Questions

1. Science, mathematics, and education faculty at state and private universities and colleges are involved with numerous efforts to advance K–12 STEM education. Conduct a search of local university projects within your region that promote the most recent science standards, including integration of science practices, for secondary science students. What did you identify?

2. How can you get involved with these potential university partners to support SPI in your classroom?

Conclusion

Several key findings became evident to the TS partnership members with respect to collaboration and are discussed in the vignettes featured in this chapter. First, to form a successful TS partnership, one must identify a collaborator who is compatible. Some research scientists are a better fit than others. Finding the right fit is key. It is fortunate that there are a significant number of research scientists nationwide who, as part of their outreach scholarship, make their research explicit to and accessible to K–12 educators (Vignette 5). In fact, there are university organizations and on-campus programs designed to assist teachers in locating the right fit, such as the Joan and James Leitzel Center for Mathematics, Science, and Engineering Education at UNH (see Appendix A).

Second, we recognize that compatible collaborations between high school science teachers and university or college science researchers are not only feasible but also enrich the teachers' instruction and their high school students' learning experience (Vignette 1). These collaborations vary depending on the parties involved and their ultimate educational goals. Nonetheless, these collaborations prove to be mutually beneficial to all parties. Teachers report benefits to their instruction and curriculum when they have access to an extended base of knowledge and skills. Researchers find value in ensuring that their science is accessible to a wider audience beyond an academic setting and engages K–12 students in real-world investigations. In the specific case of the PROBE project, graduate-level scientists gained the ability to communicate science to a more general audience, improving their confidence as scientists and their overall communication skills.

Third, we also assert that collaborations enhance the learning setting for the high school students and provide them with opportunities to do science with the methods that scientists use to conduct their research. For example, many high school students had a chance to use state-of-the-art laboratory equipment as a result of the university connection. In this way, the collaborations created an enhanced avenue to authentic science investigations that integrate the science practices (Vignettes 1 and 4).

Fourth, we recognize that collaboration allows high school teachers to be more creative. For instance, "Making Paint With Minerals in a Geology Classroom" (Vignette 2) was a creative effort that was made possible through a collaboration among several educators.

Fifth, because of their collaborations with university graduate-level scientists, the high school teachers had greater confidence working outside their comfort zone. As a result, teachers took risks and tried more innovative approaches to teaching, including more student-directed science investigations that integrate the science practices (Vignette 3).

Sixth, we have observed that collaborations between high school science teachers and research scientists make possible applications of learning to real life (Vignette 2). In this way, the classroom experience becomes more relevant in the students' eyes and engages students in a way that far surpasses the generic school laboratory experiments, echoing the vision of the *Framework* (NRC 2012).

Recommendations for Establishing a Successful Partnership

You may be wondering how you can develop a collaboration with a scientist to help enhance SPI in your secondary school classroom. You may be questioning the feasibility without a comparable program to PROBE. Fortunately, there are many ways to make connections and resources available to help you establish a partnership with scientists in your community or online (e.g., nearby university or colleges, local science museums, Cooperative Extension scientists, National Park naturalists, state agencies, and citizen science projects).

To start, identify potential collaborators. Use existing networks (e.g., alumni), contact administrative assistants in specific science departments at local colleges or universities, locate science specialists at your local Cooperative Extension, or connect with a professional organization that facilitates TS partnerships (see suggested resources in Appendix A). The most successful partnerships capitalize on the strengths and expertise of each member. Both parties need to trust one another as a team to be successful. So when identifying a collaborator, keep in mind that compatible partnerships need three things: respect, transparency, and mutual benefit.

Once you have selected the most promising partner, you and your collaborator will identify goals and create activities to realize these goals. Each partner will bring some contribution to the table, sharing the responsibility for achieving the identified goals.

Partnerships often evolve over time. So following an initial period of time, partners should review and revise activities for future efforts. This is referred to as a "feedback loop" of goal setting, planning, self-directed reflection, and evaluation.

Finally, the impact of strong leadership support must not be unmentioned. Collaborative teams who are supported by their school leaders are more likely to be successful achieving their goals, as "effective teams require dedicated time and space for their collaborative work to take place" (Carroll, Fulton, and Doerr 2010, p. 10). So work with your school leaders from the beginning of the process to ensure that you elicit their support when you forge a partnership to enhance SPI.

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DIVE IN!

IMMERSION IN SCIENCE PRACTICES FOR HIGH SCHOOL STUDENTS

A few years ago, veteran high school teachers and graduate-level scientists from the University of New Hampshire engaged in a collaborative study. One of their goals was to explain in detail how teachers and students can make the leap to implementing the recommendations of *A Framework for K–12 Science Education* and the *Next Generation Science Standards* (*NGSS*). *Dive In!* is the firsthand account of the study's illuminating results. By sharing personal examples, intriguing vignettes, and field-tested lesson plans, the book aims to inspire you to immerse your students in active learning—or at least dip your toes into new ways of teaching.

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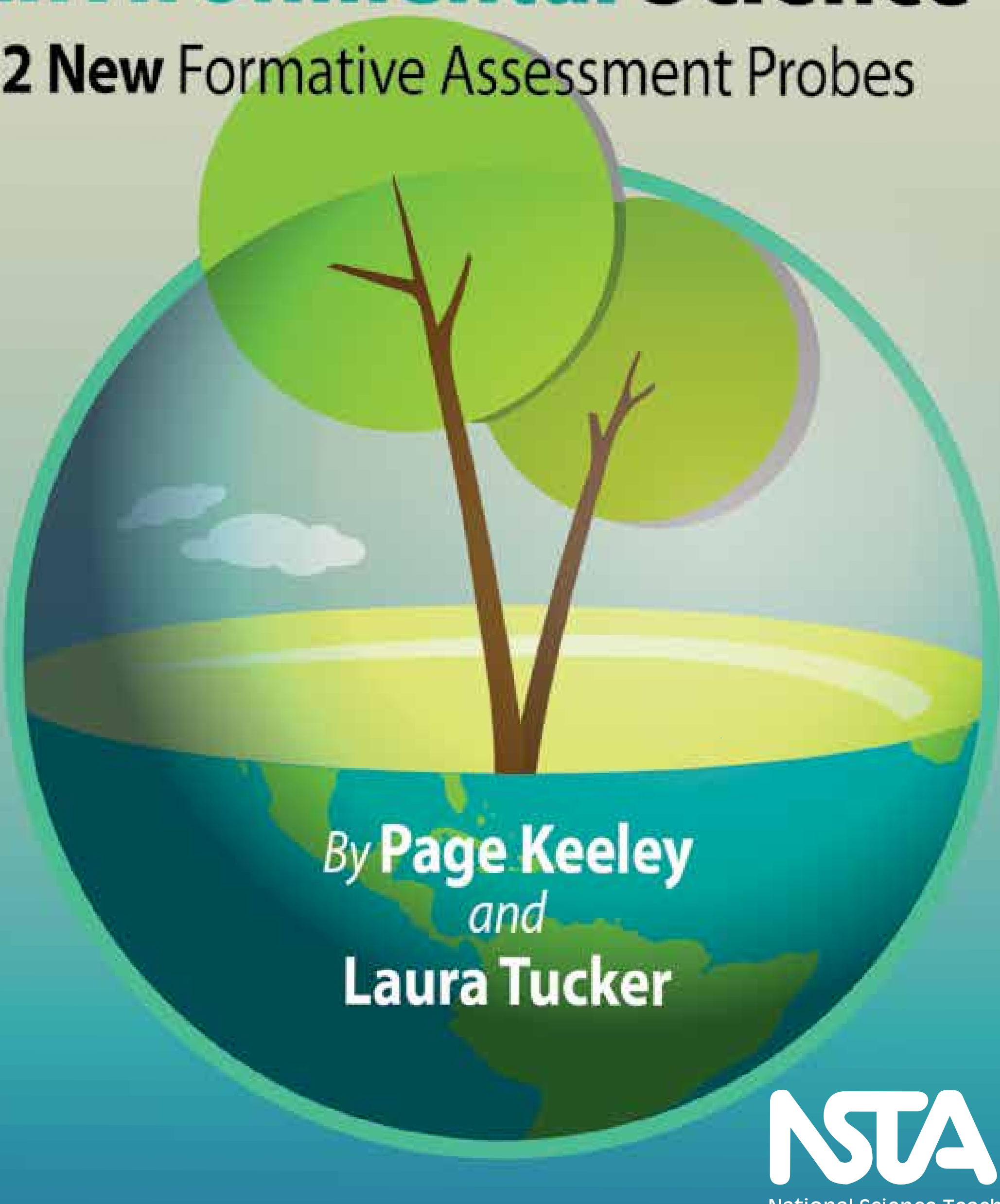

By Page Keeley
and
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Contents

Section 2. Water Cycle, Weather, and Climate

Section 3. Earth History, Weathering and Erosion, and Plate Tectonics

Section 4. Natural Resources, Pollution, and Human Impact

Foreword

In our efforts to use science to improve the quality of our lives, we have learned that our mental models of physical phenomena can be so deeply anchored as to effectively block learning. From the youngest age, we try to explain natural phenomena—the Sun "comes up" in the morning, the Earth casts a shadow on the Moon, rocks are stronger than plants—and we ask questions. Where do birds go at night? How does an acorn become a tree? Why is the ocean cold in sunny Los Angeles but warm in chilly Maryland? Once we have the answers, we tend to hold them fast, regardless of whether what we "learned" was correct.

Many will remember Science Media Group's 1987 video *A Private Universe.* The video revealed that some of our best-educated college students could not apply the science they had learned about familiar occurrences such as the changing seasons or phases of the Moon. The issue identified in the video and in very substantial research is that the presence of misinformation can prevent correct information from taking root. When teaching science, simply presenting the evidence for a more scientifically accurate explanation is not enough. Misconceptions must be explicitly identified to facilitate learning.

The *Uncovering Student Ideas in Science* series addresses this critically important step in science education. With her engaging volumes, Page Keeley gives teachers the tools they need to identify their students' and their own misunderstandings at the beginning of instruction. To ensure deeper learning, she follows up the accessible probes with related research and suggestions for instruction and assessment. *Uncovering Student Ideas in Earth and Environmental Science: 32 New Formative Assessment Probes* is the 10th book of the series and focuses on areas of science where we all have our own misconceptions, such as the formation of rock and soil, the processes of weather and climate, the water cycle, the saltiness of the ocean, and the history of Earth.

As you dive into these probes with your students, I encourage you to keep the importance of addressing misconceptions in mind. The Age of Enlightenment taught us that the use of evidence, logic, and reason—cornerstones of scientific investigation—influences how we understand our world. So ensuring that students have a good understanding of science is far more important than focusing on just memorizing "facts." And given the global challenges we face, science education is fundamental to our survival as a society—and maybe even as a species.

Today, we better understand that human activities impact the whole planet (an idea that many of us find hard to accept). Our role as stewards of the environment is thus more critical than the traditional environmentalist message; the habitat, if not the viability, of our species could be at stake. *Uncovering Student Ideas in Earth and Environmental Science* will help you guide your students in making science-based decisions as responsible members of society. I hope that your emphasis on right scientific thinking will lead to right environmental doing.

—David L. Evans, PhD
Executive Director
National Science Teachers Association

Reference

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Preface

This book is the 10th book in the *Uncovering Student Ideas in Science* series and the first one specifically targeting Earth and environmental science. Like its predecessors, this book provides a collection of unique questions, called formative assessment probes, designed to uncover preconceptions students bring to their learning, as well as identify misunderstandings students develop during instruction that may go unnoticed by the teacher. Each probe is carefully researched to surface commonly held ideas students have about the phenomenon or scientific concept targeted by the probe. Each probe includes one scientifically best answer, along with distracters designed to reveal common, research-identified alternative conceptions held by children and adults.

The 32 probes in this book uncover students' thinking about several of the big ideas in Earth and environmental science. Many of the probes are designed to uncover pre-existing ideas, often developed before the concept or idea is even taught. Therefore, we avoid the use of technical terminology in a probe and instead use everyday language students are familiar with in order to uncover their conceptual ideas that do not depend on knowing vocabulary. Some of the probes are intended for use after a concept or idea has been introduced, such as the collection of plate tectonic probes. For example, students may first need to learn the idea that Earth is composed of several plates before probing students' ideas about the characteristics of Earth's plates.

It is impossible to cover all Earth and environmental science ideas in one book. For this first volume in Earth and environmental science, we chose to focus primarily on ideas associated with strongly held misconceptions that follow students from one grade level to the next, often into adulthood. You may wonder why some ideas such as the rock cycle, energy in the Earth system, flow of matter and energy through ecosystems, and atmospheric ideas are not included in this book. Some of these ideas will be included in other books in the *Uncovering Student Ideas in Science* series. Energy in the Earth system will be covered as a crosscutting concept in the future book, *Uncovering Student Ideas about Matter and Energy.* For the environmental science probes, we chose to focus primarily on natural resources and human impact. Probes related to matter and energy in ecosystems and ecosystem dynamics are included in the collection of life science probes in the other books in this series. *Uncovering Student Ideas in Life Science, Volume 2,* to be released in 2017, will contain additional ecosystem-related probes.

Other *Uncovering Student Ideas in Science* Books That Include Earth and Environmental Science–Related Probes

The following is a description of the other books in the *Uncovering Student Ideas in Science* series to date (2016) that include probes related to Earth and environmental science.

Uncovering Student Ideas in Science, Volume 1 (Keeley, Eberle, and Farrin 2005): This first book in the series contains 25 formative assessment probes in life, physical, Earth, and space science. The introductory chapter of the book provides an overview of what formative assessment is and how it is used. Earth and environmental science probes in this book, along with suggested grade levels and related concepts, include the following:

- "Wet Jeans" (grades 3–12): water cycle and evaporation
- "Beach Sand" (grades 5–12): weathering, erosion, deposition, and beach formation
- "Mountain Age" (grades 5–12): mountain formation

Uncovering Student Ideas in Science, Volume 2 (Keeley, Eberle, Tugel 2007): This second book in the series contains 25 formative assessment probes in life, physical, Earth, and space science. The introductory chapter of this book describes the link between formative assessment and instruction. Earth and environmental science probes in this book, along with suggested grade levels and related concepts, include the following:

- "Is It a Rock? Version 1" (grades 2–5): rock and rock sizes
- "Habitat Change" (grades 3–8): adaptation and habitat change
- "Is It a Rock? Version 2" (grades 3–8): concept of a rock and natural versus human-made rocks
- "Mountaintop Fossil" (grades 3–8): fossils, mountain formation, uplift, and plate tectonics
- "Giant Sequoia Tree" (grades 6–12): photosynthesis and carbon cycle

Uncovering Student Ideas in Science, Volume 3 (Keeley, Eberle, Dorsey 2008): This third book in the series contains 25 formative assessment probes in life, physical, Earth, and space science. It also contains three nature of science probes on hypotheses, theories, and how scientists do their work. The "Is It a Theory?" probe can be combined with the collection of plate tectonics probes. The introductory chapter of the book describes ways to use the probes and student work for professional learning. Earth and environmental science probes in this book, along with suggested grade levels and related concepts include the following:

- "Rainfall" (grades 3–8): rain, precipitation, and weather
- "Rotting Apple" (grades 3–8): decay and decomposers
- "What Are Clouds Made of?" (grades 3–8): clouds and water cycle
- "Where Did the Water Come From?" (grades 3–12): water cycle and condensation
- "Earth's Mass" (grades 5–12): flow of matter through ecosystems and conservation of matter

Uncovering Student Ideas in Science, Volume 4 (Keeley and Tugel 2009): This fourth book in the series contains 25 formative assessment probes in life, physical, Earth, and space science. It also includes two probes that target the crosscutting concepts of models and systems. The introductory chapter of this book describes the link between formative and summative assessment. Earth and environmental science probes in this book, along with suggested grade levels and related concepts include the following:

- "Where Does Oil Come From?" (grades 3–8): fossil fuels
- "Where Would It Fall?" (grades 3–8): land-water distribution
- "Camping Trip" (grades 5–12): Earth's warming and cooling and radiant energy
- "Global Warming" (grades 6–12): global warming and human impact

Uncovering Student Ideas in Life Science, Volume 1 (Keeley 2011b): This sixth book in the series, as well as the first one in the series of life science probes, contains 25 life science formative assessment probes. The introductory chapter of this book describes how formative assessment probes are used in a life science context. Environmental science probes in this book, along with suggested grade levels and related concepts include the following:

- "No More Plants" (grades 2–8): role of producers, food chains, and food webs
- "Is It a Consumer?" (grades 3–8): consumer, food web, and food chain
- "Changing Environment" (grades 5–12): adaptation and ecosystem change
- "Food Chain Energy" (grades 5–12): producers, consumers, and flow of energy
- "Ecosystem Cycles" (grades 6–12): matter cycles and energy flows

Uncovering Student Ideas in Astronomy (Keeley and Sneider 2012): This seventh book in the series contains 45 astronomy formative assessment probes. Many Earth science teachers also teach space science and can use these probes to address the space sciences section of their curriculum. The introductory chapter of this book describes how formative assessment probes are used to understand students' mental models in astronomy. In addition to the astronomy probes, probes included in this book that address students ideas about the nature of planet Earth include the following:

- "Is the Earth Really Round?" (grades 2–5): concept of a spherical Earth
- "Where Do People Live?" (grades 2–5): concept of a spherical Earth
- "Falling Through Earth" (grades 6–8): Earth's gravitational attraction

Uncovering Student Ideas in Primary Science, Volume 1 (Keeley 2013): This eighth book in the series contains 25 formative assessment probes designed for K–2 students. The probes are for early or nonreaders as well as English language learners. They can also be used in grades 3–5 to check for prior knowledge. The probes are visual in nature and designed to be used in a talk format. The introductory chapter focuses on how to use the probes to support science talk and how science talk supports students' thinking. Earth and environmental science probes in this book, along with suggested grade levels and related concepts, include the following:

- "Describing Soil" (grades K–5): soil
- "Is a Brick a Rock?" (grades K–5): rock and natural versus human-made materials
- "What Makes Up a Mountain?" (grades K–5): mountains and rock

Format of This Book

This book contains 32 probes for grades 3–12 and is organized in four sections: Section 1, "Land and Water" (7 probes); Section 2 "Water Cycle, Weather, and Climate" (8 probes); Section 3 "Earth History, Weathering and Erosion, and Plate Tectonics" (12 probes), and Section 4 "Natural Resources, Pollution, and Human Impact" (5 probes). The format is similar to the other nine volumes in the *Uncovering Student Ideas in Science* series. The introductory chapter describes how to use the probes and provides an overview of teaching and learning related to Earth and environmental science. Each section begins with a concept matrix that lists the main concepts that each probe addresses. The matrix also lists the related performance expectations from the *Next Generation Science Standards* (*NGSS*) by grade level and related National Science Teachers Association (NSTA) resources, such as journal articles, books, content webinars, and science objects. These resources provide materials for teachers who wish to extend their learning. The Teacher Notes are one of the most important components of the book and should always be read before using a probe. The following pages describe the features of the Teacher Notes that accompany each probe in this book.

Preface

Purpose

This section describes the purpose of the probe—that is, what you will learn about your students' ideas if you use the probe. It begins by describing the overall concept the probe elicits, followed by the specific idea the probe targets. Before choosing a probe, you must understand what the probe is intended to reveal. Taking time to read the purpose will help you decide if the probe will elicit the information you need to understand your students' thinking.

Type of Probe

This section describes the format of the probe. The probes in this series use 10 different formats. Some of the more common formats are justified lists, friendly talk, and opposing views. The format of a probe is related to how a probe is used. The snapshot vignettes in the Introduction (pp. 1–10) illustrate how a format informs the use of a probe.

Related Concepts

Each probe is designed to target one or more concepts that are often used across multiple grade levels. A concept is a one-, two-, or three-word mental construct used to organize the ideas the probe addresses. Most of these concepts are included in core disciplinary ideas. The concepts are also included on the matrix charts that precede the probes for each section.

Explanation

The best answer choice is provided in this section. We use *best* answer rather than *correct* answer because the probes are not intended to pass judgment on students. Instead, they are used to encourage students to reveal their thinking without the worry of being "wrong." Sometimes there is no single "right" answer because the probe is designed to uncover different ways of thinking. The *best* answer is the one that scientifically addresses the purpose and intent of the probe.

A brief scientific explanation accompanies each probe and clarifies the scientific content that underlies the probe. The explanations are designed to help you identify what the most scientifically acceptable answers are, as well as clarify any misunderstandings about the content. The explanations are not intended to provide detailed background knowledge about the content. They are provided to support teachers' content knowledge; although in some cases, the explanations can be shared with upper middle and high school students as written. Some elementary and middle school science teachers have limited coursework or professional development in science, and some high school instructors teach Earth or environmental science outside of their science major. Therefore, the explanations are carefully written to avoid highly technical language so that you do not have to be a science specialist to understand them. At the same time, the explanations try not to oversimplify the science. Rather, they provide the concise information a science novice would need to understand the content he or she teaches related to the probe. If you need additional background information regarding the content of the probe, refer to the NSTA resources listed for each section to build or enhance your content knowledge.

Administering the Probe

Intended grade levels and suggestions are provided for administering the probe to students, including response methods, ways to use props, the way to demonstrate the probe scenario, modifications for different learners, or use of different formative assessment classroom techniques (FACTs) to gather the assessment data. FACTs are described in the Introduction on pages 3–9.

Related Core Ideas

This section identifies the learning goals described in the two national documents used to develop the learning goals in most states' standards and curriculum materials—the revised, online version of *Benchmarks for Science Literacy* (AAAS 2009) and *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012), of which the disciplinary core ideas were used to develop the *Next Generation Science Standards* (NGSS Lead States 2013). Because those are the primary source documents on which almost all state standards are or will be based after they are revised, it is important to look at the related learning goals in these documents. Because the probes are not designed as summative assessments, the listed learning goals are not to be considered alignments, but rather ideas that are related in some way to the probe. Additionally, the performance expectations related to probes in each section are listed under the concept matrices at the beginning of each section.

Core ideas across grade spans are included in this section. The ideas are included because seeing the related idea that precedes your grade level is useful when using the probe, as well as seeing the core idea that builds on the probe at the next grade level. In other words, teachers can see how the foundation they are laying relates to a spiraling progression of ideas as students move from one grade level to the next.

Related Research

Each probe is informed by related research when available. Three comprehensive research summaries commonly available to educators are the following: Chapter 15 in the *Benchmarks for Science Literacy* (AAAS 1993), Rosalind Driver's *Making Sense of Secondary Science: Research Into Students' Ideas* (Driver et al. 1994), and recent summaries in the *Atlas of Science Literacy* (AAAS 2007) were drawn on for the research summaries. In addition, recent research from science education journals is cited where available. Although many of the research citations describe studies that have been conducted in past decades and studies that include children in not only the United States but also other countries, most of the results of these studies are considered timeless and universal. Whether students develop their ideas in the United States or other countries, research indicates that many of these commonly held ideas are pervasive regardless of geographic boundaries and societal and cultural influences.

Although your students may have had different backgrounds, experiences, and contexts for learning, the descriptions from the research can help you better understand the intent of the probe and the kinds of thinking your students are likely to reveal when they respond to the probe. The research also helps you understand why the distracters are written a certain way. As you use the probes, we encourage you to seek new and additional published research, engage in your own action research to learn more about students' thinking, and share your results with other teachers to extend and build on the research summaries in the Teacher Notes. To learn more about conducting action research using the probes, read the *Science and Children* article "Formative Assessment Probes: Teachers as Classroom Researchers" (Keeley 2011b), or read Chapter 12 in the book *What Are They Thinking? Promoting Elementary Learning Through Formative Assessment* (Keeley 2014b).

Suggestions for Instruction and Assessment

Uncovering and examining the ideas children bring to their learning is considered diagnostic assessment. Diagnostic assessment becomes formative assessment when the teacher uses the assessment data to make decisions about instruction that will move students toward the intended learning target. Thus, for the probe to be considered a formative assessment probe, the teacher needs to think about how to design, choose, or modify a lesson or activity to best address the preconceptions students bring to their learning or the misunderstandings that might surface or develop during the learning process. As you carefully listen to and analyze your students' responses, the most important next step is to choose the instructional path that would work best in your particular context according to the learning goal, your students' ideas, the materials you have available, and the different types of learners you have in your classroom.

The suggestions provided in this section have been gathered from the wisdom of teachers, the knowledge base on effective science teaching, and research on specific strategies used to address commonly held ideas and conceptual difficulties. These suggestions are not lesson plans, but rather brief recommendations that may help you plan or modify your curriculum or instruction to help students move toward learning scientific ideas. It may be as simple as realizing that you need to provide a relevant, familiar context, or there may be a specific strategy, resource, or activity that you could use with your students.

Learning is a very complex process and most likely no single suggestion will help all students learn. But that is what formative assessment encourages—thinking carefully about the instructional strategies, resources, and experiences needed to help students learn scientific ideas. As you become more familiar with the ideas your students have and the multifaceted factors that may have contributed to their misunderstandings, you will identify additional strategies that you can use to teach for conceptual change and understanding. In addition, this section also points out other related probes in the *Uncovering Student Ideas in Science* series that can be modified or used as is to further assess students' conceptual understanding.

When applicable, the Suggestions for Instruction and Assessment section includes safety notes for the proposed activities and investigations. These guidelines need to be adopted and enforced to provide for a safer learning and teaching experience. Teachers should also review and follow local polices and protocols used within their school and school district. For additional safety information, read NSTA's "Safety in the Science Classroom" article (*www.nsta.org/pdfs/SafetyInTheScienceClassroom.pdf*) or visit the NSTA Safety Portal (*www.nsta.org/portals/safety.aspx*).

References

References are provided for the information cited in the Teacher Notes, including the original article referenced in the research summaries.

Formative Assessment Probes in the Elementary Classroom

Formative assessment is an essential feature of a learning-focused elementary science environment. To help teachers learn more about using formative assessment probes with elementary students to inform instruction and promote learning, NSTA's elementary science journal *Science and Children* publishes a monthly column by the author titled, "Formative Assessment Probes: Promoting Learning Through Assessment." Your NSTA membership provides you with access to all of those journal articles, which NSTA has archived electronically. Go to the *Science and Children* website at *www.nsta.org/elementaryschool*. Scroll down to the journal archives, and enter "formative assessment probes" in the keyword search box. This will pull up a list of all of Page Keeley's column articles. You can save the articles in your library in the NSTA Learning Center or downloaded them as a pdf.

Preface

Table 1 lists the journal issue, title of the column, and topic of the column for the articles that have been published to date related to Earth and environmental science. Check back regularly as more articles are added. Professional developers and facilitators of professional learning communities can also use the articles to engage instructors in discussions about teaching and learning related to the probes and the content they teach. In addition, several of the articles are provided in chapter form, along with a link to the probe and discussion questions for professional learning groups in *What Are They Thinking?* (Keeley 2014b).

Table 1. Earth and Environmental Science Formative Assessment Probes: Promoting Learning Through Assessment

Issue	Title	Topic
September 2010	"Doing Science"	Scientific method and how misuse of the "scientific method" affects students' ideas related to the nature of science
December 2010	"To Hypothesize or Not"	Hypothesis making and misconceptions teachers have about the nature of science that can be passed on to students
November 2011	"Teachers as Researchers"	Biological conception of an animal and how formative assessment probes can be used to engage in teacher action research
April/May 2012	"Food for Plants: A Bridging Concept"	Understanding food, photosynthesis, needs of plants; using bridging concepts to address gaps in learning goals; and understanding students' common sense ideas
July 2012	"Where Did the Water Go?"	Using the water cycle to show how a probe can be used to link a core content idea, a scientific practice, and a crosscutting concept
December 2012	"Mountain Age: Creating Classroom Formative Assessment Profiles"	Understanding weathering and erosion and organizing student data using a classroom profile for instructional decisions and professional development
March 2013	"Habitat Change: Formative Assessment of a Cautionary Word"	Adaptation and how formative assessment helps teachers be more aware of the language they use when teaching concepts such as adaptation
April 2013	"Is It a Rock? Continuous Formative Assessment"	Concept of a rock, natural versus human-made materials, and the Group Frayer Model for continuous assessment
September 2014	"Is It a Theory? Speaking the Language of Science"	Scientific theories and how colloquial language affects our understanding of what a scientific theory is
March 2015	"Soil and Dirt: The Same or Different?"	Soil and how our use of everyday language affects understanding of science concepts
April 2015	"No More Plants!"	Understanding producers, food chains, and food webs and uncovering students' ideas about interdependency and ecosystem change
October 2015	"Wet Jeans"	Understanding evaporation and the water cycle and using real world phenomena to uncover ideas
December 2015	"Mountain Top Fossil: A Puzzling Phenomenon"	Understanding how Earth's surface changes over time using a puzzling phenomenon

Preface

Formative Assessment Reminder

Now that you have the background on the probes and the Teacher Notes in this new book, let's not forget the formative purpose of these probes. Remember that a probe is not formative unless you use the information from the probe to modify, adapt, or change your instruction so that students have the opportunity to learn the important scientific ideas necessary for achieving scientific literacy. As a companion to this book and all the other volumes, NSTA has co-published the book *Science Formative Assessment: 75 Practical Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2008, 2015) and *Science Formative Assessment: 50 More Practical Strategies for Linking Assessment, Instruction, and Learning* (Keeley 2014a). In these books, you will find a variety of strategies to use, along with the probes to facilitate elicitation, support metacognition, spark inquiry and investigation, encourage discussion, monitor progress toward conceptual change, encourage feedback, and promote self-assessment and reflection. In addition, these strategies provide opportunities for students to use scientific practices such as modeling, designing investigations, argumentation, and explanation construction.

Finally, the ultimate purpose of formative assessment is to break away from teaching and assessing disconnected facts to support conceptual learning of science. Because conceptual change is the underpinning of the *Uncovering Student Ideas in Science* series, we highly recommend the book *Teaching for Conceptual Understanding in Science,* which includes chapters on understanding the nature of students' thinking, instructional strategies that support conceptual change, and content that links assessment, instruction, and learning (Konicek-Moran and Keeley 2015).

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Dedications

Page's Dedication

I dedicate this book to Christopher Keeley. I am so proud of all the work you do at the University of New Hampshire Sea Grant program to help communities understand and adapt to climate change. I also dedicate this book to Christine Anderson-Morehouse, Jean-May Brett, and Margo Murphy—three long-time friends, colleagues, extraordinary science education leaders, and passionate environmentally concerned citizens in Maine and Louisiana who have worked with and supported me in uncovering student ideas for almost two decades. I am so proud of all the work you continue to do to support students and teachers and help others appreciate and protect the pristine beauty of my former home state of Maine and the Louisiana wetlands.

Laura's Dedication

This book is dedicated to my husband, Hank—my dear friend since 1970, who is a never-ending source of support and encouragement through all life's challenges, including book deadlines. I also dedicate this body of work to the staff and students of Exploring New Horizons and Port Townsend's Students for Sustainability for bringing such meaning to my life, enriching my soul, and serving as a source of inspiration for me every day.

About the Authors

Page Keeley recently retired from the Maine Mathematics and Science Alliance (MMSA) where she was the senior science program director for 16 years, directing projects and developing resources in the areas of leadership, professional development, linking standards and research on learning, formative assessment, and mentoring and coaching. She has been the principal investigator and project director of three National Science Foundation (NSF)–funded projects, including the Northern New England Co-Mentoring Network, PRISMS (Phenomena and Representations for Instruction of Science in Middle School), and Curriculum Topic Study—A Systematic Approach to Utilizing National Standards and Cognitive Research. In addition to NSF-funded national projects, she has designed and directed several state projects, including TIES K–12: Teachers Integrating Engineering into Science K12 and a National Semiconductor Foundation grant project called L-SILL (Linking Science, Inquiry, and Language Literacy). She also founded and directed four cohorts of the Maine Governor's Academy for Science and Mathematics Education Leadership, which is a replica of the National Academy for Science and Mathematics Education Leadership of which she is a Cohort 1 Fellow.

Page is the author of 18 national best-selling books on formative assessment, teaching for conceptual understanding, and curriculum topic study. Currently, she provides consulting services to school districts and organizations throughout the United States on building teachers' and school districts' capacity to use diagnostic and formative assessment and teach for conceptual understanding. She is a frequent invited speaker on formative assessment and teaching for conceptual change.

Page taught middle and high school science for 15 years before leaving the classroom in 1996. At that time, she was an active teacher leader at the state and national level. She served two terms as president of the Maine Science Teachers Association, was a District II NSTA Director, and served as the 63rd President of NSTA in 2008–2009. She received the Presidential Award for Excellence in Secondary Science Teaching in 1992, the Milken National Distinguished Educator Award in 1993, the AT&T Maine Governor's Fellow in 1994, the National Staff Development Council's (now Learning Forward) Susan Loucks-Horsley Award for Leadership in Science and Mathematics Professional Development in 2009, and the National Science Education Leadership Association's Outstanding Leadership in Science Education Award in 2013. She has served as an adjunct instructor at the University of Maine, was a science literacy leader for the American Association for the Advancement of Science /Project 2061 Professional Development Program, and has served on several national advisory boards. She is a science education delegation leader for the People to People Citizen Ambassador Professional Programs, leading the trip to South Africa in 2009, China in 2010, India in 2012, Cuba in 2014, and Peru in 2015.

Before teaching, she was a research assistant in immunology at the Jackson Laboratory of Mammalian Genetics in Bar Harbor, Maine. She received her BS in life sciences from the University of New Hampshire and her MEd

About the Authors

in secondary science education from the University of Maine. She currently resides in Fort Myers, Florida, where in her spare time she dabbles in nature and food photography, culinary art, and cultural travel.

Laura Tucker has been a science educator for 38 years. Initially studying to be a wildlife biologist, she found her passion in teaching students in the outdoors, founding a nonprofit educational organization in 1979 (Exploring New Horizons). The program was designed to provide a comprehensive outdoor environmental science program for K–8 grade students and a summer camp program for children ranging from age 9 to 18. During her tenure, she helped develop a variety of programs, which combined environmental science curricula (redwood, coastal, and Sierra Nevada natural history and ecology, marine biology, botany, zoology, geology, and astronomy) with music, dance, drama, art, and team building. The programs blended the teaching skills and talents of staff naturalists with classroom teachers to incorporate the outdoor school experience into the classroom. Approximately 60,000 students attended the programs while Laura was the executive director. Exploring New Horizons continues to this day, serving about 6,000 students per year on three campuses in the Santa Cruz Mountains of California.

In 1992, she became the professional development coordinator for Great Explorations in Math and Science (GEMS), a nationally acclaimed resource for activity-based science and mathematics at the Lawrence Hall of Science at the University of California, Berkeley. She worked with a variety of educators, including preservice teachers; classroom teachers; district, regional, and state curriculum coordinators; university faculty members; and nonformal educators from museums, zoos, nature centers, and so on. She was a leader in establishing the GEMS Network, which comprises approximately 72 sites and centers around the United States and 11 at international locations. Laura served as a curriculum developer and reviewer for many of the GEMS publications, including *Aquatic Habitats* (Barrett and Willard 1998), *Dry Ice Investigations* (Barber, Beals, and Bergman 1999), *River Cutters* (Sneider and Barrett 1999), and *Schoolyard Ecology* (Barrett and Willard 2001) teacher guides and the GEMS kits and handbooks for leaders, literature, and assessment.

Laura has been actively involved with NSTA and has presented short courses, preconference symposia and workshops at 22 national conferences and 14 regional conferences, including a NASA/NSTA symposium on "Successful Strategies for Involving Parents in Education." Her engaging workshops have also been featured at numerous other conferences, including at science education association meetings in California and Washington.

Laura has been focusing a great deal of her energy on climate education. In 2012, she was selected as a Climate Reality Project presenter and joined former vice president Al Gore and 1,000 educators from 59 countries for three days of intensive training. She is an NOAA Climate Steward as well as a team member with the Climate Change Environmental Education Project-Based Online Learning Community Alliance in partnership with Cornell University, the North American Association for Environmental Education, and the EECapacity Project. She serves as a mentor with Students for Sustainability, a group from Port Townsend High School that is taking action to mitigate climate change at their school, in their community, in their state, and at the national level. They received the

Environmental Protection Agency's President's Environmental Youth Award for Region 10 in 2013. She serves on the Jefferson County/City of Port Townsend Climate Action Committee and chairs the L2020 Climate Action Outreach Group. She attended the Paris Climate Conference, COP21, in December 2015.

Currently, she wears two hats. She is the waste reduction education coordinator for Jefferson County, Washington, teaching the community to reduce, reuse, and recycle. She is also a consultant, providing custom professional development for formal and informal educational programs in hands-on, inquiry-based environmental and STEM (science, technology, engineering, and mathematics) education.

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Groundwater

Water found below Earth's surface is called groundwater. Five friends wondered what they would see if they could look underground and see groundwater. This is what they said:

Tyson: I think I would see a moving underground stream or river.

Yalena: I think I would see water in the tiny cracks and spaces between soil, sand, and rocks.

Jake: I think I would see a pool of water, sort of like an underground lake.

Betsy: I think I would see water spouting up from a vent or opening deep under the ground.

Armando: I think I would see chunks of ice that slowly melt and release water.

Who do you agree with the most? ____________________ Explain your thinking.

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Groundwater

Teacher Notes

Purpose
The purpose of this assessment probe is to elicit students' ideas about a major freshwater resource, groundwater. The probe is designed to find out how students visualize groundwater.

Type of Probe
Friendly talk

Related Concepts
Aquifer, fresh water, groundwater

Explanation
The best answer is Yalena's: "I think I would see water in the tiny cracks and spaces between soil, sand, and rocks." Groundwater is water found below the surface of Earth. It is the major source of water for drinking and agriculture. Groundwater is found in the pores, cracks, and spaces between earth material such as soil, fractured rock, gravel, and sand. It moves slowly through a formation called an *aquifer*.

Administering the Probe
This probe is best used with upper elementary, middle, and high school students. The probe can be extended by asking students to draw a conceptual model showing what they think groundwater looks like from a cross-sectional view below Earth's surface.

Related Core Ideas in *Benchmarks for Science Literacy* (AAAS 2009)

6–8 The Earth
- Water evaporates from the surface of the Earth, rises and cools, condenses into rain or snow, and falls again to the surface. The water falling on land collects in rivers and lakes, soil, and porous layers of rock, and much of it flows back into the oceans.

Related Core Ideas in *A Framework for K–12 Science Education* (NRC 2012)

3–5 ESS2.C: The Role of Water in Earth's Surface Processes

- Nearly all of Earth's available water is in the ocean. Most fresh water is in glaciers or underground; only a tiny fraction is in streams, lakes, wetlands, and the atmosphere.

Related Research

- A common misconception of both students and teachers is that water under the ground flows in river-like systems or in large underground lake-like reservoirs. Students who think this sometimes assume that wells will provide water forever because they are filled by underground rivers. The scale of the spaces water fills also varies from micro to macro, with some older students thinking that groundwater fills spaces the size and depth of skyscrapers. (Dickerson et al. 2007).
- The common misconception that groundwater is like an underground lake may come from the level of abstraction that is needed to understand hidden phenomena and processes that take place underground. Research indicates that students' mental model of groundwater as a static sub-surface lake results from their actual experience with the upper water system (Ben-zvi-Assarf and Orion 2005).

Suggestions for Instruction and Assessment

- Use a sponge to represent how water falling on the surface of Earth seeps into the ground and fills empty spaces. The sponge and water model the porous rock, soil, and sand and the empty spaces between the earth material. (Safety note: Immediately wipe up any spilled water to avoid slips and falls.)
- Student and teacher information about groundwater can be found on the Groundwater Foundation's website at *http://groundwater.org*.
- Visualizing groundwater can be challenging for students, as it is very different from water resources they see on the surface of Earth. Have students draw a conceptual model of the form and location of groundwater.
- A video of sixth graders discussing their ideas about groundwater (including misconceptions) can be viewed at *http://education.nationalgeographic.com/media/what-groundwater*.
- Water cycle diagrams may interfere with students' understanding of groundwater as part of the water cycle because many water cycle diagrams show only surface water. Use water cycle diagrams that also show groundwater or have students create water cycle diagrams that include groundwater as part of the cycle.
- Include the use of rock specimens when teaching about groundwater. Students can examine rocks to observe differences between rock types found in aquifers. (Safety note: Instruct students to handle rock specimens cautiously because some rocks may have sharp edges that can cut skin.)

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Uncovering Student Ideas in Earth and Environmental Science

32 New Formative Assessment Probes

"This timely edition provides a tool to help teachers emphasize Earth and environmental sciences' place alongside the traditional disciplines and their relevance to students' lives and the changing, unknown world they will enter into. *Uncovering Student Ideas in Earth and Environmental Science* will help me identify my students' preconceptions as we dive into these complex ideas."

—**Margo Murphy**
Chair, Teacher Advisory Council
National Academies of Sciences, Engineering, and Medicine

Maybe you're new to formative assessment probes, or perhaps you're among the thousands who love the *Uncovering Student Ideas in Science* series and crave probes specifically about Earth and environmental science.

Either way, you're in luck! This book gives you 32 engaging new questions that can reveal what your students already know—or think they know—about core Earth and environmental science concepts. Armed with those insights, you can present Earth and environmental science in grade-appropriate ways so students will learn the content accurately.

The probes are organized into four sections: land and water; water cycle, weather, and climate; Earth history, weathering and erosion, and plate tectonics; and natural resources, pollution, and human impact. The probes will help your students demystify why the ocean is salty, how old the Earth is, and the difference between weather and climate.

Like the other nine wildly popular books in the series, *Uncovering Student Ideas in Earth and Environmental Science* is

- designed so you'll find the probes ready to reproduce and easy to use;
- complete with field-tested teacher materials that explain the scientific ideas underlying each probe and link to national standards, including the *Next Generation Science Standards*;
- flexible enough to apply throughout the instructional cycle; and
- adaptable enough to use with different grades and student populations.

Best of all, the probes are intrinsically interesting. They're full of material to stimulate your students' intellectual curiosity, even as they transform your fundamental methods of teaching and learning.

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GRADES 3–12

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