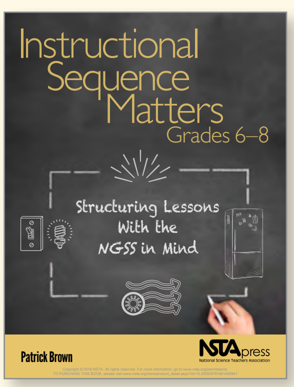
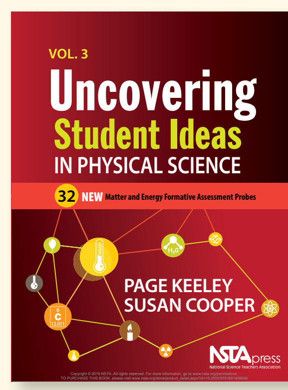
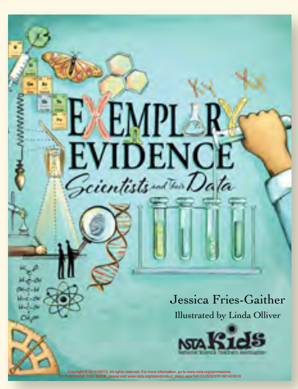
NSTA PRESS

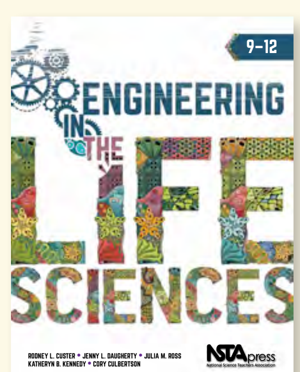
BOOK SAMPLER

A Gift from the National Science Teachers Association









Spring 2019

Table of Contents

Instructional Sequence Matters

Grades 6–8

Structuring Lessons With the NGSS in Mind

Patrick Brown

NSTA press
National Science Teachers Association

NSTApress®
National Science Teachers Association

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Deborah Siegel, Associate Editor
Andrea Silen, Associate Editor
Donna Yudkin, Book Acquisitions Manager

Art and Design
Will Thomas Jr., Director, cover and interior design

Printing and Production
Catherine Lorrain, Director

National Science Teachers Association
David L. Evans, Executive Director

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

21 20 19 18 4 3 2 1

Library of Congress Cataloging-in-Publication Data
Names: Brown, Patrick, 1978- author.
Title: Instructional sequence matters, grades 6–8: structuring lessons with the NGSS in mind / by Patrick Brown.
Description: Arlington, VA : National Science Teachers Association, [2018] | NGSS, next generation science standards. | Includes bibliographical references and index.
Identifiers: LCCN 2018021530 (print) | LCCN 2018027596 (ebook) | ISBN 9781681405858 (e-book) | ISBN 9781681405841 (print)
Subjects: LCSH: Science--Study and teaching (Middle school)--United States.
Classification: LCC Q183.3.A1 (ebook) | LCC Q183.3.A1 B76845 2018 (print) | DDC 507.1/073--dc23
LC record available at *https://lccn.loc.gov/2018021530*

Contents

Introduction

Young kids are natural scientists. For instance, they are puzzled when rainbows appear in the sky, when the leaves change colors, and when the Moon goes through different phases. Their observations can lead to questions about how the world works. Ever curious about their world, children instinctively try to answer their scientifically oriented questions by looking for patterns and causal relationships. In this way, they propel themselves to understanding from what they can investigate firsthand. Young children enter school as scientists and use firsthand explorations to explain the natural world. I firmly believe that a major task of science teaching is cultivating the innate skills child scientists bring to school. Bringing an *explore-before-explain* mind-set to science teaching is a way to developing the budding scientists in each of your students.

Two popular ways to put an *explore-before-explain* mind-set into practice is to use the POE and BSCS 5E Instructional Models. Both build students' conceptual foundation that helps them generate fundamental insights into how our world works. In addition, the POE and 5E Models allow students to derive content knowledge using science practices, a productive approach that mirrors how science is done in the real world.

If you are already aware of the power of *explore-before-explain* teaching and the POE and 5E Instructional Models, this book may help you begin to reflect on ways to make instruction even more effective for students. However, I hope it will do more than that. Others have written about using the 5E and POE Models in teaching (see Abell and Volkmann, 2006; Haysom and Bowen 2010). My approach is consistent with their ideas, but at the same time, it is unique. I hope the research, techniques, and activities that follow will help you with national reform aimed at putting *A Framework for K–12 Science Education (Framework)* and the *Next Generation Science Standards (NGSS)* into practice.

The *Framework* and *NGSS* have raised many questions for teachers. Some of the first that come to teachers' minds are "How is the *NGSS* going to change my teaching? How do I convert the *NGSS* into practice?" Although the new standards reflect advancement in how we structure lessons for students, having an *explore-before-explain* mind-set and using the 5E and POE Models allows for the seamless transition of the *NGSS* put into practice. Here is my journey to translating the *NGSS* into practice.

A General Overview for Using This Book

This book provides a self-guided professional development experience. My goal is that teachers will read the chapters, reflect on their practices, learn from the examples, and use the design principles to start creating 5E and POE lessons that align with the *NGSS*. This book draws heavily on the research on effective professional development that highlights the important role of active learning in context and explicit reflection on practice (Reiser 2013). In addition, research from *The Cambridge Handbook of Expertise and Expert Performance* recognized that developing knowledge is most meaningful if it is integrated into practice (Ericsson et al. 2006). As such, teachers will need time to think about the sequence of science instruction and the *NGSS* to become experts and will probably not be perfect right at the start.

Each chapter of this book grew out of research experiences and working with students and through teacher preparation and professional development. I have embedded activities aimed at sparking your thinking about your own experiences and designing *explore-before-explain* instructional sequences (see the activity boxes throughout the chapters). I have learned through research that teachers can have difficulty embracing the 5E Model because this instructional sequence is different from their experiences as students and their mind-set toward science teaching (see Brown, Friedrichsen, and Abell 2013). Success in K–16 science and experiences provide robust ideas about what science teaching could look like and how to best prepare students to develop their understanding. You can use the discussion questions to reflect on, both individually and with colleagues, your beliefs about science teaching and experiences as a learner. Our experiences as learners, current work with students, and beliefs about effective instruction can be powerful evidence for our ideas and inform our future practices. During the reading activities, make note of ideas so you can easily reflect on their initial discussions after experiencing model lessons. The combination of reflection questions, research chapters, and model lessons strongly supports an *explore-before-explain* mind-set.

I start with the research (e.g., Chapter 1, "Rethinking Development and Learning") on learning and cognition. This chapter takes you through some of the emerging ideas about students' intellectual abilities and the implications for instructional sequence. Chapter 1 closes with some suggestions for how to get started.

Chapter 2, "Modern Sequences of Instruction," discusses the key components of two contemporary sequences of science instruction. You will read about the phases of the POE (Predict, Observe, and Explain) and 5E (Engage, Explore, Explain, Elaborate, and Evaluate) Instructional Models. The activity boxes are aimed at helping you reflect on hands-on practices you currently use and how they may be sequenced to promote even higher levels of learning.

In Chapter 3, "Content and Process Working Together," I describe the construction of the *NGSS*. I share some activities for you to reflect on lessons you currently use and the connection to components of the *NGSS*.

Next, Chapter 4, "Where to Start," provides guidance on how you can create your own 5Es that translate the *NGSS*. I present activities following each factor you should consider when planning 5Es so they can provide planning ideas for designing *explore-before-explain* instructional sequences.

In Chapters 5–9, I share model lessons for putting the explore-before-explain mind-set into practice using either a POE or 5E instructional sequence. In addition, the model lessons illustrate how both the POE and 5E Models easily translate into the *NGSS*.

The model lessons have activity boxes to develop your abilities to design POE and 5E instructional sequences. In addition, the narrative portions of the model lessons are coded with specific elements of the *NGSS* (Appendixes F and G from NGSS Lead States 2013). An *NGSS* summary table is also provided to show the close connection between student actions and *NGSS* dimensions. The model lessons allow you to see the POE or 5E Model and *NGSS* in action.

Chapter 10, "Leadership Can Make the Difference," takes you through five key points to putting an *explore-before-explain* mind-set into practice using POE and 5E sequences and the *NGSS*. The final chapter can help emphasize the steps necessary for supporting colleagues and developing collaborative teams interested in developing POEs and 5Es into practice.

Conclusions

Teacher educators and professional developers can easily implement these lessons to model best practices in science education. Beginning teachers can use the model lessons so they have research-based strategies to improve student learning during their first years of teaching. Many experienced teachers who already value hands-on approaches but find that their lessons fall slightly short in influencing students how they intended can benefit from simple reorganizing activities. Reading and discussing the chapters provides valuable insight into why some approaches may be more beneficial than others. Thus, teachers have real-life examples and a rationale for restructuring the hands-on approaches they are currently using. Regardless of the level of experience, from novice to expert teacher, educators can read, implement, and dissect each model lesson to help reflect on how the sequence of science instruction promotes long-lasting understanding.

The chapters build on one another so you can consider why some activities may be even more effective than others and so you can try them out with your students. Many teachers realize that simple shifts in the arrangement and combination of activities can positively affect student learning to promote long-lasting understanding. In addition, effective science teaching is not always about working harder—it is about working smarter. Reflecting on and experiencing exploration before explanation instructional sequences opens up opportunities to construct a theoretical model for classroom lesson design so all students gain higher levels of science literacy.

Chapter 5

Teaching About Heat and Temperature Using an Investigative Demonstration

Chapter 5

In professional development workshops and methods courses, I use this chapter as a starting point for eliciting teachers' views of the effective sequencing of science instruction in classroom demonstrations. Many teachers already value minds-on experiences from demonstrations; however, they are unsure what knowledge students can construct. In addition, beginning teachers are not sure when they need to provide explanations that build on students' experiences. After trying the lessons, I have found that many beginning teachers have the same inaccurate conceptions that students have about thermal energy transfer.

This lesson is designed to anchor student learning around the following phenomenon: How does energy flow into, out of, or between an air-conditioned house and the outside during a hot summer day if the door to the house is left open? This is a confusing subject, and research has indicated that many middle school students have trouble understanding that thermal energy naturally transfers from the warmer object to the colder object until both objects reach the same temperature (Driver et al. 1994; Keeley, Eberle, and Tugel 2007). I have created a lesson-level performance expectation (PE) to build students' understanding toward the broader expectation (i.e., the lesson-level PE is "develop and use a model to show that energy spontaneously transfers out of hotter regions or objects and into colder ones"). By working together, teachers can create a dialogue with students about energy transfer. The model lesson highlights the connections of the learning activities to the three dimensions of the *Framework* with specific footnotes that code the narrative to the SEPs and CCs.[1] This chapter is a tool for thinking strategically and helping teachers become more reflective practitioners.

1. Footnotes in Chapters 5–9 show the relationship between student actions that occurred during the activity and specific elements of the SEPs and CCs appropriate for grades six through eight. The specific elements of the SEPs and CCs were coded from Appendix F and Appendix G, respectively (see NGSS Lead States 2013).

Activity Box: Exploring the POE Model Lessons

Use the activities below to reflect on the model lessons in Chapter 5. Go back and forth between your reflection journal and the model lessons. You can use the activities individually or as a group to reflect on how the POE sequence of instruction influences student learning.

1. **Try out a model lesson from Chapter 5 (POE lesson) with a group of students or consider using the design structure and sequence for an activity of your own.**
2. **Reflect on students' responses to the lesson in terms of their motivation and learning. Think deeply about the research on cognition and sequence of instruction (e.g., How did students react when you asked them to make predictions? List students' misconceptions/prior thoughts. Were students' prior ideas similar to those identified in the model lesson? What were students' observations and evidence-based claims?).**
3. **Identify any salient research points you noticed when using the model lesson with students that you want to remember and use when designing your first POE.**
4. **Brainstorm a list of upcoming demonstrations or student investigations you could sequence in a POE lesson.**
5. **Use the footnote connections to interpret how the narrative translates to the *NGSS*.**

Predict (Three to Four Minutes)

The demonstration begins by having students predict what will happen when two half-full beakers of water at different temperatures are mixed. Students' predictions are intimately connected to questions about what will happen when two different temperatures of water are mixed and tied back to the phenomena driving the unit (i.e., transfer of thermal energy). I involve students in the investigation by having volunteers take the temperature of the two containers of water. Later on, students will continue to play an investigative role, collecting data to answer overarching questions about energy transfer.[2]

2. Students engage in SEPs and investigate "questions that require sufficient and appropriate empirical evidence to answer" (NGSS Lead States 2013, p. 51).

Students find that one beaker contains water at 30°C and the other beaker contains water at 15°C. At this point, students commit to their predictions by recording (on a whiteboard or a piece of paper) what they think the water temperature will be after the two beakers of water are combined (see Table 5.1). Predictions that are not graded encourage students to take a risk and communicate their scientific understanding of phenomena without having to worry about the grade they will receive for their ideas.

Table 5.1. *Students' Preconceptions and Postconceptions of Heat Transfer*

- The *subtraction* conception means that students thought that the lower-temperature water would be subtracted from the higher-temperature water.
- The *average* conception means that students thought that the two different temperatures of water would reach a temperature that is the average of the two different temperatures of water.
- The *addition* conception means that students thought that the two different temperatures of water would combine and equal a new temperature of water that is greater than the two containers of water individually.

Conception	Preconceptions (n = 23) % (number of students)	Postconceptions (n = 22) % (number of students)
Subtraction	57% (13)	10% (2)
Average	30% (7)	86% (18)
Addition	13% (3)	4% (1)

Share (Three to Four Minutes)

During the next stage of the demonstration, students share their predictions with a partner and provide an explanation for their thinking while I circulate around the room and listen to their conversations. Through listening to students' explanations, I observed that some students believe their prediction to be accurate because their peer holds the same idea, while other students change their initial predictions based on their conversations, and some disagree with their partner and retain their initial conceptions.

At the end of the Share stage, students usually hold one of three conceptions of heat transfer. Most students think that the water temperature of the combined beakers will be 15°C. They explain that combining the two beakers will result in the colder water because "the 15°C water would be subtracted from the 30°C water." Some students think that the water temperature of the combined water will be 22°C. As one student explained, "The combined water temperature would be the average temperature of the two beakers." A few students think that combining the beakers will result in water that is 45°C, claiming that "the two water temperatures will add together."

Observe (Two minutes)

During the Observe stage, students collect data to help them confirm, refute, or refine their scientific ideas. Next, I combine the two beakers of water and have a student volunteer take the temperature of the water, which is approximately 22°C.

It is important that during the Observe stage students can make scientifically accurate claims based on evidence. Teachers should make sure when choosing two different temperatures of water that the difference between the two temperatures of water is not also the same as the average between the two temperatures of water. For example, if the demonstration involved water with temperatures of 5°C and 15°C, students would have difficulty formulating scientifically accurate conceptions from their observations because the difference (15°C – 5°C) and the average (15°C + 5°C) both equal 10°C.

Explain (Three minutes)

During this stage, students provide an explanation for their observation that when equal amounts of 30°C and 15°C water combine, the resulting water temperature is approximately 22°C. It is important that students develop a written artifact so that they externalize their ideas in a concrete form. Individually, students write down on an index card their explanations and what they learned from the demonstration. I grade students' responses on the spot during the Explain phase. Many students explain that the resulting water temperature is in the middle of the two combined containers of water.[3]

After their firsthand experiences with the demonstration, we discuss that the term *thermal equilibrium* describes when objects transfer heat until both objects reach the same temperature.

Investigating Convection and Conduction (Five to Seven Minutes)

Because the mixing-water demonstration does not make this explicit, students have additional experiences to learn that the transfer of thermal energy naturally occurs only in one direction—from "warmer" to "colder" objects. To help students learn this concept, they participate in an activity exploring convection and conduction.

In pairs and wearing chemical splash goggles, students fill a coffee cup with hot water (approximately 70°C) and place a glass beaker filled with water at room temperature on top of the coffee mug. (The beaker is larger than the coffee mug, so it balances on top of the mug.) Students begin by making predictions about what will happen to a drop of dye placed in the beaker and provide a reason for their thinking. Using a pipette, students then place one drop of red food coloring at the bottom center of the beaker directly above the coffee mug. (Students need to slowly and carefully

3. Students' questions and data collection during the Predict and Observe phases, respectively, lead directly to an SEP in the Explain phase, and they "construct a scientific explanation based on valid and reliable evidence obtained from their own experiments" (NGSS Lead States 2013, p. 61).

place a small amount of red dye in the beaker or they will not be able to observe the red dye's movement.) Next, students repeat the procedure, this time using cold water (close to 0°C) in the coffee mug. When using hot water in the coffee cup, students will observe that the red food coloring slowly moves from the area that contains warmer water located at the bottom of the beaker to an area that contains cooler water located at the sides and top of the beaker. Conversely, when using cold water in the coffee cup, students observe that the red dye remains at the center bottom of the beaker and does not move significantly. This experience serves as an investigation that provides qualitative data for their evidenced-based claim.

To demonstrate their understanding, students create a model that explains thermal energy transfer. In their models, they describe the direction in which energy transfers. In addition, students use the length of the arrows to indicate the "rate" at which molecules move. In this way, students' models have a "predictive value" and students can represent how varying the "warmness" of the water can influence the rate that energy transfer (i.e., warmer temperatures transfer energy faster). I remind students that models are useful in science for explaining and making accurate predictions about phenomena.

Using "Molecular Talk" to Learn About Heat Transfer (15 Minutes)

The final activity in the lesson is a whole-group discussion, which I initiate by asking students to explain whether the demonstrations could be explained using what we call molecular talk. Molecular talk refers to when students go back and forth between hands-on experiences and their knowledge of molecular properties and behaviors that are too small to observe. (Note: Earlier in the school year, students learned about energy transfer and the properties and phases of matter.) I have students close their eyes and visualize how "warm" water molecules might look different from "cold" water molecules. Students explain that warm-water molecules move rapidly and vibrate more than cold-water molecules. I encourage students to act out their ideas, as student-driven visual representations provide additional support for what they have learned. For example, a pair of my students had one student wiggle and move around the room to represent a warm-water molecule while the other student remained relatively still to represent a cold-water molecule. Another student used his hands to represent molecules, moving his fingers rapidly on one hand (to represent warm-water molecules) while he moved his fingers slowly on his other hand (to represent cold-water molecules) to show differences in thermal energy.[4]

I use probing questions and ask students to describe how thermal energy transfers in a closed system if the warm-water molecules encounter cold-water molecules. Based on their prior knowledge, students talk about "warmer" molecules having more kinetic energy than "colder" molecules. They explain that when warmer molecules (with more kinetic energy) encounter colder molecules (with less kinetic energy), energy transfers from warm to cold. At this point in the discussion, students want my approval of their ideas. I introduce a formal explanation from their textbook and discuss that thermal energy transfers through the collision of molecules that are too small for firsthand observation. In the demonstrations, thermal energy transfers from "warm" molecules with more thermal energy to the "cold" molecules with less thermal energy due to the collision of molecules. Over time, the molecules reached a state where all of the energy was equal; hence, no more thermal energy transfer. I tie students' developing conceptual understanding in this activity to a theme in the course that thermal energy transfer drives the motion of molecules.[5]

The final activity in the investigation involves a reading from their textbook. Students learn from reading their textbook that the term *convection* describes heating by the movement of currents in a fluid such as water. In addition, students learn that the term *conduction* describes when heat transfers from one molecule to another molecule in a substance without matter moving. Next, I ask students where they see conduction in the coffee mug and beaker demonstrations. Students explain that heating by conduction occurs where the coffee mug and beaker touch each other. Thus, the exploration they did before the new terms (convection and conduction) were introduced helps students attach the meaning of these new concepts to data they observed and explanations of science phenomena they generated.

Developing Long-Lasting Science Knowledge

More than 10 weeks after I first taught the thermal energy lesson (24 weeks into the semester), students completed the paper-and-pencil formative assessment worksheet described by Keeley, Eberle, and Tugel (2007) as part of an end-of-semester assessment. The formative assessment worksheet asked students to predict what the temperature of the water would be when two half-full glasses of water of the same size—

4. Students use the convection demonstration and wiggle about the room to simulate molecular motion highlights. Students are using the SEP of modeling, and they "develop a model to predict and describe a phenomenon" (NGSS Lead States 2013, p. 6). Modeling is a theme of how they can explain science and is direct evidence for the CC they use throughout the class. Students' models "can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems" (NGSS Lead States 2013, p. 93). Finally, the modeling activities directly tie to another SEP, and students "communicate scientific information through presentations" (NGSS Lead States 2013, p. 65).

5. Students' experiences with thermal energy relate to many themes in physical science, and their experiences add additional evidence for the CC that states "Within a natural or designed system, the transfer of energy drives motion and/or the cycling of matter" (NGSS Lead States 2013, p. 94).

one containing 50°C water and the other containing 10°C water—are combined and to provide reasoning for their answer. Students had the following selected response answers: (A) 20°C, (B) 30°C, (C) 40°C, (D) 50°C, and (E) 60°C. (See Keeley, Eberle, and Tugel [2007] for the full formative-assessment-probe worksheet.) I also added a second selected-response item to the formative assessment probe worksheet in which students identified the direction in which heat is naturally transferred: (A) only from "hot" to "cold," (B) only from "cold" to "hot," (C) both directions simultaneously, and (D) none of the above. When I assessed students' responses, I was pleased by their ideas, given that many students' initial misconceptions about energy transfer are persistent and survive in spite of learning about these concepts (Driver et al. 1994). Most students selected 30°C and reasoned that "when two temperatures are mixed together, they even out" and that they "found the middle between the two different temperatures." Some students still thought that "you take the higher temperature (50°C) and minus the lower temperature (10°C) and they equal 40°C." Very few students thought that the temperature would be 60°C (see Table 5.1, p. 40). In addition, most students held scientifically accurate postconceptions of heat transferring naturally only from "hot" to "cold" (see Table 5.2).

Although teachers would expect that students would learn this content after being taught it, the small number of students with inaccurate conceptions speaks to the resiliency of students' misconceptions in spite of firsthand experiences learning content. For most students, the experiences in the PSOE lesson helped them develop long-lasting, scientifically accurate conceptions of heat transfer. This lesson also addresses the three dimensions of the *NGSS* (see the *NGSS* connections in Table 5.3)

Table 5.2. *Students' Postconceptions of the Direction in Which Heat Transfers*

Postconceptions	Breakdown of Student Responses (n = 22) % (number of students)
"Hot" to "cold"	86% (19)
"Cold" to "hot"	5% (1)
Both directions	9% (2)
None of the above	0% (0)

Table 5.3. *Unwrapping the Standards in Chapter 5*

MS. Energy	Connections to Classroom Activity
Performance Expectation	
MS-PS3-4: Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.	Students investigate the transfer of thermal energy using food coloring and different colors of water (hot vs. cold). Students' observations are supported by "molecular talk" when they describe the relationship among temperature, thermal energy, and the motion energy of particles (kinetic energy).
Science and Engineering Practices	
Asking questions and defining problems	Students make predictions about how different temperatures of water interact when they encounter each other.
Analyzing and interpreting data	Students use qualitative data from their observations of the demonstration to learn which direction thermal energy transfers.
Developing and using models	Students use water that is colored using dye as a model for understanding how heat transfers. In addition, students wiggle around the room to explain how molecules interact on the microscopic level. The model helps them make sense of how molecules interact and transfer thermal energy.
Planning and carrying out investigations	Students carry out investigations to learn how "hot" and "cold" water interact.
Constructing explanations and designing solutions	Students formulate claims based on evidence statements.
Obtaining, evaluating, and communicating information	Students act out how "warm" and "cold" molecules move and interact as they move and wiggle around the classroom.

Continued

Table 5.3 (*continued*)

Disciplinary Core Ideas	
PS3.B: Conservation of energy and energy transfer. Energy is spontaneously transferred out of hotter regions or objects into colder ones.	Students observe that when different temperatures of water that have been dyed with food coloring come into contact with each other, water moves from areas that are "hot" to "cold." During students' molecular talk conversations, they discuss how energy transfers from "hot" to "cold" molecules.
PS3.A: Definitions of energy Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.	Students talk about motion energy (kinetic energy) on a molecular level and compare the movement of molecules for "hot" versus "cold" water.
PS3.A: Definitions of energy Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.	During molecular talk conversations, students talk about how the movement of molecules (motion energy) is related to the temperature of the object.
Crosscutting Concepts	
Systems and system modeling	Students investigate how "warm" and "cold" water interact. They use food coloring as a tool for learning how energy is transferred between "warm" and "cold" water
Energy and matter: Flow, cycles, and conservation	Students track the flow of movement of thermal energy to understand how heat transfers in a system.

Note: The materials, lessons, and activities outlined in this chapter are just one step toward reaching the performance expectation listed in this table. Additional supporting materials, lessons, and activities will be required. See *www.nextgenscience.org/msps-e-energy* for more information.

Instructional Sequence Matters

Grades 6–8

Structuring Lessons With the NGSS in Mind

"[This book] uses the 5E instructional model and presents descriptions of the model with insightful examples. Without any hesitation, I recommend this book."

—Rodger W. Bybee, author of *The BSCS 5E Instructional Model: Creating Teachable Moments* (NSTA Press, 2015)

Instructional Sequence Matters, Grades 6–8 is a one-stop resource that will inspire you to reimagine how you teach middle school physical science. The book discusses two popular approaches for structuring your lessons: POE (Predict, Observe, and Explain) and 5E (Engage, Explore, Explain, Elaborate, and Evaluate). It also shows how simple shifts in the way you arrange and combine activities will help students construct knowledge, while allowing you to put the *Next Generation Science Standards* into practice.

Designed as a complete self-guided tour, *Instructional Sequence Matters, Grades 6–8* helps you understand

- **Why sequence matters.** A concise review of cognitive science and science education research explains why the order in which you structure your lessons is so critical.
- **What you need to do.** An overview of important planning considerations covers becoming an "explore-before-explain" teacher and designing 5E and POE instructional models.
- **How you do it.** Ready-to-teach physical science lessons use either a POE or 5E sequence to cover heat and temperature, magnetism, electric circuits, and force and motion. Detailed examples show how specific aspects of all three dimensions of the *NGSS* can translate into practice in your classroom.
- **What to do next.** Reflection questions will spark thinking throughout the sequencing process and help you develop the knowledge to adapt these concepts to your students' needs.

Regardless of whether you are a novice teacher or a classroom veteran, *Instructional Sequence Matters, Grades 6–8* will give you both the rationale and the real-life examples to restructure the hands-on approaches you are now using. The result will be a sequence for science instruction that promotes long-lasting understanding for your students.

PB438X
ISBN: 978-1-68140-584-1

Grades 6–8
NSTApress
National Science Teachers Association

STAGING FAMILY SCIENCE *Nights*

DONNA GOVERNOR
DENISE WEBB

NSTApress
National Science Teachers Association

NSTApress®
National Science Teachers Association

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Andrea Silen, Associate Editor
Jennifer Thompson, Associate Editor
Donna Yudkin, Book Acquisitions Manager

Art and Design
Will Thomas Jr., Director
Joe Butera, Senior Graphic Designer, cover design
Capitol Communications LLC, interior design

Printing and Production
Catherine Lorrain, Director

National Science Teachers Association
David L. Evans, Executive Director

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

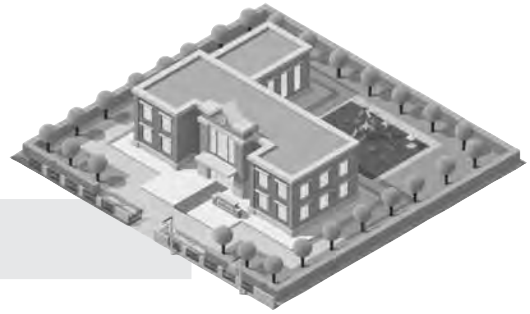
22 21 20 19 4 3 2 1

NSTA is committed to publishing material that promotes the best in inquiry-based science education. However, conditions of actual use may vary, and the safety procedures and practices described in this book are intended to serve only as a guide. Additional precautionary measures may be required. NSTA and the authors do not warrant or represent that the procedures and practices in this book meet any safety code or standard of federal, state, or local regulations. NSTA and the authors disclaim any liability for personal injury or damage to property arising out of or relating to the use of this book, including any of the recommendations, instructions, or materials contained therein.

Library of Congress Cataloging-in-Publication Data
Names: Governor, Donna, 1957- author. | Webb, Denise, 1968- author.
Title: Staging family science nights / by Donna Governor and Denise Webb.
Other titles: Family science nights
Description: Arlington, VA : National Science Teachers Association, [2018].
Identifiers: LCCN 2018039313 (print) | LCCN 2018051160 (ebook) | ISBN 9781681406244 (e-book) | ISBN 9781681406237 (print)
Subjects: LCSH: Science--Study and teaching (Elementary)--Activity programs. | Science--Study and teaching--Activity programs. | Science--Study and teaching--Parent participation. | Student-centered learning. | Project method in teaching. | Science and the arts. | Education in the theater. | Education--Parent participation. | Community theater. | Family recreation.
Classification: LCC Q164 (ebook) | LCC Q164 .G66 2018 (print) | DDC 372.35--dc23
LC record available at *https://lccn.loc.gov/2018039313*

Table of Contents

Introduction



Our experience with hosting Family Science Nights has been one of the most exciting aspects of our teaching careers. We launched a successful partnership organizing these events in 2013 while teaching in adjacent schools. We met serving on the board of the state science teachers association, and one of our discussions turned to our joint interest in planning a Family Science Night. Denise was trying to find a way to bring science nights to her elementary school, while Donna was looking for a way to get high school students involved in hosting science nights, after successfully organizing these events at the middle school level for the prior seven years. A productive and enduring partnership (and lasting friendship) came out of those early discussions. That partnership resulted in successful events for thousands of families at multiple schools over the past several years.

We both were products of the same preservice teacher program for elementary educators at the University of West Florida, although Donna completed the program 10 years prior to Denise. We lived and taught in different cities, and our paths wouldn't cross for more than two decades after Denise's graduation. When we began teaching, neither one of us dreamed that we'd eventually become teachers of science, as we both started our careers as elementary teachers. Yet today Denise is a STEM specials teacher at an elementary school where she provides hands-on labs and engineering activities for every student in the school on a weekly basis. Donna is now teaching preservice teachers at the university level, after having taught elementary school for 15 years, middle school science for 14 years, and high school science for 3 years.

For both of us, our early vision of a Family Science Night event was rooted in hands-on science events hosted by teachers at our respective elementary schools during the school day in the 1990s. How that experience evolved into organizing successful Family Science Night events, hosting thousands of students and their families each year, was very different for each of us. For Denise, these events started with teacher-led curriculum nights where she enthusiastically took charge of science activities. Denise saw students are naturally curious about the world, and science not only excited children about learning, but also inspired them to read and write more. Her interest gravitated to science based on the enthusiasm she saw when students engaged in STEM activities at these events.

Donna's path was more complex. After hosting a successful Star Party for her own middle school students in 2005 (with the help of a local astronomy club), the school parent-teacher-student organization asked her to host a similar event for the entire school in the following year. Although three attempts were made at holding the event, each was canceled due to cloudy skies and bad weather. The following year (2007), Donna tried again, this time with a different twist. Instead of relying on clear skies, she made the decision to include make-and-take activities, bring in a portable planetarium, and have the amateur astronomers prepared to "show and tell" their telescopes, should the skies not cooperate. Rather than relying on teachers to run the hands-on activities, she asked her eighth-grade students to take charge. Once students became involved, the plans began to snowball and more than 15 sessions ended up on the schedule. The skies cooperated, hundreds of students and their families showed up, and a new tradition at the middle school was born. These events continued to grow and evolve, until Donna made the move to teaching high school in 2013.

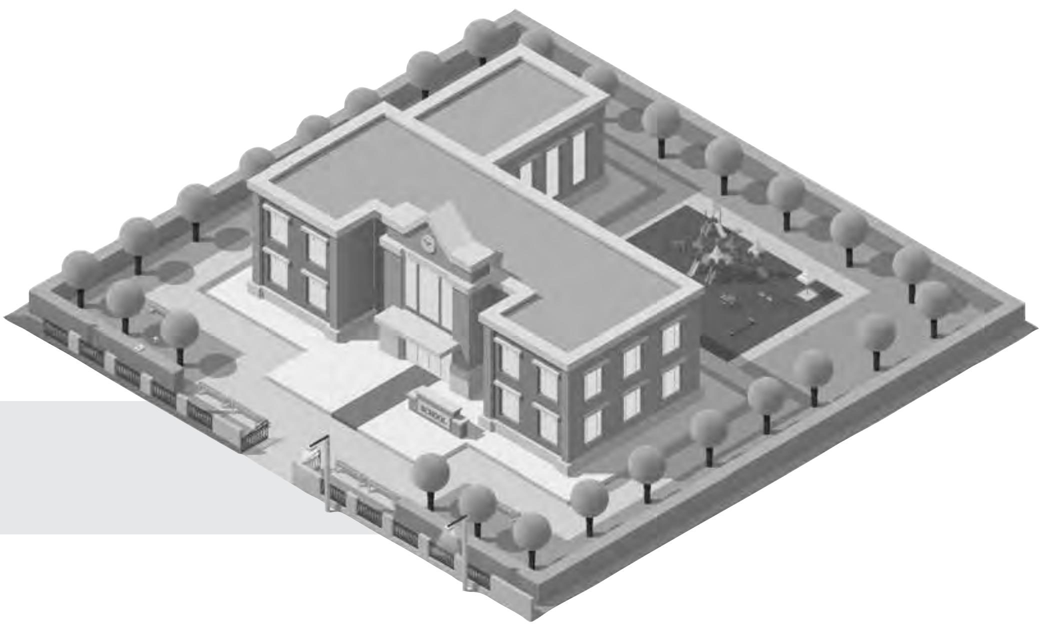
The partnership begun by Donna and Denise in 2013 started with a single school. Donna's former middle school students, now at the high school where she taught, asked to find a way to continue to sponsor Family Science Night events. Denise wanted to bring a Family Science Night to her school but needed volunteers to run the sessions. It was a match made in heaven. Our first collaborative event was held in January 2014 at Denise's elementary school, where several hundred students showed up with their families. In the same way that Donna's middle school nights evolved, the joint program took on a life of its own and continued to expand. Within two years, our high school students were hosting events at a half dozen local elementary schools for thousands of students and their families.

We want to make it clear, this book is not just for elementary teachers who want to host a Family Science Night at their own school. This book is for teachers of all levels—elementary teachers, secondary teachers, and teachers of preservice teachers. Through our collaboration, we found that Family Science Night events are great for our youngest students, but are important for older students as well. Middle school and high school students who are put in charge of running these events get as much, if not more, out of hosting Family Science Nights as the elementary students who attend. We've seen older students develop a sense of self-efficacy in science in ways that never would have happened in the classroom. If you are a secondary teacher interested in building a love of science in your students, this book is for you, as much as it is for the elementary teacher who wants to organize an event at his or her school.

Over the years, we've learned a great deal about how to host a Family Science Night. Throughout this book, we hope to share what we've learned and provide insights that can inspire you to organize an event in your school that truly excites learners of all ages about science.

Section 1

Producing the Event



Chapter 1

Overture

Overview

In this chapter, we will introduce you to Family Science Night events and discuss the benefits of holding an event at your school.

- The Case for Family Science Nights
- Building a Culture of Science
- Our Audience: Who Is This Book For?
- Evolution of Family Science Nights
- Summary

On March 22, 2007, aliens invaded Liberty Middle School in Cumming, Georgia. Approximately 40 students from Donna's eighth-grade science classes organized and hosted an Astronomy Night, which was to become our school's first Family Science Night event. Originally, the program was supposed to be small, with just a few telescopes borrowed from the local astronomy club scheduled to show students the stars. Hot chocolate and warm cookies were planned to keep things toasty and cozy. But, worried about the potential for bad weather, Donna scheduled a few extra activities to make sure the event could be held regardless of weather. She arranged for a portable planetarium from the local nature center and added a few make-and-take sessions to the program, such as making star clocks and planispheres.

Donna asked her eighth-grade students to help with the hands-on activities. That's when things exploded.

As soon as word got out, students started coming to Donna asking to participate. It was great to see students interested in hosting an after-hours event, and Donna started finding roles. Sessions were added to the plan, including activities on phases of the Moon, spectroscopy, exoplanets, and stellar evolution, as well as a "tour" of our Solar System. Students started coming up with additional ideas: How about T-shirts? What about a cookout? Where can we put an art show? What about music? By the night of the event, we had acquired over 1,000 Oreos, a dozen bags of marshmallows, inflatable planets, thousands of glow-in-the-dark stars, gallons of hot chocolate, and a dozen blow-up aliens. One very supportive parent even made over 1,000 candy stars for one of the activities!

We invited families from the local elementary school as well as those from our school. Students organized and hosted 17 different activities, including a performance by the school chorus, a local storyteller with myths about the night sky, and a hamburger dinner. Teachers were asked to participate as room monitors, and many chose to bring their own families. Six 25-minute sessions were held, with guests choosing the activities that interested them the most. The event went off almost flawlessly (although in all honesty, it was a bit of a whirl!). The students who led sessions were amazing! They knew their science, and they managed each event with a minimum of assistance from monitoring teachers. An estimated 600 people attended that first event. (See Figure 1.1.)

Figure 1.1. Donna and Denise at a Family Science Night Event

It was at the end of the evening that Donna realized what had occurred: a perfect coming together of informal science learning, student leadership, community support, and schoolwide excitement. Some of the comments made by the students who hosted the event will never be forgotten, such as "I couldn't believe how much fun it was!" and "I didn't realize how hard it was being a teacher!" It was immediately clear that this wasn't a one-time event, but the beginning of a new tradition that would evolve and grow. The event took on a life of its own and became a favorite for the school and community.

When Donna eventually transferred to teaching at a high school and met with Denise, a teacher at the neighboring elementary school, a new collaborative adventure began. We brought Donna's high school students to Denise's school to be ambassadors at our Family Science Nights.

The Case for Family Science Nights

Family Science Nights such as these are considered an "informal" science learning environment—settings where children and adults can engage in and learn science beyond the classroom. The National Science Teachers Association's (NSTA's) official position statement on Parent involvement in Science Education states that "by sharing science experiences, parents demonstrate that learning is an important and enjoyable process. The parents also become more aware of the importance of science in their own lives" (NSTA 1994). We've found that science nights are one of the best ways to get students excited about and parents engaged with science. While participating in these events, students and their parents build science literacy, learn more about careers in STEM fields, and participate in scientific practices.

Family Science Nights are a relatively new phenomenon. They are first referenced in the professional literature beginning in the 1990s, which is when Denise and Donna were first exposed to them as teachers. The research tells us that Family Science Night programs can improve both knowledge and attitudes about science. For students who attend events, science literacy, general knowledge, and attitudes about science are improved (McDonald 1997). In a study published by Mike Watts (2001), the author found that benefits go far beyond impacting individuals who attend and extend into the community as well.

> As former PTO [Parent-Teacher Organization] president, I can confidently say that Science Night is one of the most important events of the year. It promotes family participation and the awareness of STEM. Everyone, no matter what the age, is highly engaged and leaves with a smile. Our PTO board always received positive feedback from the community on how much they enjoyed participating.
>
> **—Kim Hickman**
> *Former PTO President*

In the last decade, the National Science Foundation has published a number of reports on the importance of informal science learning, including *Learning Science in Informal Environments: People, Places, and Pursuits* (NRC 2009), *Surrounded by Science: Learning Science in Informal Environments* (NRC 2010), and *Identifying and Supporting Productive STEM Programs in Out-of-School Settings* (NRC 2015). Each of these documents discusses the importance of engaging students in learning outside the classroom environment for developing science literacy. In these reports, they also discuss the importance of learning in other informal learning environments, including museums, after-school programs, camps, and more.

We feel that student participation in a Family Science Night most closely parallels the experience of learning science in a "designed setting," as described in *Learning Science in Informal Environments* (NRC 2009). In these experiences, learners choose from multiple activities in which they can participate. The programs we present in this book fit this type of experience, as our programs are annual events that include dozens of different activities for students to choose from. Participating in these experiences can engage students, get them interested in science concepts, promote independent learning, and lead to deeper conceptual understanding of science content. For teachers, this means students who engage in learning science OUTSIDE the classroom are better prepared for learning IN the classroom.

What is written in the literature reinforces what we've seen with our own programs: participating in these events engages our students in unexpected ways. Young students ask better questions, discover new interests, and are better prepared for learning science in the classroom. Older students who run events suddenly see themselves as successful in science and as having the potential to be "good" at science. Families bond over experiences with meaningful discussions about phenomena and hands-on activities. For Donna's middle school students, the annual event became the high point of the year. With our high school collaboration model, the students who run the events not only discovered that they enjoyed working with children, but also found that their own sense of self-efficacy in science was improved. Students who never saw science as something they could "do" suddenly became active participants in the culture of science. Regardless of the age or role, these events seemed to bring out the science enthusiast in everyone who participated.

There are multiple models for running a Family Science Night. One model is to base activities on discrepant events that engage students and their parents through conceptual conflict (Lundeen 2005). Another model is for parents and students to work together at home to complete an investigation before participating in a culminating activity at a school-based evening event (Watts 2001). Some events are theme-based, such as the Astronomy Night project described at the beginning of this chapter (Governor and Richwine 2007). There is no one right way. Regardless of model, however, all events involve similar planning and preparation.

In this book, we will primarily discuss the models that we have experience with. The one described in Donna's first Astronomy Night is what we'll call a *session* model. This is much like a teacher conference, where concurrent sessions are scheduled and participants choose which activities to attend. The other type of model presented we call a *flow* model. In this type of event, multiple activities are set up, and participants move from one activity to another as they complete each activity. Both models include a variety of activities. However, in the session model, there is time to present a brief content overview to groups of participants. During a flow model, hosts must present content on a one-to-one basis, as attendees enter and leave each activity at different times. While the events look different, they require similar planning and preparation. Chapter 2 will discuss these models in more detail.

Regardless of which model you choose, planning should begin months before you want your event to occur. Selecting a date and time is dependent on a range of variables. Community events, sports, and even the onset of daylight savings time are variables that can make a difference in an event's success (more on this in Chapter 2). These events can be expensive (although not necessarily so), and raising funds to defray costs has always been part of the preparation for us. Part of planning an event includes deciding on formats, themes, and activities, recruiting volunteers, managing supplies, and arranging facilities. However, running a successful Family Science Night event is one of the most rewarding activities of any teacher's career, and this book is designed to help you make that process easier by learning from our experiences. Whether you are a classroom teacher, administrator, scout leader, or museum director, we hope you can benefit from our experience.

Building a Culture of Science

Teaching and learning about science formally happens in the classroom. But learning about science involves interacting in the world around you. Since the beginning of the 21st century, science education has changed based on an ever-evolving body of research about teaching and learning. The release of *A Framework for K–12 Science Education* (the *Framework*; NRC 2012) and the *Next Generation Science Standards* (*NGSS;* NGSS Lead States 2013) has shaped what science education should look like in the classroom at the beginning of the 21st century. Engaging students in hands-on science experiences in a Family Science Night environment can address all three dimensions of learning identified in the *Framework*. "Three-dimensional" science activities engage students in both the content and practices of science, while emphasizing concepts that cross all scientific domains. Activities can be included in any Family Science Night event that span a variety of science and engineering practices, while engaging students in exploring patterns, relationships, system models, or causality. These three dimensions of learning are appropriate in and out of the classroom. They are specifically referenced in all the activities we present in the second half of this book and are important considerations when planning science activities.

National Academies of Sciences presents a parallel framework for learning in informal science environments in the report *Learning Science in Informal Environments: People, Places, and Pursuits* (NRC 2009). The report presents the six broad goals, or strands, to guide learning science outside the classroom. These strands are the following:

- Strand 1: Sparking Interest and Excitement
- Strand 2: Understanding Scientific Content and Knowledge
- Strand 3: Engaging in Scientific Reasoning
- Strand 4: Reflecting on Science
- Strand 5: Using Tools and the Language of Science
- Strand 6: Identifying With the Scientific Enterprise

For Family Science Night events, each of these important goals should be addressed to make sure that learners of all ages are engaged in meaningful science learning. These strands provide insight into how to engage learners beyond the classroom. A summary of these strands and how they apply to Family Science Night events follows.

Strand 1: Sparking Interest and Excitement

This strand deals with issues of motivation, excitement, and interest in learning science. It is probably the easiest of all goals to address when organizing a Family Science Night event for your school. There is extensive literature that discusses the importance of emotion in learning, concluding that students who are engaged and excited learn more and retain longer. But as every teacher knows from watching her own students, science activities spark excitement! Small children and their parents are excited whether they are exploring forces and motion with a water rocket, observing the Galilean moons of Jupiter, or dissecting owl pellets. Students who get excited about science in an

> Last night I took my two children to the science event put on by the high school students. I wanted to tell you that it was incredible! The science experiments were great, and every high school student that we encountered engaged with the kids and taught them the science behind the project. Please know how impressed I was with the organization of the Science Night and the overall science program. My oldest child is going into fifth grade, so we have a few years before he goes to high school, but he is definitely looking forward to being a Science Ambassador. Thanks for your great leadership to the school and community.
>
> —**Chris Emmitt**
> *Parent*

after-school event are more likely to come to the classroom ready to read to find answers, write stories about their experiences, and engage in classroom science instruction. We've seen young children find a new passion for a topic because of an activity at a Family Science Night event, and older students who are hosting events suddenly feel as if they can be good at science for the first time in their educational career. Regardless of the age and role, engaging students in these events can spark interest and excitement. (See Figure 1.2.)

Strand 2: Understanding Scientific Content and Knowledge

While we admit that science content cannot be learned in depth at a Family Science Night, there are many ways in which learners can improve their understanding of scientific content while attending an event. One way is by presenting scientific models that will help clear up misconceptions. For example, participating in experiences that model Moon phases will challenge misconceptions and help lay the ground work for classroom instruction. In this setting, younger children can experience a specific concept at an earlier age (such as Newton's Laws), and with the right questions, this will prepare them for future learning. Family Science Night events can also help by providing experiences that go beyond what classroom teachers can provide, such as the opportunity to observe planets at night. Providing experiences that activate new interests can result in later learning and deeper understanding. For example, when young students participate in a simulated fossil dig at such an event, they may not only ask important questions when they return home or to class, but might also be inspired to check out books at the school library to learn more about fossils. We've seen passions lit during these events that resulted in students seeking out more information. So while many students may not actually learn a great deal of content in short sessions, they can participate in experiences that will provide a base for constructing important knowledge at a later date, discovering a new area of science they might be interested in, or reengaging in content they may have forgotten. In *Learning Science in Informal Environments*, the report confirms what we found: Not a lot of

Figure 1.2. Students Participate in a Robotics Demonstration at a Family Science Night Event

content is learned in a single event. However, these events do improve students' potential for later learning (NRC 2009).

When older students are put in charge of a Family Science Night event, their understanding of science content and knowledge increases dramatically. Students who are responsible for presenting sessions at an event DO learn content at a much deeper level because they have to be able to teach the information to attendees. Our experiences include both middle and high school students who present sessions to younger students. In both our models—session and flow—middle and high students select a topic (with guidance), identify a hands-on activity, prepare a presentation, and then deliver content to attendees. These students had to learn the science and be able to explain it to younger students and their families. They couldn't always answer every question, but they certainly became more knowledgeable and had a strong motivation for developing a deeper understanding of the content.

> I have enjoyed being involved with the students and teachers taking science into the community of our local elementary schools as Science Ambassadors. The excitement of showing the students our experiments and watching them learn and see their reaction is priceless. The high school students and their leaders watch each child, wondering how far she or he will take their love of science. There might be an astronaut, chemist or doctor who starts at that one moment."
>
> —**Lorrie Angell**
> *High School Parent*

Strand 3: Engaging in Scientific Reasoning

Scientific reasoning in this context correlates with the scientific practices identified in the *Framework* and includes observing, asking questions, predicting, experimenting, collecting data, and constructing explanations from evidence. These are at the heart of activities presented in a Family Science Night event. Discrepant events help students ask questions, engineering challenges require predicting and testing, and simple experiments involve data collection and interpretation. How much students engage in scientific reasoning will depend on the activities or stations you prepare. One of our favorite inquiry activities involves exploring potential and kinetic energy by making a "hall roller" (see p. 155 for this activity). This simple device can be constructed out of cardstock, straws, plastic cup lids, and rubber bands. The more you wind up the rubber band, the farther it rolls. Students can explore the relationship between potential and kinetic energy as they experiment with different amounts of elastic potential energy stored in the device. After constructing a hall roller, participants can collect data, manipulate variables, and measure outcomes as they compete to see which prototype is the best. By carefully selecting activities that encourage experimentation and asking the right questions of attendees, Family Science Night events can help build an understanding of science and engineering practices.

Strand 4: Reflecting on Science

Reflection, in this setting, deals with understanding science in a broad, social context as well as one's personal reflections on learning science. Understanding how science progresses, both historically and culturally, is an important component of scientific literacy in society. Reflecting on learning promotes metacognitive awareness, which is another way in which Family Science Night events can promote this strand. We see evidence of this strand as we hear from parents how much their children enjoyed the program every event. For our older students who host sessions at these events, they seek deeper levels of understanding to be able to answer questions from younger children. Integrating historical aspects of science can be accomplished either through specific activities or by selecting a theme based on building scientific literacy. For example, one of Donna's most memorable Family Science Nights was when the theme A Night of Discovery was used for the event. All sessions revolved around discoveries in science, focusing on a specific inventor, explorer, or researcher who made a historic contribution to advance science. Sessions included in this event covered the contributions of Annie Jump Cannon, Marie Curie, Gregor Mendel, Nikola Tesla, and more. Single sessions at nonthemed events that include references to history and culture can easily be integrated into any program.

Strand 5: Using Tools and the Language of Science

This strand is perhaps one of the easiest to see in action at a Family Science Night event. Because of the nature of the program, students get to experience both tools and language that they might not be exposed to in the classroom. In our experience, many K–6 teachers don't have access to equipment that can be found in upper-level science labs. However, we've found that when organizing these events, it's easy to borrow the tools you need from a high school or ask for resources in the community. We've received donations of exam gloves from doctors, microscope slides from labs, and flowers from florists. Our local astronomy club has brought telescopes to our events, giving our students experience with the tools of science.

Perhaps the most important benefit from an event is exposing students to the language of science. Vocabulary used in various activities can connect with a wide range of science concepts. Asking, "What is your hypothesis?" before one activity, or introducing an "independent variable" during another, can help reinforce concepts students hear in class. More specific terminology can be introduced as students dissect flowers, manipulate Newton's laws in the Balloon-Powered Cars activity, and identify fossils from different geologic eras. Family Science Night activities introduce new words in meaningful and relevant ways.

Strand 6: Identifying With the Scientific Enterprise

The focus of this strand is on "how learners view themselves with respect to science" (NRC 2009, p. 46). This is one of the strongest outcomes we have seen with holding Family Science Night events at our schools. Young children who attend these events become engaged with science and excited about new concepts. In our collaborative program, High School Science Ambassadors (more about that in Chapter 3), where Donna's high school students hosted events at Denise's elementary school, it was common for our elementary students to be overheard leaving saying, "I can't wait until I get to high school and can be a Science Ambassador!" These events make lasting impressions on the young children who attend and, we believe, foster a special relationship with science from their very first program.

It is with our older students—those who are responsible for hosting events—that we see the greatest shift in scientific identity. As these students take on the challenge of leading events for younger children, they develop a sense of confidence and love of science that they may have not developed in their classrooms. These student hosts spend months preparing for events and take great pride in their work. In becoming experts in a single topic, they develop an identity as not only a learner but also teacher of science. When working with our High School Science Ambassadors, Donna loved recruiting those who didn't necessarily have a positive self-image of their ability to learn and "do" science. It often took some encouragement to get students to attend their first event, but once they did, they were hooked!

> As a parent of a college-bound student, I appreciate the leadership opportunities Science Ambassadors provide for students. Each group is given an activity. How they teach and share is their responsibility. High school students make decisions about how to handle difficult concepts, engage young children, and involve parents. They develop experiences and make memories that will last a lifetime.
>
> —**Charlotte Stevens**
> *Teacher and Parent*

We've seen these students blossom and thrive when they become an expert that young children look up to. Additionally, as a high school teacher, Donna has seen a side of her students while participating in our Science Ambassadors program that was hard to find in the classroom. Students who don't seem to like science in class suddenly see themselves as being "good" in science, which, in turn, improves their classroom interactions and motivation. For us, the transformation we've seen in high school students is one of the best parts of running the Science Ambassadors program.

Our Audience: Who Is This Book For?

So, who is this book designed for? Really, anyone who wants to hold a family or community science event. It is written from our experiences hosting these events in public, K–12 schools (see Table 1.1). Elementary and middle school teachers can use the information included here to run events in their own schools. High school teachers might find this book a helpful guide to organizing a student program for future teachers or a science club to sponsor events at elementary schools, as we have done. Scout leaders and youth programs may want to use this book with clubs and organizations to help improve their events. Museum directors might find some useful tips for improving their outreach programs. Homeschool networks might also find ways to implement our ideas in community spaces. Just about anyone who wants to organize a science extravaganza outside the classroom could benefit from this book. In fact, we recently implemented ideas we learned while running Family Science Nights as part of a community science festival.

Table 1.1. Who Should Use This Book and How to Use It

WHO	HOW
Elementary Teachers	As a guide to organize and prepare a program for your school, using teachers or volunteers to host activities. If you wish to use students to host activities, we recommend you partner with a high school teacher to coordinate with and oversee students.
Middle School Teachers	As a guide to organize and prepare a program for your school, using students or volunteers to plan and host activities.
High School Teachers	As a guide to organize high school students to plan and host programs at local elementary schools. It is recommended you partner with an elementary teacher at the schools you intend to visit.
Others	As a guide to organize and prepare a program in an informal learning environment. This can include museums, community centers, children's activities at science festivals, and other venues.

Depending on your current experience and program goals, you may only want to implement specific aspects of Family Science Nights or add certain features to an existing program. This book is intended to be a comprehensive resource, culminating from decades of combined experience.

Evolution of Family Science Nights

One of the biggest considerations as you begin to implement your first Family Science Night event is that over time these programs tend to take on a life of their own and grow in unexpected ways. It is important to start simple and then expand as you gain experience. The vision we present here took us years to build. We recommend that you start with a small program and a limited number of activities, picking and choosing some of the ideas that we present in this book. In successive years, plan to expand your program to include more features. Sometimes our ideas have guided our programs, but more often than not, it's a student or someone else who has brought a great idea into play. A PTSA dinner held in collaboration with our event became a regular fundraiser. The art teacher added an art show with work related to the chosen theme. One year students included a coffee shop and listening room, performing original science songs (they actually produced a CD the first year the songs were performed). We adopted mascots, and the robotics club has presented demonstrations on multiple occasions. None of these ideas were ours, but they became important components of our programs over the years.

Summary

Hopefully, by now we've built the case for why you should want to host a Family Science Night. Elementary students are engaged with science at an early age. Secondary students hosting Family Science Night events develop leadership skills and enhance their self-efficacy as learners of science. For families, these events provide a culture of science and build scientific literacy in the school and community. We've seen how they can provide a positive change for learners of all ages who participate in these events. In the next chapter, we'll talk about what you need to know to get started planning your own Family Science Night.

References

Governor, D., and P. Richwine. 2007. Invite an alien to astronomy night. *Science Scope* 31 (3): 48–53.

Lundeen, C. 2005. So, you want to host a Family Science Night? *Science and Children* 42 (8): 30–35.

McDonald, R. 1997. Using participation in public school "Family Science Night" programs as a component in the preparation of preservice elementary teachers. *Science Teacher Education* 81 (5): 577–595.

National Research Council (NRC). 2009. *Learning science in informal environments: People, places, and pursuits*. Washington, DC: National Academies Press.

National Research Council (NRC). 2010. *Surrounded by science: Learning science in informal environments*. Washington, DC: National Academies Press.

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

National Research Council (NRC). 2015. *Identifying and supporting productive STEM Programs in out-of-school settings.* Washington, DC: National Academies Press.

National Science Teachers Association. 1994. Parent involvement in science education. *www.nsta.org/about/positions/parents.aspx.*

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

Watts, M. 2001. The PLUS factor of family science. *International Journal of Science Education* 23 (1): 83–95.

STAGING FAMILY SCIENCE *Nights*

Maybe you'd like to encourage young scientists to ask better questions, discover new interests, and be better prepared to learn science in class. Maybe you'd like to involve older students in events where they can see themselves as successful in science. And maybe you'd love to see families bond over scientific phenomena and hands-on activities—from balancing bugs to creating color slime to competing in a Bubble Olympics.

"Running a successful Family Science Night event is one of the most rewarding activities of any teacher's career, and this book is designed to help you make the process easier by learning from our experiences."

—from Chapter 1 of *Staging Family Science Nights*

If so, *Staging Family Science Nights* is the playbook for you. It provides the script you need to create an informal learning environment that will generate enthusiasm and enjoyment of science for the entire family. Written by teaching pros with years of experience directing science nights, the book is

- **PERFECT FOR PRAGMATIC PLANNERS.** You get detailed, step-by-step guidance from the earliest planning stages to the day of the event to post-production. Topics include funding, supplies, safety, costumes, and snacks.
- **DEDICATED TO GOOD SCIENCE.** The activities are designed to help learners improve their understanding of science in a setting that's fun for everyone. Activities provide a base of experiences for constructing important knowledge at a later date, discovering an interesting new area of science, or re-engaging with content participants have forgotten.
- **FLEXIBLE ENOUGH FOR STUDENTS FROM ELEMENTARY THROUGH HIGH SCHOOL.** You can also adapt the book for use with scout troops, homeschoolers, libraries, summer camps, and museums.
- **VERSATILE.** It's written to be a crowd-pleaser, whether you're a science-night veteran looking for fresh ideas or a first-time organizer asking, "Where do I start?"

As the authors write, "From our years of experience with Family Science Nights, we found that this is one of the most anticipated events of the school year." The event will bring your community together while fostering a positive attitude about science and science education. Best of all, the authors say, "Students who engage in learning science outside the classroom are better prepared for learning in the classroom."

Grades K–12

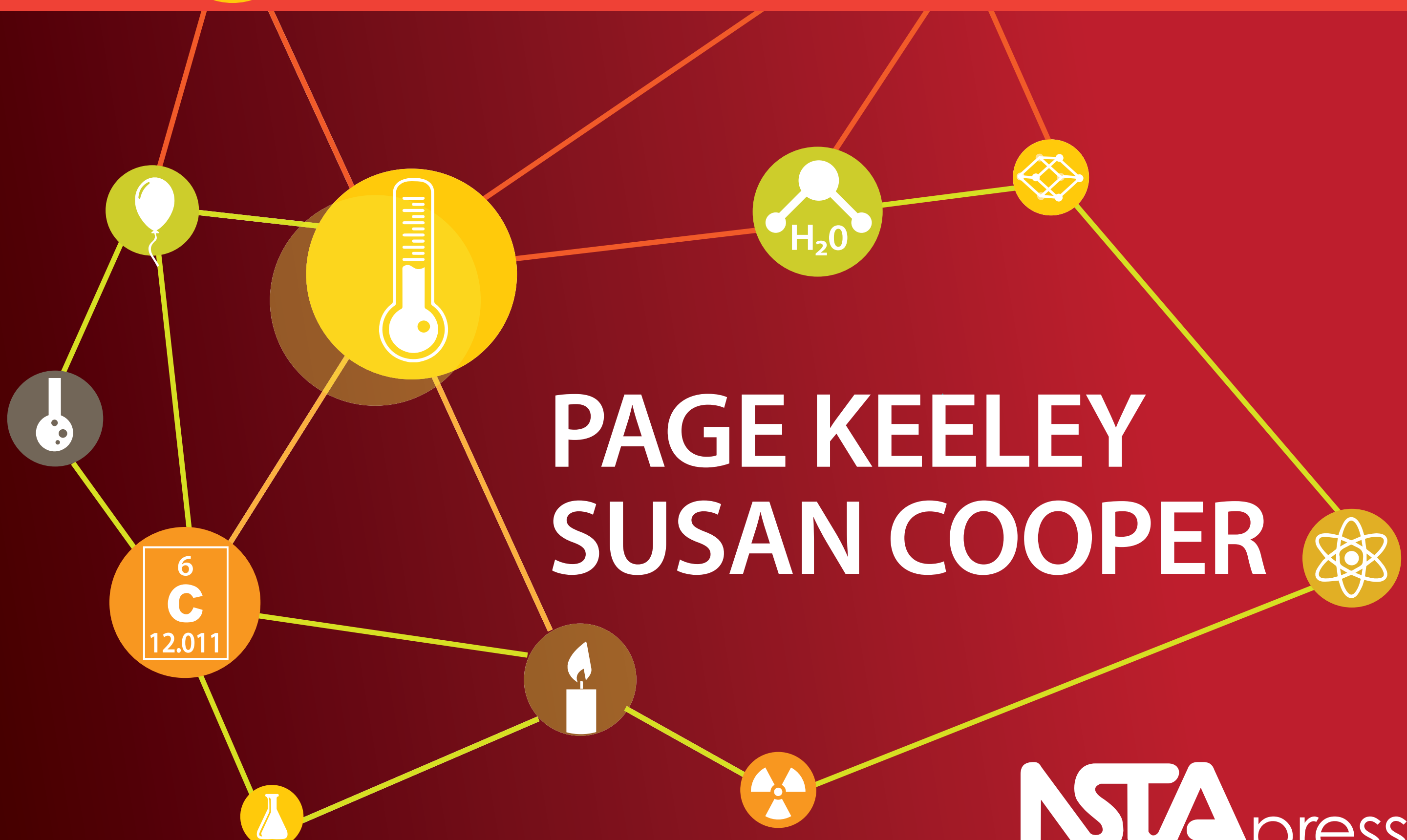
NSTApress
National Science Teachers Association

PB443X
ISBN: 978-1-68140-623-7
9 781681 406237

VOL. 3

Uncovering Student Ideas IN PHYSICAL SCIENCE

32 NEW Matter and Energy Formative Assessment Probes



PAGE KEELEY
SUSAN COOPER

NSTApress
National Science Teachers Association

NSTA press®
National Science Teachers Association

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Andrea Silen, Associate Editor
Jennifer Thompson, Associate Editor
Donna Yudkin, Book Acquisitions Manager

Art and Design
Will Thomas Jr., Director
Cover, Interior Design, and Illustrations
by Linda Olliver

Printing and Production
Catherine Lorrain, Director

National Science Teachers Association
David L. Evans, Executive Director

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

22 21 20 19 4 3 2 1

NSTA is committed to publishing material that promotes the best in inquiry-based science education. However, conditions of actual use may vary, and the safety procedures and practices described in this book are intended to serve only as a guide. Additional precautionary measures may be required. NSTA and the authors do not warrant or represent that the procedures and practices in this book meet any safety code or standard of federal, state, or local regulations. NSTA and the authors disclaim any liability for personal injury or damage to property arising out of or relating to the use of this book, including any of the recommendations, instructions, or materials contained therein.

Library of Congress Cataloging-in-Publication Data
Keeley, Page.
45 new force and motion assessment probes / by Page Keeley and Rand Harrington.
p. cm. -- (Uncovering student ideas in physical science ; v. 1)
Includes bibliographical references and index.
ISBN 978-1-935155-18-8
1. Force and energy--Study and teaching. 2. Motion--Study and teaching. 3. Educational evaluation. I. Harrington, Rand. II. Title. III. Title: Forty-five new force and motion assessment probes.
QC73.6.K44 2010
530.071--dc22
2010010354

eISBN 978-1-936137-70-1

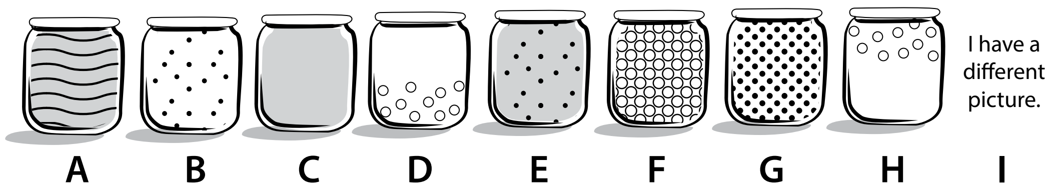
The ISBN for this title is 978-1-68140-604-6 and the e-ISBN is 978-1-68140-605-3.

Contents

Section 3: Classifying Matter, Chemical Properties, and Chemical Reactions

Section 4: Nuclear Processes and Energy

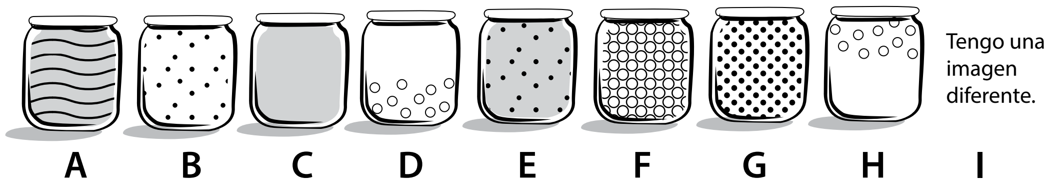
Model of Air Inside a Jar



The drawings show different models of air inside a sealed jar. Circle the drawing that best matches how you would draw a model of air inside a jar.

Explain your thinking. If you chose I, draw your model below and explain it. Describe how it is different from the other models.

Modelo de Aire Dentro de un Frasco

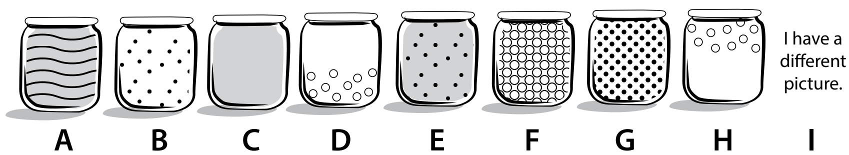


Los dibujos muestran diferentes modelos de aire dentro de un frasco sellado. Marque el dibujo que es más cómo dibujarías un modelo de aire dentro de un frasco.

Explica lo que piensas. Si eliges I, dibuja tu modelo y explícalo. Describe cómo es diferente comparado a los otros modelos.

Model of Air Inside a Jar

Teacher Notes



Purpose

The purpose of this assessment probe is to elicit students' ideas about the particle model of matter. The probe is designed to find out if students recognize that air is made up of particles that are widely spaced with empty space between the particles.

Type of Probe

Representation analysis

Related Concepts

Air, gas, molecule, particle

Explanation

The best representation is B, which represents particles widely and randomly distributed throughout the jar with empty space between them. Air is a gaseous mixture made up of molecules of different gases (nitrogen, oxygen, argon, water vapor, carbon dioxide, and small amounts of other gases). In a gas, the molecules are randomly spaced further apart than in a solid and liquid and are free to move about. The molecules are not arranged as a continuous form of matter; instead, there is empty space between the molecules that does not contain matter. A, C, and E represent a continuous model of matter in which there is something filling the space. A and C may also reveal a non-particle view of matter. E represents both a particle and continuous model of matter. D represents a particle model with nothing between the particles but the particles are not distributed throughout the jar. The particles are at the bottom and there is empty space above them. F shows particles packed tightly with very little space between them. G represents a particle model but the particles have a very orderly, structured arrangement. H is the opposite of D, with empty space at the bottom of the jar. Some students may think the particles float to the top. Some students may choose I and draw their own model. Carefully examine their model, which could be similar to B or reflect a completely different conceptual model.

Under normal conditions, gases are typically considered to be 100 to 1,000 molecular diameters apart. The size of the particles in B is also not to scale. These aspects of a particle model are difficult to portray to scale in the diagrams. It is important to recognize that models cannot always portray all aspects of the real thing.

Administering the Probe

This probe is best used with grades 5–12. Hold up an empty open jar for students to see and seal it with the top. Explain that the jar contains air just like the jars in the diagrams. It may be helpful to explain that the representations are mental models—what someone might visualize in their head if they had a very powerful imaginary magnifier that let them see the air in the jar. Refrain from using the terms *particle* or *molecular model,* as the probe intentionally does not use these words to reveal whether students have the idea that air is composed of particles or molecules. Emphasize that if the pictures do not exactly match a students' mental model of air, they should choose the one that is most like their mental model. You might also point out that models cannot always represent all aspects of the real thing, especially scale size and distance. Let students know that if their mental model of air inside the jar is significantly different, they may choose I and draw their model and explain it. Some students may choose G and provide the explanation that the particles are distributed throughout the jar and there is empty space between them, even though the representation depicts a very orderly, structured arrangement. It is this explanation of particles distributed throughout the jar with empty space between them that may be evident in G or I, even though B may be considered the best representation.

Related Disciplinary Core Ideas and Crosscutting Concepts From the *Framework* (NRC 2012)

3–5 PS1.A: Structure and Properties of Matter

- Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model showing that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon and the effects of air on larger particles or objects.

3–5 Crosscutting Concept: Energy and Matter

- Matter is made of particles.

6–8 PS1.A: Structure and Properties of Matter

- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations.

Related Research

- Students of all ages show a wide range of beliefs about the nature and behavior of particles. For example, they do not accept the idea that there is empty space between particles (AAAS 2009).
- In a study by Benson, Wittrock, and Bauer (1993), elementary through college age students were asked to imagine they had magic magnifying glasses that would let them see the particles of air in a sealed flask. They drew their mental models. Students

with a continuous view of matter shaded in the flask or drew continuous straight or wavy lines throughout the flask. Students with a particulate view drew dots or circles, some spread out, others packed tightly. The tightly packed drawings indicated a lack of understanding of the amount of empty space between molecules. The study also showed that 30% of college students' drawings of air showed particles in a highly packed and orderly arrangement.

- Students at all grade levels frequently do not believe in the notion that there is empty space between the particles of matter. They often hold on strongly to the presupposition that all empty spaces are filled with air (Talanquer 2009).
- Novick and Nussbaum (1978) studied 13- and 14-year-old students' conceptions of a gas inside a sealed flask containing air. Sixty percent indicated that a gas is made up of particles, 46% mentioned empty space between the particles, and 50% recognized that the distribution of the particles was due to their motion.
- Students do not develop particle ideas equally across all three states. Water and gases seemed to be easier substances for students to make the shift from continuous to particulate or molecular views (Nakhleh, Samarapungavan, and Saglam 2005).
- Researchers have associated the students' misunderstanding of the particulate nature of matter with ineffective instruction (Johnson 1998) as well as misrepresentation of the model in some textbooks (Harrison and Treagust 2002).

Suggestions for Instruction and Assessment

- This probe provides an opportunity for students to evaluate mental models. Develop the idea that mental models are a type of conceptual model and that models can also be physical, mathematical, or symbolic.
- Integrate visual tools into instruction when teaching about the particulate nature of matter. Both static and animated representations should be included with multiple opportunities for students to critique and discuss visual models they develop as well as ones used in instructional materials.
- Extend this probe to ask students to draw their model of the air in the jar after half the air is removed from the sealed jar.
- Extend the probe by asking students to draw their model of air in an open jar.
- For probes such as this one that ask students to visualize the "invisible," have students imagine they have special glasses with unlimited magnification that allows them to see the very smallest things that exist. Ask them to draw what they see through these imaginary glasses.
- Simply telling students that gases are made up of small particles that spread out to fill their container is not enough to change their strong preconceptions. Carefully chosen demonstrations, simulations, and animations are most effective when they stimulate cognitive conflict that enables learners to reconsider their existing ideas.
- Use large veterinary syringes (without needles) to let students explore how to catch air inside and feel the air pushing against their hands when they push the plunger. Ask students to use particle ideas to explain why the air can be compressed into a smaller space.
- Emphasize how models cannot always represent all aspects of the real thing, especially scale size and distance. After students agree on which diagram is the best representation of air in a sealed jar, ask them what would need to be done to improve the model.

References

American Association for the Advancement of Science (AAAS). 2009. Benchmarks for science literacy online. *www.project2061.org/publications/bsl/online.*

Benson, D., M. Wittrock, and M. Bauer. 1993. Students' preconceptions of the nature of gases. *Journal of Research in Science Teaching* 30 (6): 587–597.

Harrison, A., and D. Treagust. 2002. The particulate nature of matter: Challenges in understanding the submicroscopic world. In *Chemical education: Towards research-based practice,* ed. J. Gilbert, O. Jong, R. Justi, D. Treagust, and J. Driel, 189–212. Dordrecht, Netherlands: Kluwer Academic Publishers.

Johnson, P. 1998. Progression in children's understanding of a "basic" particle theory: A longitudinal study. *International Journal of Science Education* 20 (4): 393–412.

Nakhleh, M., A. Samarapungavan, and Y. Saglam. 2005. Middle school students' beliefs about matter. *Journal of Research in Science Teaching* 42 (5): 581–612.

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

Novick, S., and J. Nussbaum. 1978. Junior high school pupils' understanding of the particulate nature of matter: An interview study. *Science Education* 62 (3): 273–281.

Talanquer, V. 2009. On cognitive constraints and learning progressions: The case of "structure of matter." *International Journal of Science Education* 31 (15): 2123–2136.

VOL. 3

Uncovering Student Ideas IN PHYSICAL SCIENCE

32 NEW Matter and Energy Formative Assessment Probes

Have you been wanting to probe your students' thinking about major concepts in matter and energy? Have you been wishing for formative assessment tools in both English and Spanish? Then this is the book you've been waiting for.

Like the other 10 books in the bestselling *Uncovering Student Ideas in Science* series, *Uncovering Student Ideas in Physical Science, Volume 3* does the following:

- Presents engaging questions, also known as *formative assessment probes*. The 32 probes in this book are designed to uncover what students know—or think they know—about the concept of matter and particle model of matter; properties of matter; classifying matter, chemical properties, and chemical reactions; and nuclear processes and energy. The probes will help you uncover students' existing beliefs about everything from a particle model of matter to ways of describing energy.
- Offers field-tested teacher materials that provide the best answers along with distracters designed to reveal conceptual misunderstandings that students commonly hold. Since the content is explained in clear, everyday language, teachers can improve their own understanding of the science they teach.
- Is convenient and saves you time. The probes are short, easy-to-administer activities for speakers of both English and Spanish that come ready to reproduce. In addition to explaining the science content, the teacher materials include connections to *A Framework for K–12 Science Education* and the *Next Generation Science Standards*, provide summaries of the research on students' ideas, and suggest grade-appropriate instructional methods for addressing students' ideas.

Uncovering Student Ideas in Physical Science, Volume 3 has the potential to help you transform your teaching. As the authors write in the book's introduction, "When teachers take the time to uncover [existing] ideas, understand where they came from, and make instructional decisions that will help students give up their strongly held ideas in favor of scientific ways of thinking, they are taking an important first step in teaching for conceptual understanding."

PB274X3
ISBN: 978-1-68140-604-6

9 781681 406046

GRADES 3–12

NSTApress
National Science Teachers Association

EUREKA, AGAIN! K–2

SCIENCE ACTIVITIES AND STORIES

DONNA FARLAND-SMITH
JULIE THOMAS

NSTApress
National Science Teachers Association

EUREKA, AGAIN! K–2 SCIENCE ACTIVITIES AND STORIES

DONNA FARLAND-SMITH
JULIE THOMAS

NSTApress
National Science Teachers Association
Arlington, Virginia

NSTA press®
National Science Teachers Association

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Deborah Siegel, Associate Editor
Andrea Silen, Associate Editor
Donna Yudkin, Book Acquisitions Manager

Art and Design
Will Thomas Jr., Director
Joe Butera, Senior Graphic Designer, cover and interior design

Printing and Production
Catherine Lorrain, Director

National Science Teachers Association
David L. Evans, Executive Director

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

21 20 19 18 4 3 2 1

NSTA is committed to publishing material that promotes the best in inquiry-based science education. However, conditions of actual use may vary, and the safety procedures and practices described in this book are intended to serve only as a guide. Additional precautionary measures may be required. NSTA and the authors do not warrant or represent that the procedures and practices in this book meet any safety code or standard of federal, state, or local regulations. NSTA and the authors disclaim any liability for personal injury or damage to property arising out of or relating to the use of this book, including any of the recommendations, instructions, or materials contained therein.

Cataloging-in-Publication Data
Names: Farland-Smith, Donna, author. | Thomas, Julie, 1947- author.
Title: Eureka, again! : K-2 science activities and stories / by Donna Farland-Smith and Julie Thomas.
Description: Arlington, VA : National Science Teachers Association, [2018] | Includes index.
Identifiers: LCCN 2018019041 (print) | LCCN 2018022737 (ebook) | ISBN 9781681403175 (e-book) | ISBN 9781681403168 (print)
Subjects: LCSH: Science--Study and teaching (Elementary)--Activity programs--United States. | Next Generation Science Standards (Education)
Classification: LCC LB1585.3 (ebook) | LCC LB1585.3 .F36 2018 (print) | DDC 372.35/044--dc23
LC record available at *https://lccn.loc.gov/2018019041*

CONTENTS

CONTENTS

CONTENTS

CONTENTS

FOREWORD

Julie Thomas

Jane Goodall showed considerable interest in science and nature as a young girl. She is known for watching a chicken until she understood how the egg came out (Winter 2011) and tucking a handful of earthworms under her pillow (Goodall 1999). As Jane remembers, her mother did not scold her for bringing the soil and worms to bed. Instead, her mother took time to explain that the worms needed to be returned to the outdoors or they would die. Still today, Jane insists her mother's support greatly influenced her early thinking and lifelong passion for scientific understanding. What's important here is that Jane's mother didn't shy from teaching a young child about the relationships between organisms and their environment. The worms, of course, needed the moisture and nutrients found in soil—and some plants needed the benefit of the worms' tunneling and some animals looked to the worms as food.

Certainly, developing complex understandings of the interdependence of living things also seems a lofty goal for K–2 children. However, giving some thought to purposeful ways we can begin to deepen students' knowledge and awareness of science and engineering lays a foundation for later learning. The purpose of this foreword is to provide some insight into what research says about children's developing capacity to learn science and what teachers can do to broaden K–2 students' interests in science, engineering, and medical (SEM) careers.

Early Science Learning

Have you ever watched a toddler's playful highchair game—the one where the child repeatedly pushes a spoon over the edge of the tray and then leans over to watch the spoon hit the floor? These repeated actions (and observable feedback loops) help young children gather information about the mechanics of physical objects and help us know they develop general reasoning and problem-solving skills (i.e., underpinnings of the scientific processes) from a very young age. In fact, research tells us children are not as cognitively limited as we once thought. Rather, they bring a wealth of capabilities to the learning process (Duschl, Schweingruber, and Shouse 2007). Young children have a natural interest in science, and their reasoning abilities suggest they can benefit well from relatively complex lessons. Our challenge as teachers is to build on children's prior knowledge as we help them further understand and apply scientific knowledge.

One thing to keep in mind is that not all children experience the same early science learning opportunities. There is likely great variability across your students' prior experiences when it comes to visiting science museums, reading science books, engaging in experiments, or interacting with scientists. Teachers can help equalize opportunities for all K–2 students by exposing them to a variety of resources to help broaden their knowledge and understanding of the work of scientists and engineers and inspire SEM careers.

How Do Children Form Career Aspirations?

Curricula and assessments that are based on the *Next Generation Science Standards* (NGSS Lead States 2013) are intended to improve students' understanding of science and boost interest in science careers. Importantly, though most career awareness programs begin with middle or high school, career choices actually begin as early as kindergarten (Wahl and Blackhurst 2000) and are primarily influenced by socioeconomic status (Auger, Blackhurst, and Wahl 2005). One way to make sense of this is to think about how children first become aware of the work world via the people and places their parents know. For example, my research among elementary students with low socioeconomic status in rural Oklahoma helped explain why so many fifth graders aspired to medical careers (Hulings, Thomas, and Orona 2013). Conversations with the children helped me learn they regularly accompanied their pets and grandparents to visit the doctor—and usually went right along with them into the examination rooms. These students could tell us a lot about the tools and procedures these doctors used. One unique student, Brittney, aspired to a career in cosmetology—and she had learned what she knew by spending time in her aunt's beauty shop:

> I think [cosmetologists] need to know about science … what types of chemicals [they're] using and how to use them in the right way so they don't affect the person. So there won't be any problems. You need to know how much you need to put in their hair … and whether or not it's too much or too little. (Hulings, Thomas, and Orona 2013)

Some research reveals how children view scientists and engineers—and the kinds of experiences that influence children's drawings of scientists and engineers. Draw-a-scientist studies conclude that most students organize stereotypical views of scientists as white males and occasionally monsters who primarily work indoors (Barman 1997); even students of color are likely to draw white scientists (Finson 2002). Similarly, draw-an-engineer studies find elementary students have a limited conception of the work of engineers (i.e., they mistakenly expect engineers to be mechanics, laborers, and technicians). Chambers (1983) determined children's images of scientists usually begin to appear in when they are in second or third grade and are fully formed by the time children are in fourth or fifth grade. Clearly, the long view of elementary science education is to recognize that scientists and engineers include a broad representation of diverse males and females and encourage and inspire young children to consider SEM careers. So, given that children's home and community experiences limit children's career awareness, how can teachers expand students' career awareness via school experiences?

What Can Teachers Do?

Efforts to broaden children's knowledge and understanding of the work of scientists and engineers will help expand SEM career awareness and aspirations for all—regardless of race, gender, or socioeconomic status. These efforts can include connecting science lessons to science and engineering careers, inviting scientists and engineers to visit your classroom and talk about their work, engaging and involving parents as SEM education allies, and introducing biographies and the personal traits of scientists and engineers.

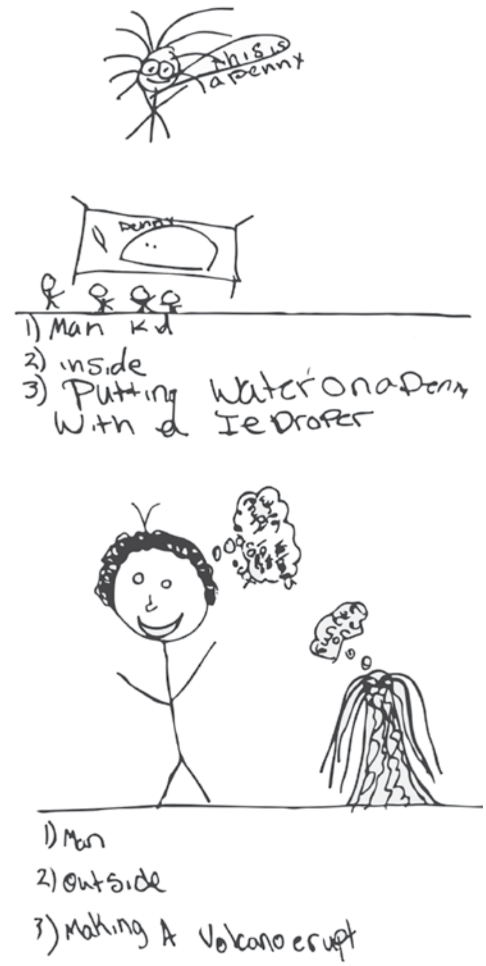
Connect science lessons to science and engineering careers. Think about linking science lessons to real-world career applications (e.g., when and why scientists or engineers measure things). This purposeful addition will illuminate children's observations of scientists and engineers' work and help motivate and inspire students' thinking about SEM careers. Figure 1 shows the importance of augmenting science lessons with conversations about how hands-on classroom activities link to the real world of SEM workers. Of course, opportunities to link lessons to the real world will grow as you become more aware of the work of scientists and engineers—but you can begin in your own community. You might choose to take photographs of these community workers yourself or simply share community news with your students. Consider sharing a photo and asking your students to think about the picture (e.g., how the conservation biologist is observing migrating monarch butterflies). You might be surprised to find real-world connections embedded in science lessons you are already using or in a little-used-section of your science textbook.

Invite scientists and engineers into your classroom. Local career role models can both share the excitement of their work and familiarize your students with the ways scientists and engineers in your area are working to make the world a better place. Certainly, nothing can approximate the personal opportunity to meet an SEM professional. Think about looking to medical groups, engineering societies or firms, universities, or city and state agencies (e.g., transportation and city planning, utilities, recycling, or waste management departments)—even students' parents and families—to recruit enthusiastic SEM professionals. Endeavor to reflect diversity in the workforce (e.g., females, varied ethnic and racial backgrounds) with these classroom guests and to represent a variety of fields and disciplines.

You might also think about the possibility of bringing in virtual classroom guests. There is an ever-increasing number of internet sites designed to demystify the work of scientists and engineers and otherwise encourage SEM career aspirations. My absolute favorite among these is PBS's The

Figure 1

Science Lesson Misconceptions



Some children's drawings of scientists show us how science lessons can confuse students' thinking about the work of scientists. Scientists do not actually use an eyedropper to count how many water drops fit on a penny (a common lesson to teach about water properties) but scientists do follow similar practices to observe phenomena. For example, scientists may not build model volcanoes to watch them erupt but they might build model volcanoes to understand or explain how and when they erupt. Classroom conversations can help deter these misconceptions.

Secret Life of Scientists and Engineers website (*www.pbs.org/wgbh/nova/secretlife*), which is appropriate for people of all ages. Two distinct features of this website are suitable for use with early elementary students: video clips of scientists and engineers telling about their "secret lives" and explaining how their unique passion relates to their work (*www.pbs.org/wgbh/nova/blogs/secretlife/teachers/#video*) and teaching tips that offer ideas about how to incorporate the scientists' stories into your teaching (*www.pbs.org/wgbh/nova/blogs/secretlife/teachers/#teachers*).

At the very least, these scientists and engineers will help you and your students break down stereotypes about who can aspire to an SEM career. The video clips bring young SEM researchers to life and introduce them via a surprising secret life that fuels their work, and vice versa. Some of the inspiring researchers featured on the website include the following:

- Bisi Ezerioha (*www.pbs.org/wgbh/nova/blogs/secretlife/engineering/bisi-ezerioha*) is a high-performance engineer and drag racer. As an engineer, he creates fire-breathing automotive beasts for the track and the street. As a drag racer, he sets speed records but "drives like a grandma" when off the race track.
- Cheri Blauwet (*www.pbs.org/wgbh/nova/blogs/secretlife/blogposts/cheri-blauwet*) is a medical doctor and an accomplished athlete. As a doctor, she specializes in sports medicine and, as a champion wheelchair racer, she earned a gold medal in the Athens games.
- Kathy Reichs (*www.pbs.org/wgbh/nova/blogs/secretlife/anthropology/kathy-reichs*) is a forensic anthropologist and a TV hero. As a scientist, she studies remains to solve real-life crime mysteries and, in the TV world, she was a producer and writer for the series "Bones," which is based on her novels.

Include parents. One way to expand your students' science learning opportunities is to also teach parents and guardians. Are you thinking this idea is "out there" or beyond the call of duty? Well, parent education programming helps parents appreciate what you are teaching and why it makes a difference. Research suggests that parents who "get the message" support the teacher and encourage school learning opportunities (Weiss et al. 2009).

Your parent education efforts could be as simple as regular science feature stories in a school newsletter or on a classroom website. The "work" here might be as simple as posting pictures and stories about the science goings-on in your classroom or alerting parents to science learning opportunities in the community (e.g., programs at a nearby museum or community library). Another easy way to educate parents is to invite them to help (e.g., manage materials) when you plan an engineering design activity with your students. Consider creating some at-home science learning opportunities such as literature-linked science activities from *More Picture-Perfect Science Lessons* (Ansberry and Morgan 2007) to encourage children to explore bubble fluid recipes and bubble wand shapes with their families.

You might also consider organizing parent learning through creative workshops, social gatherings, or content-focused event nights. Family night events—informal, interactive activities—can be a great way to engage family members as engineering teams to imagine, plan, create, and improve together. Smetana et al. (2012) encourage us to think broadly about family—not only parents and grandparents but also siblings, caregivers, and neighbors, too. As these educators learned, multigenerational family units particularly enjoy working together at these events.

When it comes to organizing family learning events, a guidebook titled *Family Engineering* (Jackson et al. 2011) is particularly useful for both novice and experienced planners. This guide, modeled after the popular book *Family Math* (Stenmark, Thompson, and Cossey 1986), provides excellent details about how and why to organize a family engineer event—from how to put together the planning committee, to choosing the location, to developing volunteer roles, agenda guides, and sample room layouts. *Family Engineering* includes two types of event formats (opener activities and engineering challenges); lists of simple, inexpensive materials (e.g., plastic cups, brads, and craft sticks); and step-by-step directions. *Opener activities* are self-directed tabletop activities families can engage in at their own pace and *engineering challenges* are more in-depth activities that introduce a variety of engineering fields and engage families in the processes of engineering. One especially nice feature is the organization of the two-sided tabletop activity directions. One side provides a leading question and activity guide while the other side provides an explanation or *engineering connection*. Having organized several family engineering events using this guidebook, we can attest to how easily diverse audiences are drawn in to these activities and engage in thinking and problem-solving challenges as family units.

Introduce biographies and the personal traits of scientists. *Eureka, Again!* presents a series of science lessons linked to biographical books about the accomplishments and early interests and inclinations of famous scientists and engineers. Here, a focus on specific character traits helps us understand how the human dimension of such traits both encourages and supports SEM career choices. One book, *Me … Jane* (McDonnell 2011), introduces Jane Goodall as a young girl whose favorite toy was a stuffed chimpanzee. Jane's career as primatologist began with backyard observations of birds and squirrels. She set her mind to observing animals in Africa when she was 10 years old. As a scientist, Jane showed her observant nature in the discovery of chimpanzees' ability to make and use tools. Another of the books, *Shark Lady* (Keating 2017), tells the story of Eugenie Clark, a young shark lover whose zoology career began with reading about sharks in the library and studying fish in school. As a scientist, Eugenie demonstrated her *fearless* nature when she dove into the open ocean and proved herself "smart enough to be a scientist and brave enough to explore the oceans" (p. 21).

These biographies can help your students realize they possess some of these same character traits and can become scientists and engineers themselves. After all, famous scientists and engineers were once young children who began with a particular disposition or character trait, found a passion, and became famous adults. It just makes sense that explicit focus on character traits (while reading a story and doing a science activity to learn more about a scientist or engineer) will help students understand more about potential SEM career choices. Such explicit connections may be a necessary component to the National Science Foundation's (2008) mission to broaden SEM participation among diverse populations by providing "for the discovery and nurturing of talent wherever it may be found" (p. iii).

References

Ansberry, K., and E. Morgan. 2007. *More picture-perfect science lessons: Using children's books to guide inquiry, K–4*. Arlington, VA: NSTA Press.

Auger, R. W., A. E. Blackhurst, and K. H. Wahl. 2005. The development of elementary-aged children's career aspirations and expectations. *Professional School Counseling* 8 (4): 322–330.

Barman, C. R. 1997. Students' views of scientists and science: Results from a national study. *Science and Children* 35 (1): 18–24.

Chambers, D. W. 1983. Stereotypic images of the scientist: The draw-a-scientist test. *Science Education* 67 (2): 255–265.

Duschl, R. A., H. A. Schweingruber, and A. W. Shouse, eds. 2007. *Taking science to school: Learning and teaching science in grades K–8*. Washington, DC: National Academies Press.

Finson, K. D. 2002. Drawing a scientist: What we do and do not know after fifty years of drawings. *School Science and Mathematics* 102 (7): 335–345.

Goodall, J. 1999. *Reason for hope: A spiritual journey*. New York: Warner Books.

Hulings, M., J. Thomas, and C. Orona. 2013. Influences on 5th grade students' images of scientists and career aspirations. Paper presented at the annual conference of the Association for Science Teacher Educators, Charleston, SC.

Jackson, M., D. Heil, J. Chadde, and N. Hutzler. 2011. *Family engineering*. Portland, OR: Foundation for Family Science and Engineering.

Keating, J. 2017. *Shark lady: The true story of how Eugenie Clark became the ocean's most fearless scientist*. Naperville, IL: Sourcebooks Jabberwocky.

McDonnell, P. 2011. *Me … Jane*. New York: Little, Brown and Company.

National Science Foundation (NSF). 2008. *Broadening participation at the National Science Foundation: A framework for action*. Washington, DC: NSF.

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

Smetana, L. K., J. C. Schumaker, W. S. Goldfien, and C. Nelson. 2012. Family style engineering. *Science and Children* 50 (4): 67–71.

Stenmark, J. K., V. Thompson, and R. Cossey. 1986. *Family math*. Berkeley, CA: Lawrence Hall of Science.

Wahl, K. H., and A. Blackhurst. 2000. Factors affecting the occupational and educational aspirations of children and adolescents. *Professional School Counseling* 3 (5): 367–374.

Weiss, H. B., S. M. Bouffard, B. L. Bridglall, and E. W. Gordon. 2009. *Reframing family involvement in education: Supporting families to support educational equity*. Equity Matters: Research Review, Brief No. 5, The Campaign for Educational Equity, Teachers College, Columbia University, New York.

Winter, J. 2011. *The watcher: Jane Goodall's life with the chimps*. New York: Schwartz & Wade.

SCIENTISTS AND ENGINEERS ARE

CATALYSTS

Learning About Isatou Ceesay

Catalyst (n.): a person or event that quickly causes change or action

Lesson: Engineering a Solution

Description

In this lesson, students test different types of plastics for strength and create a new design just as Isatou Ceesay did with the families in her community.

Objectives

Students will consider being a catalyst as the character trait that helped Isatou Ceesay do something about the quality of her environment and create new uses for old plastic bags.

- In the Play portion of the lesson, students will arrange plastic bags from strongest to weakest based on their observations and predictions.
- Students will hear the story *One Plastic Bag: Isatou Ceesay and the Recycling Women of The Gambia* by Miranda Paul and discuss how it relates to the character trait of being a catalyst.
- In the Explore portion of the lesson, students will keep a running tally of how many bags they use at their house in a week. Students will observe several items that can be made from plastic bags.
- In the Discuss portion, students will observe several items that can be made from plastic bags and attempt to make a new item from the materials.

Learning Outcomes

Students will (1) discuss what being a catalyst means and why being a catalyst is an important trait for scientists and engineers and (2) ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.

Connections to the *NGSS*

The following sections make one set of connections between the instruction outlined in this lesson and the *NGSS*. Other valid connections are likely; however, not all possibilities are listed.

Performance Expectation	Connections to Activity
K-2-ETS1-3: Analyze data from tests of two objects designed to solve the same problem to compare the strengths and weaknesses of how each performs.	• Students analyze data from testing plastic bags and design a new tool from the plastic using the data collected.
Science and Engineering Practice	**Connections to Activity**
Constructing Explanations and Designing Solutions	• Students construct a new design from plastic bag strips that will solve a problem they have identified.
Disciplinary Core Idea	**Connections to Activity**
ESS3.C. Human Impacts on Earth Systems Things that people do to live comfortably can affect the world around them. But they can make choices that reduce their impacts on the land, water, air, and other living things.	• Students will learn about and observe different types of plastic bags in a fair test. They will consider how one plastic versus another would best solve a problem.
Crosscutting Concept	**Connections to Activity**
Structure and Function	• The structure and function of the plastic bag affects the new design.

Overview

In this lesson, students learn how one woman addressed the overwhelming challenge of cleaning up garbage and plastic debris in the form of plastic bags in her community in The Gambia, West Africa. By reading the featured book, students will learn that men and women from all backgrounds choose careers as scientists. The character trait of being a catalyst refers to Isatou Ceesay's determination to solve the problem she encountered in her community. Students will share their

Isatou Ceesay

ideas about scientists as engineers and will discuss how problems are solved. Students will explore multiple solutions for recycling plastic bags and learn why Isatou Ceesay decided to recycle plastic bags and transform her community.

Materials

You will need a copy of the featured book *One Plastic Bag: Isatou Ceesay and the Recycling Women of The Gambia* by Miranda Paul (2015). For each small group (or the class as a whole), you will need approximately 50 plastic bags from grocery stores (send the letter on p. 193 home with students, asking parents to help them collect plastic bags to bring to class). You will need three different kinds of bags (resealable plastic bags, trash bags, and store bags) to test the strength of each in the Explore portion of the lesson.

Safety Notes

(1) Remind students not to place the plastic bags over their heads or mouths during the activity. (2) Use caution when working with scissors or sharps—these can cut or puncture skin.

Setting the Context

Play

Ask students if they have ever noticed that not all plastic bags are alike. There are some that we put our groceries in, some that we put our trash in (trash bags), and some that we put our sandwiches in (resealable plastic bags). Ask students what other kinds of plastic bags they can think of. Discuss these observations with the entire class and make a list in the classroom of the different types of plastic bags. Bring in samples for students to observe, and have the class work together to line up the bags from strongest to weakest. *(Teacher Note: Plastics are used for all sorts of purposes in our lives today. The scientists that study and make new plastics are called engineers [chemical engineers]. Plastics are often used because they are less expensive to make and more durable than other materials, but they are not always good for the environment if they are not disposed of properly or if they are overused, as students will learn from the story you read.)*

Guided Reading

Students will be learning about Isatou Ceesay and her attempt to solve a problem and clean up her community. Find The Gambia on a map and explain to students that it is part of West Africa. Introduce the book by holding up the cover and asking, *What do you think this story is about?* Read the story aloud.

1. **Pages 1–5:** What clues in the first few pages tell you that this story does not take place in America? *(Teacher Note: Some students may notice Isatou's clothing, which is traditional African clothing, or the fact that she carries a basket on her head. If students notice her carrying a basket on her head, you might ask,* Why would she carry a basket on her head? *[If people are carrying loads long distance, it makes it easier if they carry these loads on their heads.] Other students might notice a goat being near Isatou. A goat is not uncommon, but having a goat at your house may seem strange to some students.)*

2. **Pages 5–9:** Isatou is carrying fruit back home in her basket and the basket breaks. What does she notice floating around outside? Why do people seem to let their bags float away? *She notices plastic bags in different colors either floating in the wind or piled up in the dirt. They become part of the scenery until she decides to do something about them as a grown woman.*

3. **Pages 12–14:** The plastic bags tossed out into the open caused many problems for the villagers and the animals. Name at least two problems caused by the piles of plastic bags all around Isatou's village. *One problem was the smell of dirty trash. Animals such as goats would scavenge for food, and they risked eating the bags and dying. Mosquitoes also swarmed near the trash piles.*

4. **Pages 15–17:** Isatou asked her friends one important question that began a positive change in behavior. What was that question? And how did this question solve a problem? *The question Isatou asked was* What can we do? *Isatou and her friends began problem solving to find solutions. They began to wash the bags and then laid them out on the clothesline. Isatou's sister was crocheting as the bags were drying, and they came up with the idea to make "thread" from the bags hanging on the clothesline.*

5. **Pages 20–26:** Isatou teaches the other women to crochet by candlelight, and they design a purse. How did the people in the village react to the women "who believed they were doing something good by crocheting the plastic"? *Some people laughed at the women. Some people said they were dirty for working with those old, ripped, and stinky plastic bags. But many people also wanted to pay for the purse, and Isatou soon had enough money for a new goat. The new plastic purses she engineered not only brought her financial wealth—but also did something very important: They reduced the amount of trash and rubble in the streets.*

Making Sense

Explore

In the story, the plastic bags are able to be recycled and used in a different way because of the plastic they were made from. The bags, once cut and woven together, are actually stronger than before. In this portion of the lesson, students will explore the properties of plastic.

THE *HOW* OF THE EXPLORE

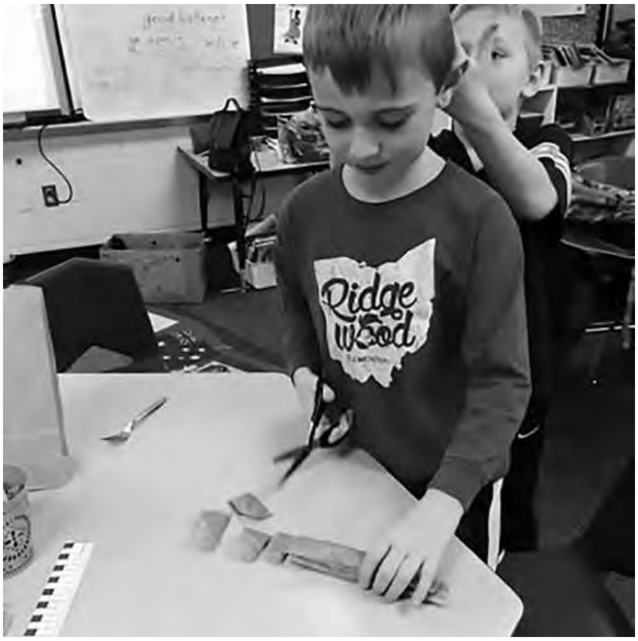
Select three types of plastic bags for students to experiment with. Ask them to record their predictions in the prediction portion of Table 7.2 (p. 191). Ask students to develop a way to test these ideas. Discuss how a "fair test" is conducted. *(Teacher Note: A "fair test" controls for variables and uses a number of trials. For example, I typically ask my students to identify what will be the thing that is different in testing the strength of the plastic bags. The one thing that will be different is the type of plastic bag to be tested. This is the variable. Then I ask students how many times scientists do experiments—for example, do they just do them once and get an answer? Most students are aware that a scientist must test something more than once to arrive at a conclusion that will be respected by the science community. Usually we arrive at a "three and done" rule for testing any* *kind of science experiment. We end by asking the students if they think this is fair or not because we are trying to conduct a "fair test.")* In this portion of the lesson, students will also have to determine the size of the plastic bag to test. For example, a trash bag is much larger than a plastic bag from the store, so how can they make three different bags the same size, and how can you make this lesson about the material versus the size of the bag? Select an appropriate amount of weight to test. Books are usually readily available and easy to manage with younger children. Gather students around and test out the number of books each piece of plastic can hold before breaking. Have students design a new product from the bags if time allows.

Figure 7.2

A Purse Made From Recycled Plastic Bags

Figure 7.3

Trim the Handles Off the Bag

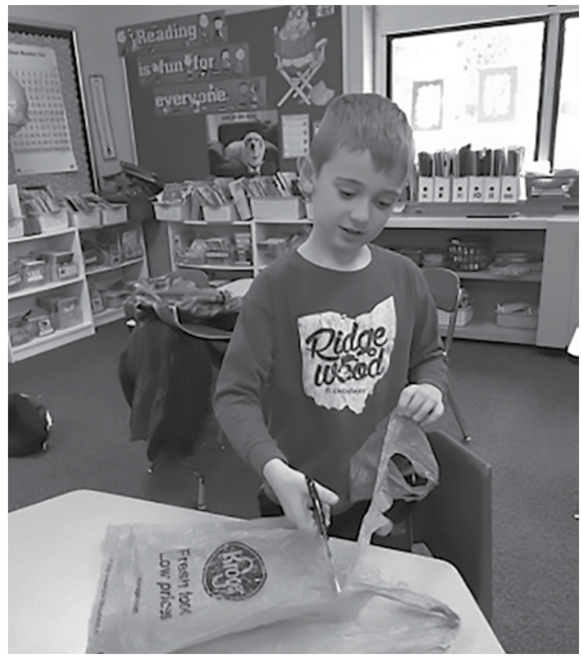


THE *WHY* OF THE EXPLORE

In the featured book, the plastic bags are able to be recycled and used in a different way because of the plastic they were made from. The bags, once cut and woven together, are actually stronger than before. In this portion of the lesson, students will explore different ways plastic bags can be recycled and will be challenged to make a new creation from recycled plastic parts. *(Teacher Note: There are many items that can be made from plastic bags, including flowers* [www.sillysimpleliving.com/2012/01/17/use-plastic-bags-to-make-your-own-flowers], *shoes, and coats. You may want to share some websites with students, such as "12 Amazing Things Made from Plastic Bags"* [www.oddee.com/item_97040.aspx]*).* You may have an example to show your students (see Figure 7.2 for an example of a purse). You can also easily make a jump rope. Challenge students to create a new item from recycled bags. Begin by cutting off the top of a recycled bag (Figure 7.3) and then cutting the remaining bag into 1-in. circular strips (see Figure 7.4) . This will take some preparation on your part, and child or parent volunteers could be very helpful.

Figure 7.4

Fold the Remainder of the Bag into a 1-in. Strip and Then Cut



Discuss

Hand out the plastic bags students have brought to school and allow students to imagine, create, and design items however they wish. Ask them to bring items into class and share these with other students once they have created a new item from an old bag as a way to solve a problem. Students should receive a checklist about asking questions, making observations, and gathering information about a situation people want to change to define a simple problem that can be solved by developing a new or improved object or tool (see p. 194).

Table 7.2

Data Collection Log for the Engineering a Solution Activity

Plastic Type	Prediction	Size		Strength Test
		Length	Width	Books
Plastic A: Grocery Store Bag				
Plastic B: Trash Bag				
Plastic C: Resealable Plastic Bag				

Note: A larger version of this table is available at *www.nsta.org/EurekaAgain*.

Evaluate

Summative evaluation of this lesson will include assessment of students' understanding of (1) the character trait of being a catalyst and (2) how to ask questions, make observations, and gather information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool.

Figure 7.5

Weaving From Plastic Bags to Make a Jump Rope

CHARACTER TRAIT

Encourage students to answer the following questions:

1. If Isatou Ceesay had not developed a solution for her village, how might it look today? *Her village may still have trash bags all around if no one motivated and inspired others to clean up the trash. Of course, someone might have eventually thought to pick up plastic bags, but would they have thought of using the bags in such a creative way for financial gain? Isatou Ceesay was the catalyst who envisioned and initiated this engineering feat before anyone else did. (Teacher Note: The point here is to review Isatou Ceesay's effort to help her village and do something about the plastic bags when others just looked the other way. It is important that children understand that the change started with her.)*

2. Why is being a catalyst an important character trait for scientists and engineers? *Oftentimes, people see problems but no solution, so they don't try to make the world a better place. Isatou Ceesay saw the problem and developed a solution on her own. This character trait reinforces the idea that one person can make a difference for many others.*

CONTENT

Once the class has completed their new designs, evaluate these according to the graphic organizer on asking questions, making observations, and gathering information about a situation people want to change to define a simple problem that can be solved through the development of a new or improved object or tool. A new design from a recycled bag should accompany students' journal illustrations. A model of the jump rope they created in class might look like the one shown in Figure 7.5.

LETTER TO PARENTS

Dear Parents,

We have started investigating plastic in class, and students are learning how one woman, Isatou Ceesay, addressed the overwhelming challenge of cleaning up garbage—especially plastic bags—in The Gambia, West Africa. In the book *One Plastic Bag: Isatou Ceesay and the Recycling Women of The Gambia* by Miranda Paul (2015), Ceesay discovers that these bags are able to be recycled and used as purses and in many other ways because of the plastic they are made from. Once cut and woven together, the purses are actually stronger than when they were simply plastic bags! In our classroom lesson related to this book, we will discuss the properties of plastic. Students will explore multiple solutions for recycling plastic bags and learn why Ceesay decided to recycle plastic bags and transform her community.

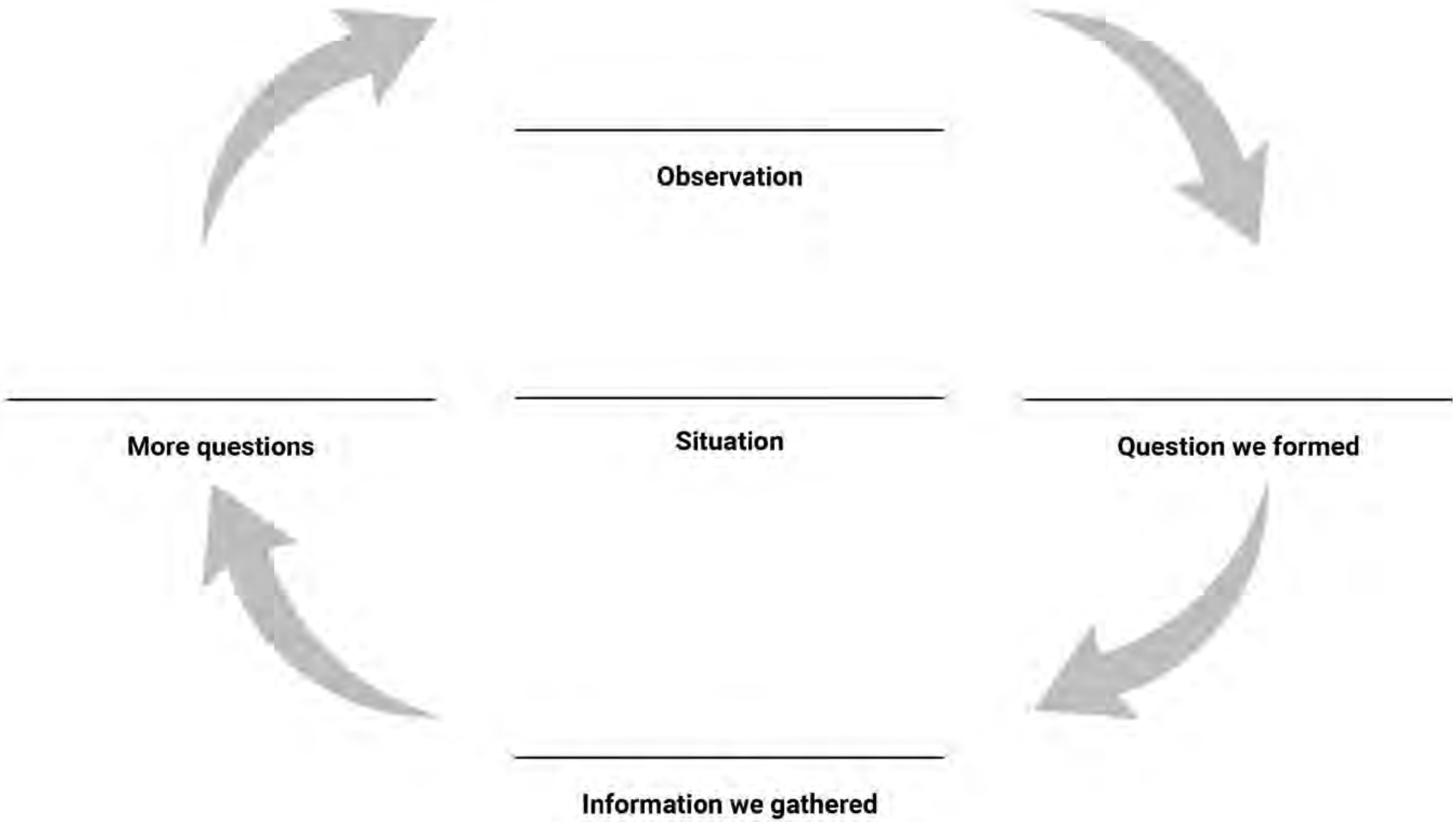
Please collect as many plastic grocery bags as possible for your child to bring into class. We will use them to create new products, just like Ceesay did. Over the next several weeks, be sure to discuss with your child what he or she is learning about plastic and how humans can impact the environment.

Thank you,

____

Name: ______________________________

GRAPHIC ORGANIZER



EUREKA, AGAIN!

K–2 SCIENCE ACTIVITIES AND STORIES

"*Eureka, Again!* offers a rich suite of science lessons expressly developed to involve and inform young learners. This book features an innovative use of age-appropriate, hands-on activities linked to the lives and experiences of actual scientists and engineers and is designed to engage students in learning a wide range of science content and process skills. Simply put, this resource and its grade 3–5 companion have the potential to transform science teaching and learning in the elementary grades."

—William F. McComas, Parks Family Professor of Science Education, University of Arkansas

It's never too early to put a human face on science and engineering! Research shows that a child's ideas about how scientists and engineers look and what they do start to form in the earliest grades. Teachers can help students understand that everyone can do science by introducing inquiry activities in the primary grades. Like its best-selling counterpart for grades 3–5, *Eureka, Again! K–2 Science Activities and Stories* evokes Archimedes's famous cry. That's because it helps children make discoveries of their own about who scientists and engineers are and what they do. The book is so engaging and easy to use that it will become a resource you'll be excited to teach with every year.

Eureka, Again! is appealing because of its lively lessons, which are grounded in 27 children's trade books. Some of the biographies feature famous individuals, such as Rachel Carson and George Washington Carver. Others are not as well known, such as paleontologist Mary Anning and recycler Isatou Ceesay. All of their stories will help students see scientists and engineers not as stereotypes in lab coats but as real people whose success grows out of their life experiences and character traits. They may even inspire children to consider STEM-related careers.

Each chapter is designed to do the following:

- **Focus on science and engineering practices.** These include asking questions and defining problems, planning and carrying out investigations, and analyzing and interpreting data.
- **Bring the processes to life** through the trade books and related lessons. You'll introduce a skill-building, inquiry-based investigation while highlighting the scientists' and engineers' work and the character traits that helped each succeed. You can teach one lesson or all three from each chapter—whatever will enrich your curriculum the most.
- **Be easy to use.** In addition to supporting the *Next Generation Science Standards*, each chapter uses a learning-cycle format and begins with a personal story from the authors that provides valuable insights into teaching this exciting grade range.

Authors Donna Farland-Smith and Julie Thomas point out one other big benefit that makes *Eureka, Again!* a resource you'll keep coming back to. "We like to think of this book as a way to invite scientists and engineers into your classroom," they write, "without the hassle of finding and scheduling guest speakers."

Grades K–2

NSTA press
National Science Teachers Association

PB423X2
ISBN: 978-1-68140-316-8

9 781681 403168

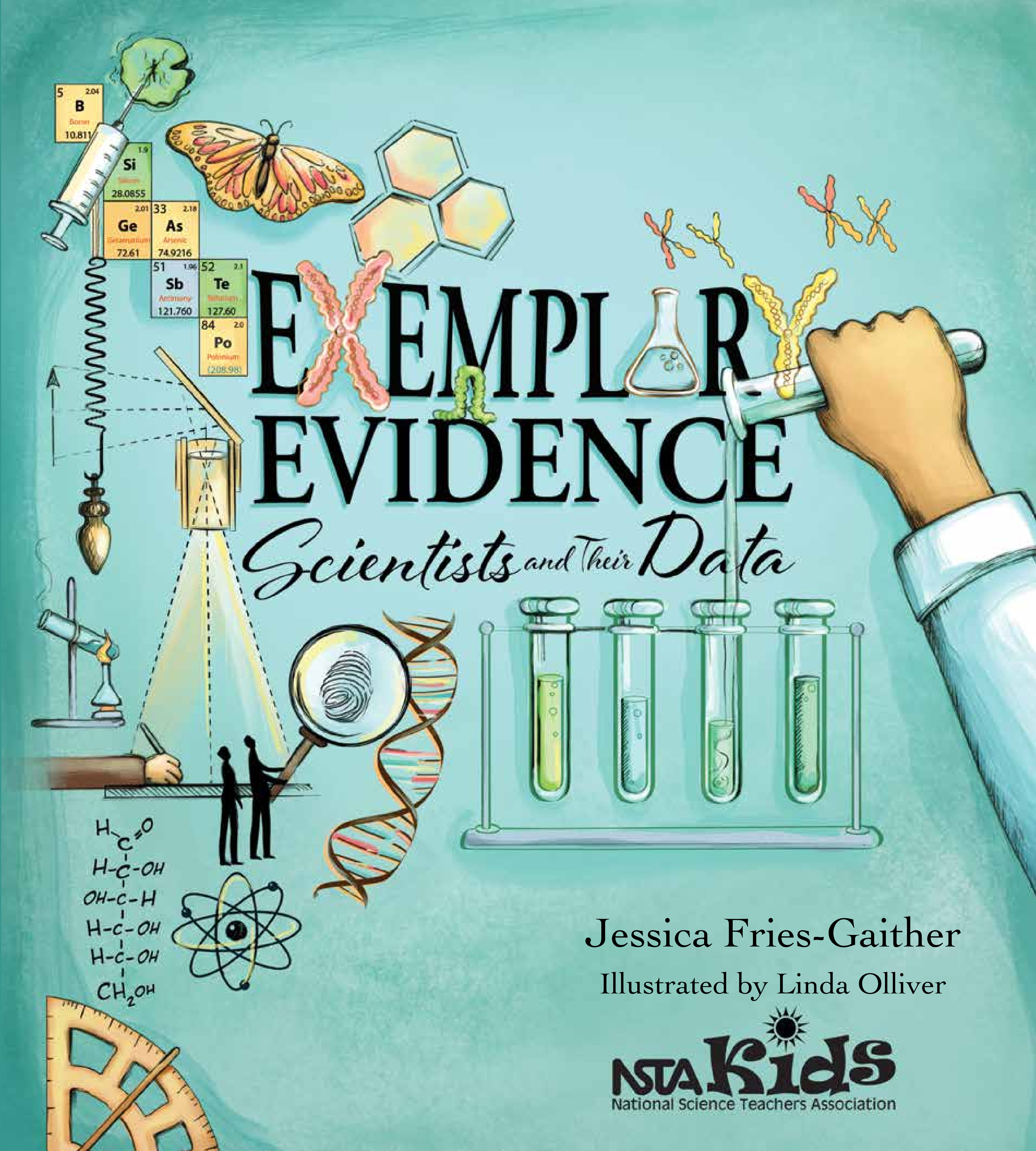
EXEMPLARY EVIDENCE

Scientists and Their Data

Jessica Fries-Gaither

Illustrated by Linda Olliver

NSTA Kids
National Science Teachers Association



NSTA Kids™
National Science Teachers Association

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Deborah Siegel, Associate Editor
Andrea Silen, Associate Editor
Donna Yudkin, Book Acquisitions Manager

ART AND DESIGN
Will Thomas Jr., Director
Linda Olliver, Cover, Interior Design
Illustrations by Linda Olliver

PRINTING AND PRODUCTION
Catherine Lorrain, Director

NATIONAL SCIENCE TEACHERS ASSOCIATION
David L. Evans, Executive Director

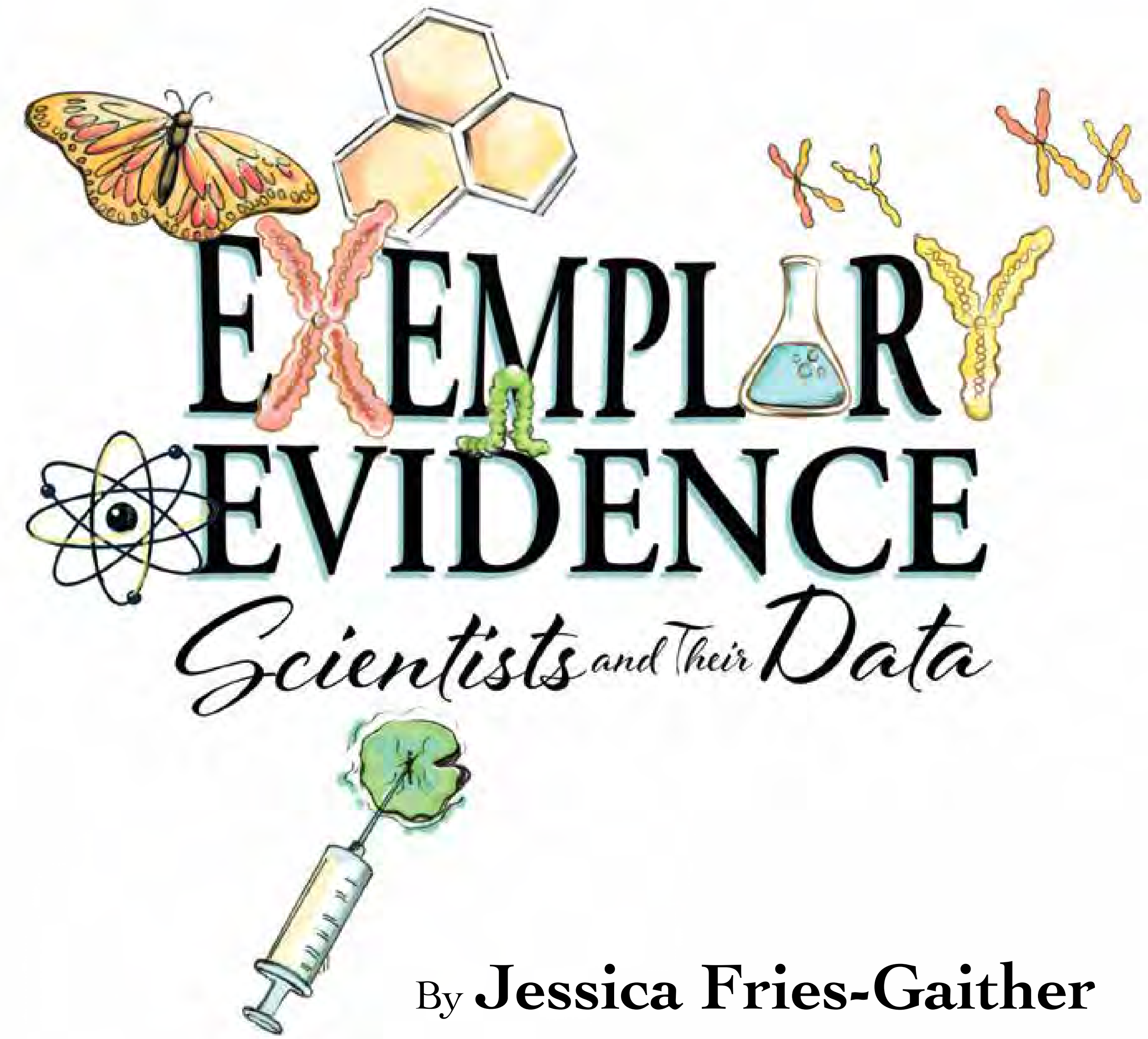
1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

Lexile® measure: 990L

22 21 20 19 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Names: Fries-Gaither, Jessica, 1977- author. | Olliver, Linda, illustrator.
Title: Exemplary evidence : scientists and their data / by Jessica Fries-Gaither ; illustrated by Linda Olliver.
Description: Arlington, VA : National Science Teachers Association, [2018] | Audience: Ages 8-10. | Audience: Grades 4 to 6.
Identifiers: LCCN 2018013924 (print) | LCCN 2018017550 (ebook) | ISBN 9781681403625 (e-book) | ISBN 9781681403618 (print)
Subjects: LCSH: Science--Methodology--Juvenile literature. | Science--History--Juvenile literature. | Scientists--Juvenile literature.
Classification: LCC Q175.2 (ebook) | LCC Q175.2 .F74945 2018 (print) | DDC 507.2/1--dc23
LC record available at https://lccn.loc.gov/2018013924



Exemplary Evidence
Scientists and Their Data

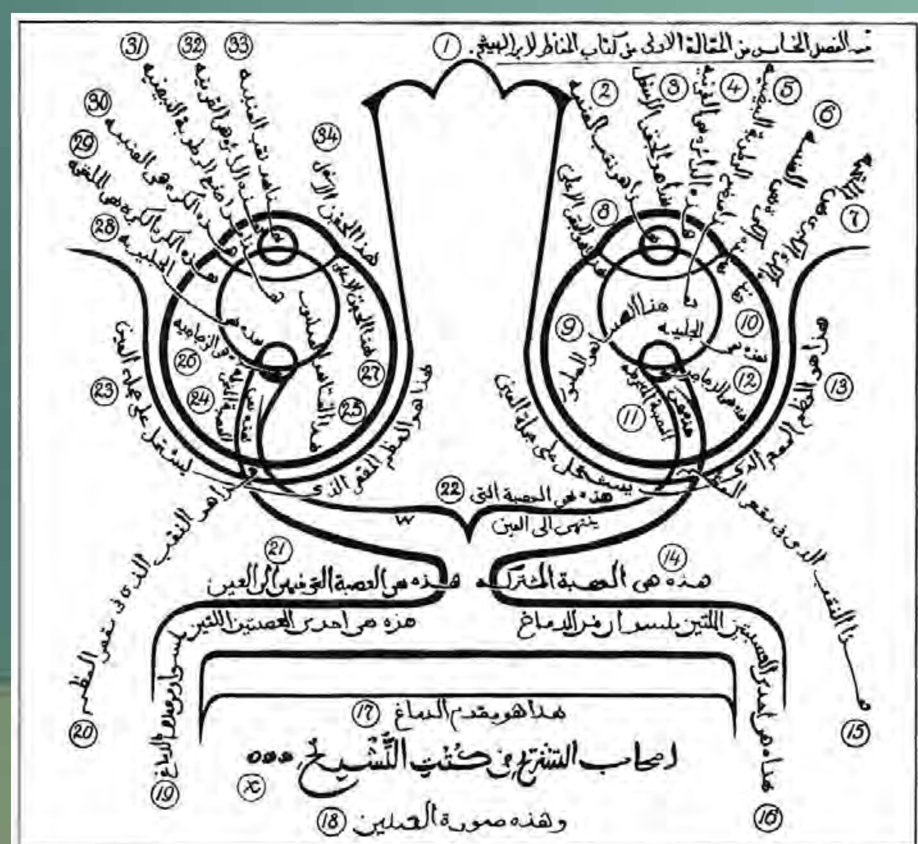
By **Jessica Fries-Gaither**

Illustrated by **Linda Olliver**

NSTA Kids
National Science Teachers Association
Arlington, VA

Alhazen lived in Egypt a thousand years ago,
yet still is important for what he did show.
A groundbreaking study not hard to understand;
investigations need not always be grand.

Into a darkened room, two lanterns shone light,
each of them hung from a different height.
On the far wall, two bright spots could be seen,
each of them formed by a lantern's strong beam.



Alhazen's schematic of the visual system

If he covered a lantern, the spot became dark.
This simple finding ignited a spark.
Light did not come from our eyes, as believed!
Instead, it came from a source, he perceived.

Alhazen went on to more complex topics
and even wrote seven books about optics.
He is remembered, as his method was clear.
He was the first to use data to support
his idea.

The power to show that an idea is untrue—
it's amazing what **collecting data** can do.

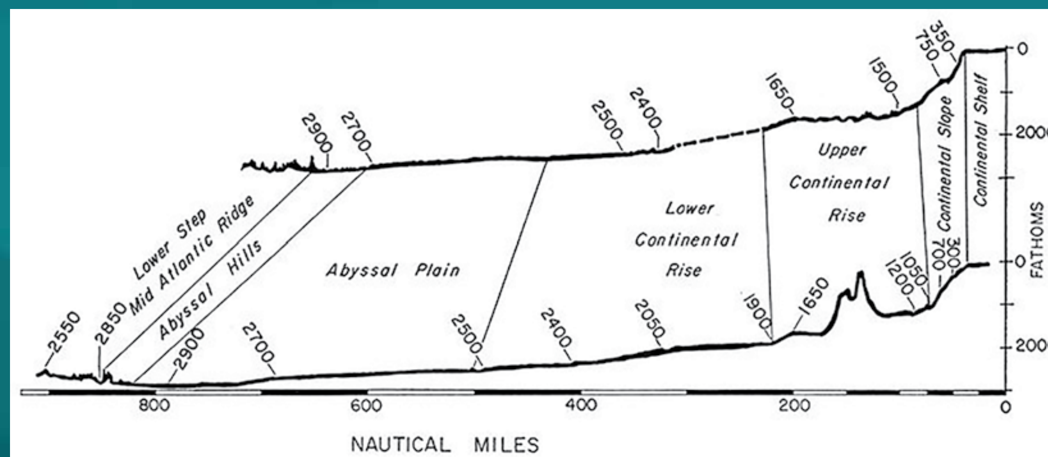
Down deep in the ocean, at the bottom of the sea,
Marie Tharp wondered what there might be.
Very few scientists cared about that,
for they assumed it was boring and flat.

No one could travel there, she had to concede.
So how could they get the data they'd need?
Sonar was used—a great innovation
to measure the depth of underwater locations.

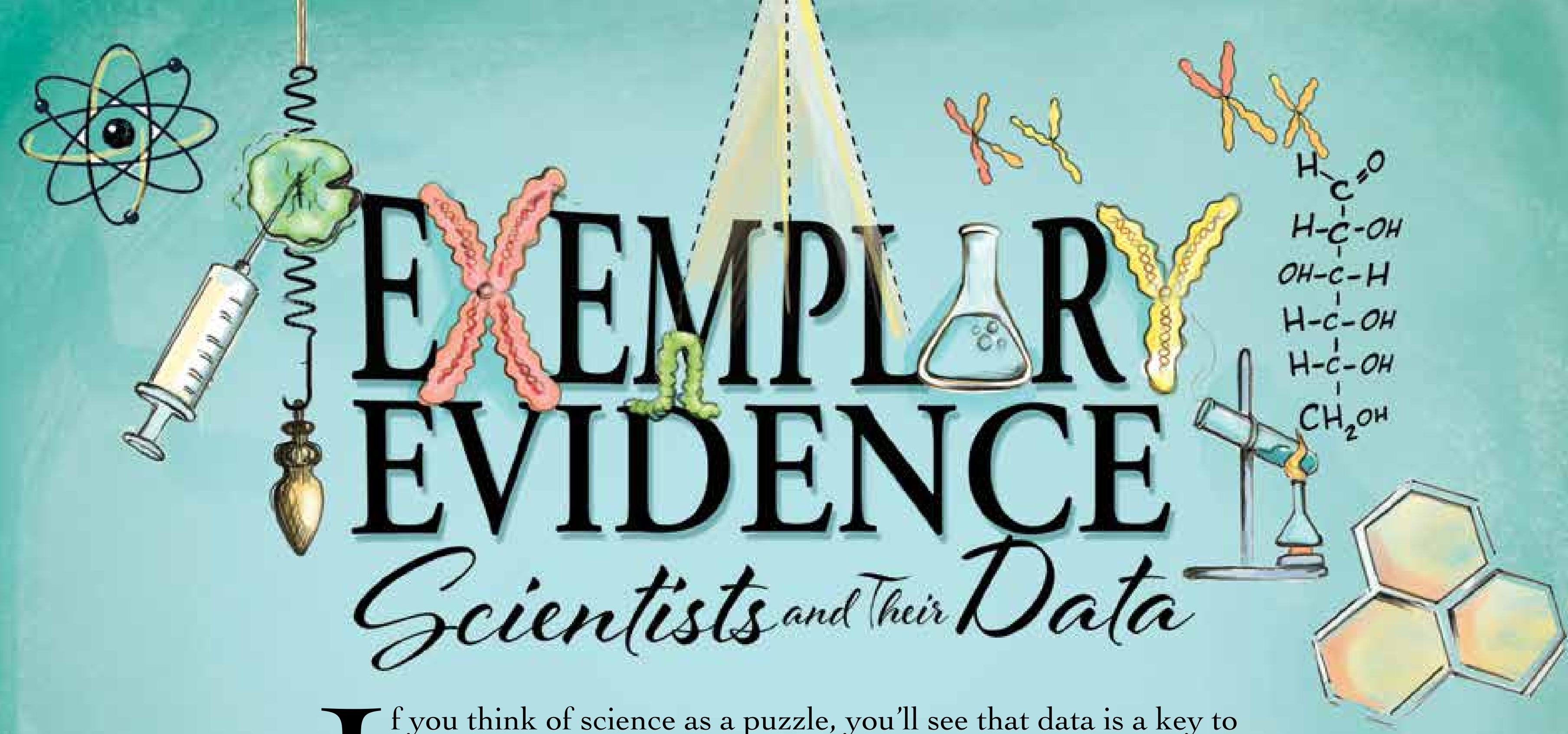
She couldn't go to sea; she stayed on dry land,
plotting out thousands of soundings by hand.
Tedious work, but she and her partner pressed on,
consulting the data for what should be drawn.

Mountain ranges and valleys began to take shape;
it was an entire underwater landscape!
The map she created of the whole ocean floor
was used to prove others' theories and more.

The power to change our current world view—
it's amazing what **visualizing data** can do.



Map of the ocean floor created using Marie Tharp's sounding data



I f you think of science as a puzzle, you'll see that data is a key to unlocking it. *Exemplary Evidence: Scientists and Their Data* touches on the world's many riddles—from how we see to what's at the bottom of the ocean. It shares how scientists have solved such puzzles by collecting measurements, taking notes, and even making sketches. The book also provides mini-bios of the nine featured scientists plus four steps to using data to tease out your own answers about how the world works.

Exemplary Evidence's author is Jessica Fries-Gaither, a science educator who also wrote the award-winning NSTA Kids book *Notable Notebooks*. Once again, she mixes sprightly storytelling with energetic rhyme, and Linda Olliver's light-hearted drawings bring the ideas to life. It all helps explain how a sometimes-unappreciated part of science is as important now as it has been to scientists for centuries. As the author writes:

> *Data supports conclusions; it can change people's minds;*
> *it is used to build theories that help humankind.*
> *Scientists all along have known this to be true:*
> *Data is powerful! Now, what will yours do?*

PB441X
ISBN: 978-1-68140-361-8

Grades 3–5
Lexile® measure: 990L

NSTA Kids
National Science Teachers Association

US $14.95 • CAD $19.95

9–12

ENGINEERING IN THE LIFE SCIENCES

RODNEY L. CUSTER • JENNY L. DAUGHERTY • JULIA M. ROSS
KATHERYN B. KENNEDY • CORY CULBERTSON

NSTA press
National Science Teachers Association

NSTA press®
National Science Teachers Association

Claire Reinburg, Director
Rachel Ledbetter, Managing Editor
Deborah Siegel, Associate Editor
Andrea Silen, Associate Editor
Donna Yudkin, Book Acquisitions Manager

Art and Design
Will Thomas Jr., Director
Joe Butera, Senior Graphic Designer, cover and interior design

Printing and Production
Catherine Lorrain, Director

National Science Teachers Association
David L. Evans, Executive Director

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

21 20 19 18 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Names: Custer, Rodney L., author.
Title: Engineering in the life sciences, 9-12 / by Rodney L. Custer, Jenny L. Daugherty, Julia M. Ross, Katheryn B. Kennedy, and Cory Culbertson.
Description: Arlington, VA : National Science Teachers Association, [2018] | Audience: Grades 9-12. | Includes bibliographical references and index.
Identifiers: LCCN 2018019046 (print) | LCCN 2018021167 (ebook) | ISBN 9781681404783 (e-book) | ISBN 9781681404776 (print)
Subjects: LCSH: Bioengineering--Study and teaching (Secondary)--Juvenile literature.
Classification: LCC TA164 (ebook) | LCC TA164 .C87 2018 (print) | DDC 660.6071/2--dc23
LC record available at *https://lccn.loc.gov/2018019046*

CONTENTS

LESSON 1

B-POCALYPSE

Lesson Overview

Student teams collaborate to design a solution to the challenge of a decrease in pollinator availability for crop production. Life science topics of plant reproduction and systems modeling are integrated with engineering concepts of modeling and design. Teams experience the design loop while designing a hand pollinator prototype based on their understanding of sonication. Teams rely on data collected during investigations and an examination of properties of materials to design a prototype with the desired function of a pollinator as well as the structural characteristics of a model flower. Students use mathematical thinking (through the analysis of graphs and tables) to support design recommendations. Their designs should reflect the structure-function relationship in the context of interdependence within ecosystems. See Table L1.1 (p. 16) for more details.

TABLE L1.1

LESSON 1 ALIGNMENT WITH THE *NEXT GENERATION SCIENCE STANDARDS;* SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) IDEAS; AND PEDAGOGY

Performance Expectations

HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

SCIENCE AND ENGINEERING PRACTICES	DISCIPLINARY CORE IDEAS	CROSSCUTTING CONCEPTS
• Developing and Using Models • Planning and Carrying Out Investigations • Constructing Explanations and Designing Solutions • Obtaining, Evaluating, and Communicating Information	• LS1.A. Structure and Function • LS4.C: Adaptation • LS4.D: Biodiversity and Humans • ETS1.B: Developing Possible Solutions • PS3.A: Definitions of Energy • PS3.B: Conservation of Energy and Energy Transfer • PS4.A: Wave Properties	• Patterns • Cause and Effect • Systems and System Models • Energy and Matter • Structure and Function • Influence of Engineering, Technology, and Science on Society and the Natural World

OBJECTIVES	STEM IDEAS	PEDAGOGY (STEM)	PEDAGOGY (EQUITY)
• Introduce the design challenge • Engage in engineering design process • Deepen understanding of interdependency within ecosystems	• Criteria and constraints • Trade-offs • Prototype • Structure-function • Ecosystem interdependency • Reproductive strategies of plants	• Real-world context • Public artifacts • Engineering vs. science: Design notes	• Think-pair-share • Prior knowledge • Shared public knowledge: Presentation

Purpose

This lesson has three goals. The first goal is to introduce students to justified design, which occurs when design choices for an engineering solution are based on evidence collected from preliminary investigations and understanding of scientific and mathematical principles. In the lesson activities, materials selection is based on properties of the resources that will be available for the prototype development as well as the influence of understanding of interdependence within ecosystems. Justified design occurs when design choices made for an engineering solution are based on data collected during preliminary investigations and the understanding of scientific and mathematical principles. The design should reflect the structure-function concept that supports interdependence between the pollinator and plant. The second goal is for students to develop mathematical thinking skills through data analysis. The third goal is to provide the opportunity for students to gain more experience with the design cycle.

Assessment Criteria

Rubrics covering engineering and life science concepts are included at the end of the teacher section and should be used in the assessment of this lesson. The Engineering Rubric focuses on concepts associated with process, such as defining the problem and developing and revising solutions. Explicit attention to process minimizes overemphasis on the product developed. A Poster and Presentation Rubric is also included to help you assess the relevant work product.

To complete the engineering design challenge, student teams will develop, construct, and test a hand pollinator based on sonication. You should assess each team's design plan, prototype, and testing data using the rubrics described in the preceding paragraph.

Lesson Planning Within a Unit and Learning Progression

This lesson is recommended to be done within an ecosystem unit. Prior learning should address the following topics:

- Organisms, and populations of organisms, are dependent on their environmental interactions with both other living things and nonliving factors.
- In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with one another for limited resources, access to which consequently constrains their growth and reproduction.

The design of the pollinator builds on earlier understanding in the K–12 progression of structure and function within ecosystems. The use of data through graphs and tables increases the complexity of the lesson and places it within the 9–12 learning progression. In regard to the *Next Generation Science Standards* (*NGSS*; NGSS Lead States 2013) science and engineering practice Asking Questions and Defining Problems, this lesson reinforces engagement at the 6–8 level where students ask questions to clarify and define an engineering problem. The disciplinary core idea (DCI) of ETS1.A: Defining and Delimiting Engineering Problems also reinforces the 6–8 level, demonstrating that the more precisely a design task's criteria and constraints can be identified, the more likely it is that the designed solution will be successful. The DCIs of LS1.A: Structure and Function, LS4.C: Adaptation, and LS4.D: Biodiversity and Humans are at the 9–12 level, as are the DCIs of PS3.A, PS3.B, and PS4.A.

An explicit alignment of the three dimensions of *A Framework for K–12 Science Education* (NRC 2012) and the *NGSS* to the components of the 6E lesson cycle is found in the matrix at the end of the teacher section.

Content Outline

Life Science

1. Plant reproduction
    a. Parts and functions of a flower's reproductive system
    b. Pollination mechanisms and environmental adaptations
    c. Animal pollinators and their features and behavior
    d. Interdependency within ecosystems

2. Systems modeling
    a. Physical models versus conceptual or mathematical models
    b. Selecting analogous structures for a functional model
    c. Uses and limitations of functional models

Engineering

1. Modeling
    a. Similarities to scientific modeling
    b. Differences from scientific modeling

2. Design
    a. Working within constraints to develop a design solution
    b. Criteria for evaluating solutions
    c. Redesign and optimization

Materials

Explore Stage Activities

You should construct the model blueberry flower before the students begin the Explore stage activities so it is available for them to use during that stage. You will need the following materials to construct the model flower:

- Cup (clear or Styrofoam, 6 oz size)
- Gauze (cut into 2" × 2" squares, 2 or 3 per flower)
- Baking soda (1 teaspoonful)
- Pipe cleaner
- Twist tie
- Velcro square (see example in Figure L1.3, p. 20)

You will construct the model flower within a Styrofoam cup that contains two or three layers of gauze (2 or 3 layers) filled with a teaspoonful of baking soda. The gauze is folded into a ball and attached to the bottom of the cup with a pipe cleaner or twist tie that can be poked through the top. Invert the cup before testing; note that baking soda will come through the gauze during testing. Examples of model flowers produced are seen in Figures L1.1–L1.3 (pp. 19–20).

FIGURE L1.1

Example of Model Flower (Close-up view of one section)

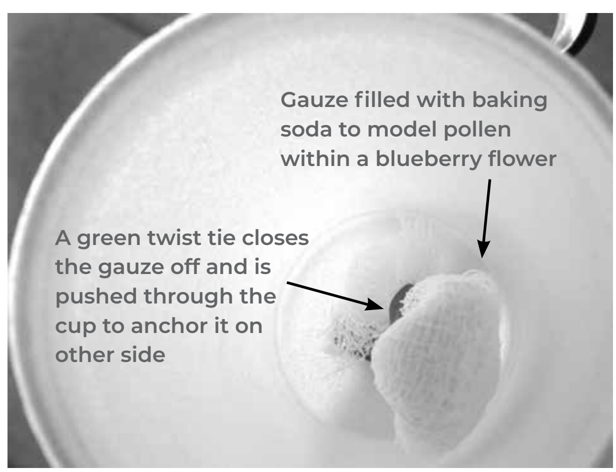


FIGURE L1.2

Example of Model Flower

Note: A full-color version of this figure is available on the book's Extras page at *www.nsta.org/engineering-lifesciences.*

FIGURE L1.3

Alternative Model Flower Design

Note: A full-color version of this figure is available on the book's Extras page at *www.nsta.org/engineering-lifesciences.*

Each student team will need the following materials for the tuning forks and toothbrushes investigations:

- Indirectly vented chemical-splash goggles
- Tuning forks (low, medium, and high frequencies)
- Rubber mallet
- Inexpensive electric toothbrushes (there should be more toothbrushes available than the number of teams so that each team can choose from several options; we suggest that you have 15 toothbrushes, assuming four or five teams in the class, and that you have a large supply of toothbrushes with the lowest frequency)
- Small cereal size bowl half-filled with water
- Baking soda (10 cm^3)
- Pipe cleaners (2–5)
- Craft pompons (3–5, various colors and sizes)
- Clay (a lump the size of a golf ball)
- Craft glue

- Craft sticks (various sizes)
- Paper cup (3 oz)
- Sponge
- Scissors

SAFETY NOTES

1. Remind students that personal protective equipment is to be worn during setup, the hands-on activity, and takedown.
2. Immediately wipe up/pick up any water, glue, and other spills off the floor to avoid a slip or fall hazard.
3. Use caution when working with scissors, sticks, pipe cleaners, and other sharp materials, because they can cut or puncture skin.
4. Keep clear of electrical receptacles and other electricity sources when working with water to avoid a shock hazard.
5. Wash hands with soap and water after completing the lab.

Engineer Stage Activities

Each student team will need the following materials for the engineering design challenge:

- Indirectly vented chemical-splash goggles
- Inexpensive electric toothbrush (there should be more toothbrushes available than the number of teams so that teams will have to make a choice and will not be limited to the only toothbrush available; we suggest that you have 15 toothbrushes, assuming four or five teams in the class)
- Testing papers such as colored construction paper (for pollen drop)
- Straws
- Floral wire
- Tape
- Hot glue gun
- Pipe cleaners (2–5)
- Craft pompons (3–5, various colors and sizes)
- Clay (a lump the size of a golf ball)
- Craft glue

- Craft sticks (various sizes)
- Paper cup (3 oz)
- Sponge
- Scissors

SAFETY NOTES

1. Remind students that personal protective equipment is to be worn during setup, the hands-on activity, and takedown.
2. Use caution when working with scissors, sticks, pipe cleaners, wires, and other sharp materials, because they can cut or puncture skin.
3. Use caution when working with the glue gun—it is hot and can burn skin!
4. Keep clear of electrical receptacles and other electricity sources when working with water to avoid a shock hazard.
5. Wash hands with soap and water after completing the lab.

Evaluate Stage Activities

Each student team will need to present its work with either a poster or computer presentation. The following materials may be used during the Evaluate stage:

- Poster paper
- Markers (assorted colors)
- Computer with presentation software

Resources

Each student should be given the student worksheet packet. Additionally, the resources listed in Table L1.2 are suggested for the Explore and Explain activities. These resources promote analysis of data, and use of these resources supports the science and engineering practices at the grades 9–12 level as described in the *NGSS.* The sources marked with an asterisk (*) must be used to ensure that students meet the level expected in the standards. Table L1.2 also provides suggestions for how to use the resources by stating what the general "big idea" is within each one and what learning targets can be developed with the use of each resource.

TABLE L1.2

Resources for the Explore and Explain Activities

BIG IDEA	LEARNING TARGETS	SOURCE	SUGGESTED USE
The biology of buzz pollination	• Review of plant reproduction • Role of bee as a pollinator • Structural features of bee • Role of sonification in pollination	De Luca, P. A., and M. Vallejo-Marin. 2013. What's the "buzz" about? The ecology and evolutionary significance of buzz-pollination. *Current Opinion in Plant Biology* 16 (4): 429–435.	Page 2: Summary of pollination Page 3, Figure 3: Frequency ranges of bees
The impact of hand pollination of cherimoya plants	• Timing of hand pollination • Effects of inadequate pollination • How long this strategy has been used	Schroeder, C. A. 1947. Hand pollination of cherimoya practical method for improving fruit set for better yields. *California Agriculture* 1 (8): 2. *http://calag.ucanr.edu/archive/?type=pdf&article=ca.v001n08p2a.*	• What can you say about how long hand pollination has been commercially used? • What is the impact of hand pollinators on fruit sets? • What is the scale of this issue?
How China has responded to an increased need for farming and the decreased bee population **Agricultural role in and responses to a decreased bee population.**	• Role of modern farming in decrease of insect pollinators • Role of hand pollination in increasing yields	*Goulson, D. 2012. Decline of bees forces China apple farmers to pollinate by hand. *www.chinadialogue.net/article/show/single/en/5193-Decline-of-bees-forces-China-s-apple-farmers-to-pollinate-by-hand.*	This one-page article is used in the Engage stage: • How did human activity affect the environment and, subsequently, the bee population? • What is the scale of the bee problem? • How has China addressed the need to increase pollination in apple or pear trees?
Blueberry plant development	• Understanding of anther structure and the interdependency on insect pollinators • Clarification of fruit sets	*Williamson, J. G., J. W. Olmstead, and P. M. Lyrene. 2015. *Reproductive growth and development of blueberry*. Document HS976. Gainesville, FL: University of Florida/Institute of Food and Agricultural Sciences. *https://edis.ifas.ufl.edu/pdffiles/HS/HS22000.pdf.*	This resource is used in the Explore stage. Page 2: How is the structure of the anther modified in blueberry plants? Why is it that only sonication releases the pollen?

Continued

Table L1.2 (*continued*)

BIG IDEA	LEARNING TARGETS	SOURCE	SUGGESTED USE
Pollen, nectar, and crop yield data	• Extracting information from a data table • Introduction of commercial application of ecosystem interdependency	U.S. Department of Agriculture. 2015. *Attractiveness of agricultural crops to pollinating bees for the collection of nectar and/ or pollen. www.oisc.purdue.edu/pesticide/pdf/crops_pollinated_usda_rpt_2015.pdf.*	Prompts for students: • Describe the degree to which pollen and nectar are attractive to the pollinator. • How does crop yield depend on pollen attraction? Suggested sample crops for contrast: almond, apples, blueberries, chickpeas (data on pp. 9–12)
Honeybees as a managed pollination strategy compared with wild insects	Reading graphs to make inferences	*Garibaldi, L. A., I. Steffan-Dewenter, R. Winfree, et al. 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Science* 339 (6127): 1608–1611.	This resource is used in the Explore stage. Page 1: What is a fruit set? What is the association of fruit set with wild pollination? Figure 2A: Which strategy, use of honeybees or use of wild bees, is closely associated with fruit production?
The interaction between pollinators and plants	How different crops interact with honeybees with varying degrees of success	*Pollinator Partnership. "Pollinators need you. You need pollinators." *http://pollinator.org/pollinators* (accessed June 29, 2018).	This resource is used in the Explore stage. Why is it essential to have enough pollinators to produce a sustainable crop?

A useful video resource is the National Geographic overview of sonication and buzz pollination: *https://video.nationalgeographic.com/video/til/160628-sciex-til-clay-bolt-bumblebees-buzz*. This short video demonstrates the bee sonication approach and also includes a visual using the tuning forks to release pollen. This video can be used as a wrap-up after research and testing have been done.

Time Recommendations

The estimated time for each 6E stage is as follows:

- *Engage:* 15 minutes
- *Explore:* 40 minutes research (may take more or less based on class structure), 40 minutes using materials during testing
- *Explain:* 30 minutes

- *Engineer:* 50 minutes (formative and/or summative assessment)
- *Elaborate:* 40 minutes
- *Evaluate:* 40 minutes to create final presentations, 40 minutes for all teams to present to the whole class (summative assessment)

Instructional Sequence

Engage

To begin this stage, have students read the article "Decline of Bees Forces China Apple Farmers to Pollinate by Hand," which provides a real-world context to the challenge of decreasing pollinators. Hand out the student worksheet packet (each student should be given a packet) and then introduce the design challenge through the Bluebell Inc. memorandum. After the memorandum is read, have students fill out the Memorandum Debrief section of the packet using a think-pair-share approach. In this approach, students first think of their own ideas and record them. They then pair up with another student or work in a small group to discuss their ideas and thoughts. Finally, students share their thoughts that they discussed with their partner(s) with the whole group.

Answer questions that students may have about criteria and constraints. The criteria relate to what the designed pollinator must do to be able to pick up and drop off pollen, and to the need for the pollinator to have structural features that complement the designed model flower. The constraints of materials and time are likely to come up in student discussions, as are questions such as "What is sonication?" and "What animals are pollinators?" Record these questions on the board and let students know they will explore resources to address these questions and those in the student worksheet packet in the Explore stage.

TEACHING TIPS

The Memorandum Debrief section of the student worksheet packet includes questions to help you assess how students are thinking about the engineering terms *criteria* and *constraints.* You may also need to have a class discussion to formatively check their understanding of these terms. Depending on student experience with the design cycle, this discussion can be used as an opportunity to deepen student understanding that criteria describe the characteristics of a successful solution and that constraints are restrictions placed on the design team to meet the challenge. This is a good time to introduce engineering terminology if the class is not familiar with the terms.

Explore

Student teams will have the opportunity to develop a deeper understanding of the factors that affect pollination by reading a selection from Table L1.2. The Reading Guide section of the student worksheet packet provides questions to direct student learning of the pollination process and to determine the feasibility of sonication and the interdependency of bees and plants such as a blueberry plant.

Student teams will also explore the phenomenon of sonication using tuning forks and model anthers. Teams will examine the available materials to build understanding of the properties needed for pollen transfer. Students will need to keep in mind the following questions that they will need to answer in the Explain stage:

1. The tuning forks create splatter when their energy is transferred to the water. Do all tuning forks create the same splatter pattern? Does the frequency of the tuning fork correlate to the distance of the splatter? Is this relationship present in toothbrushes? How could you use the toothbrush data to support a cause-and-effect relationship between frequency and the resulting motion of water?
2. What do the splattering water molecules serve as a model for in the design of your hand pollinator? *OR* What do the water molecules represent in your pollination system?

HANDS-ON INVESTIGATION OF PROPERTIES OF MATERIALS

Teams will test a minimum of three materials to compare ability to pick up pollen (baking soda) and drop it off. Make sure students clarify how data will be collected and recorded. Provide students with a sample data table if needed.

DIRECT EXPERIENCE WITH SONICATION USING TUNING FORKS AND TOOTHBRUSHES

Use a bowl of water to have students visualize how vibration can transfer energy to another object and cause movement. The water molecules that are splattered are models of how the pollen will be released. Each tuning fork, when struck with a rubber mallet or tapped on the edge of a table or bowl, will create water splatter when the open end of the tuning fork is placed on the surface of a bowl of water. This splatter is also a function of how much energy was originally supplied to the tuning fork, so students will need to consider how hard the fork was hit. It may be necessary to discuss with students how they can control for this variable within the testing that they conduct. Have the teams determine which frequency causes the biggest splatter. This can be done qualitatively in a comparative manner, or, to add a quantitative component, students can measure the distance outside the bowl that water molecules splatter (see Figure L1.4). It is suggested that the bowl be placed in the center of a piece of paper. The teams can measure the distance to the farthest splatter point.

When the tuning fork activity is finished, direct teams to test the toothbrushes in a similar manner as the tuning forks to determine which toothbrush creates the biggest splatters and would cause the release of the most pollen in a flower-pollination interaction. A secondary layer of analysis would be with the sound of the various frequencies. The large tuning forks, with the lowest tones, produce the biggest splatter. Toothbrushes with a low tone will likely produce the biggest splatters.

FIGURE L1.4

Splatter Field

Note: A full-color version of this figure is available on the book's Extras page at *www.nsta.org/engineering-lifesciences*.

ANALYSIS OF GRAPHS AND OTHER DATA RELATED TO ECOSYSTEMS AND POLLINATION

Use the U.S. Department of Agriculture and the Garibaldi et al. resources (see Table L1.2) to strengthen student ability to use tables and graphs to identify relationships. This is an important step in student development of scientific literacy and will allow them to use data to support their design decisions. It is also this analysis of external resources that will provide students with the background information necessary to meet the *NGSS* performance expectation standards listed in Table L1.1.

TEACHING TIPS

The articles listed in Table L1.2 are not all required, but the ones with an asterisk are required to meet grade-level requirements for this lesson. Depending on the time available, you may assign one or more of the other articles that are suggested for this lesson, either to complete in class or as homework.

The tuning fork and pollinator materials sections of the student worksheet packet have focus questions that are helpful to direct student attention during the investigations. You may decide to post them in front of the class, either all together or one at a time, depending on the pace and level of your students.

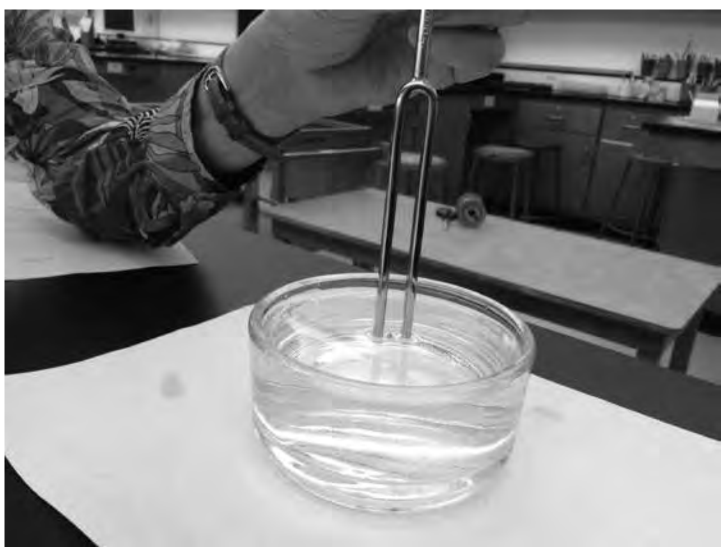
1. The tuning forks create splatter when their energy is transferred to the water. Do all tuning forks create the same splatter pattern? Does the frequency of the tuning fork correlate to the distance of the splatter? Is this relationship present in toothbrushes? How could you use the toothbrush data to support a cause-and-effect relationship between frequency and the resulting motion of water?
2. What do the splattering water molecules serve as a model for in the design of your hand pollinator? *OR* What do the water molecules represent in your pollination system?

Depending on availability of lab equipment, you can choose to have stations and rotate teams through the hands-on portions and have another station working with research information. Have lab equipment set up so that each team can do an exploration of their materials. For some classes you may have a data sheet already set up.

To ensure that students understand the significance of single-variable testing, have students discuss the strategy that they intend to use before conducting multiple trials. This is a formative assessment opportunity for the teacher to see if the teams understand that to conduct a fair test it is necessary to isolate only one variable at a time as in single-variable testing. You can set up a single-variable testing station such as the one shown in Figure L1.5 if you use the station model, but if teams are given all of the materials at their table, they may be modifying multiple variables simultaneously (with the exception of the intensity of the mallet strike on the tuning fork).

FIGURE L1.5

Tuning Fork Setup



Explain

During this stage, students will clarify their understanding of the pollination interaction and its mirroring of structure-function phenomena. This understanding will be captured in the student worksheets and in team and class discussion. The teacher acts as a facilitator to clarify understanding through this discussion. We suggest that you go through the student answers to the Explore section and clarify necessary science content to ensure student understanding. In the student worksheet packet these answers are in the Investigations section. The focus should be on connecting *why* the design choices are made and *how* the choices should align as a model for the biological structures and processes.

TEACHING TIPS

Clarify with small-group discussion possible examples of the structure-function relationships and how that supports sexual reproduction in some plants. One such example is the specific hertz (Hz) of sonication that is needed for plants that have evolved poricidal anthers. These anthers release their pollen in bursts only after stimulation from vibration. The vibration must be within a specified range, and this range is what bees use during their own movement.

Use think-pair-share approaches to elicit student understanding of concepts and clarify science understanding of flower anatomy. The male part, the stamen, is composed of the anther and filament and produces pollen (sperm). The female part, the pistil, is composed of the stigma, style, and ovary. When the pollen lands on the stigma, the usually sticky part of the pistil, a pollen tube develops and fertilizes the egg; fruit (e.g., apples, pears, berries) then develops.

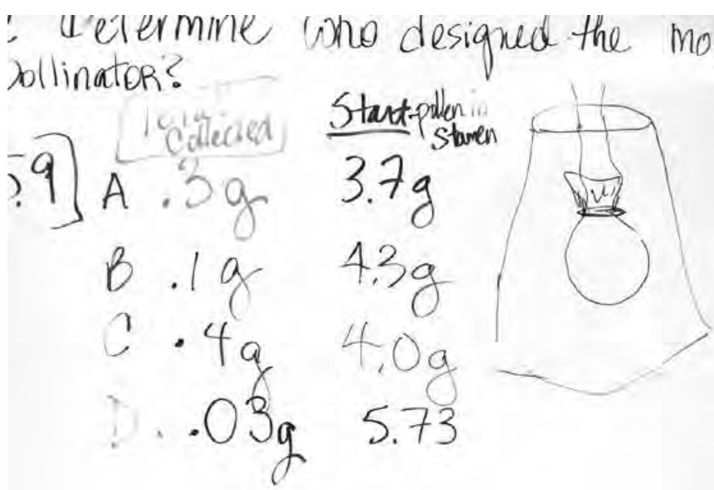
Engineer

Engineering design challenge: Design, construct, and evaluate a hand pollinator prototype based on sonication.

Design teams will learn about and experience the design process when they use an electric toothbrush to develop a hand pollination prototype that depends on sonication as the strategy to maximize pollen exchange. Data from the Explore stage will inform design choices related to material selection and also inform design to reflect structure-function criteria. Figure L1.6 shows sample pollen transfer data collected during the Explore stage that were used during the Engineer stage to inform design choices.

FIGURE L1.6

Sample Data Collected During Design Testing



The student worksheet packet directs teams to design one team solution that is ready for building and to sketch and label the prototype. The teacher must approve

FIGURE L1.7

Sample Prototype

the sketch before the team builds and tests the prototype. A sample prototype is seen in Figure L1.7.

TEACHING TIPS

We suggest that you have a visible design cycle poster that you can reference with teams during discussion. To promote individual and team engagement, the Planning: Individual Sketches section of the student worksheet packet provides space for individual initial designs as well as peer-learning opportunities after sharing initial concepts. After initial design sketches, students are asked to share their designs with their teammates and reflect on and identify which elements should be incorporated into a team design. To promote team collaboration, we suggest that a new piece of paper be used for the team design. The relevant student worksheet indicates that the team design must be approved by the teacher; this approval requirement ensures that you can meet with each team before they begin building.

You will need to have ample supplies of possible materials so that teams will have a choice in their designs as well as the ability to promote multiple solutions. Do not distribute materials until you have approved the team design plan. You can make materials available for teams to inspect, but, to minimize waste through trial and error and to manage materials, allow teams to only take materials that are reflected in their design.

Teams can redesign their pollinators to enhance effectiveness. Redesign is an important component of the design cycle for students to experience.

Elaborate

Teams may modify their prototype to align with the structure-function characteristics of a different flower. Initial designs will be targeted to the blueberry flower, but the memorandum also mentions tomatoes and cherries as the company's crops.

An alternative focus for prototype development (and to develop understanding of engineering concepts) is on the design of the model flower and how that can be used to evaluate the effectiveness of the prototype. You can challenge the teams to improve the accuracy of the model flower. You can also ask the teams to develop a method to quantify the analysis of their pollination system so that the data can inform revisions.

TEACHING TIPS

Teams can redesign their pollinator to improve its effectiveness at pollen transfer. Alternatively, teams can suggest modifications that would be made if a different plant was targeted; students will need to reconsider the structure-function relationship if targeting a different plant. We recommend selecting a plant whose flower is strikingly different from the blueberry.

An additional option is to assign price values to the component materials after the initial design activity and ask teams to determine the cost of their original prototype and then have teams redesign the prototype to reduce the cost, while collecting evidence that effectiveness has been maintained with this redesign.

Evaluate

Teams will share information on the feasibility of their prototype through a PowerPoint presentation or poster that they will create as requested in the memorandum. Based on details in the memorandum, teams will present the prototypes that they developed and describe supportive evidence that informed the design choices. This summary evidence will be drawn from research the team has done and the materials testing data. Teams will also report on how their prototype works and how they have tested and improved it during this process.

TEACHING TIPS

Give time in class for students to connect their experience back to the task assigned in the memorandum by sharing their research and designs. Teams will review and reflect on the entire process as part of the preparation for the presentation. Teams must decide how they will present information, and the discussions for this task are an opportunity to process information and deepen understanding. You may circulate around the room and mini-conference with teams in an informal manner to check that conversations are focused on facts gathered during research, how teams intend to explain their evidence gathered from investigations, the prototyping and revision process, and group collaboration. The final sharing of research and designs through presentations creates the opportunity to promote student understanding that multiple solutions can satisfy the design challenge criteria. Direct a discussion in class that highlights the similarities and differences between solutions and promotes how teams used data from science investigations to justify design decisions.

When assessing student work, you can look at individual and group levels. Student worksheets provide evidence of student understanding, and group collaboration to produce the PowerPoint or poster presentation reveals understanding of the use of data for recommendations as well as the structure-function relationship of the pollinator and plant.

Differentiation

You may need to provide explicit direction for student presentations for some groups. The explicit direction may include what evidence should be integrated into the presentation, how to define fruit yield, how to use data from a specific article (e.g., what Hz level to use in the sonication device), and how many articles from the resource list should be used to provide information for the presentation.

It is appropriate for teachers to provide multiple avenues for students to express understanding. These avenues may include multisensory techniques, pictures, graphs, charts, data tables, and multimedia approaches. English language learners may benefit from multiple literacy strategies.

The reading material listed in Table L1.2 (p. 23) ranges in difficulty and depth of analysis. The following resources (see Table L1.2 for full citations and more information) are introductory articles that provide context and a summary of the situation: "Pollinators Need You. You Need Pollinators" (*http://pollinator.org/pollinators)* and "Decline of Bees Forces China Apple Farmers to Pollinate by Hand" (*www.chinadialogue.net/article/show/single/en/5193-Decline-of-bees-forces-China-s-apple-farmers-to-pollinate-by-hand*).

Research on Student Learning

Most high school students seem to know that some kind of cyclical process takes place in ecosystems. Some students see only chains of events and pay little attention to the matter involved in processes such as plant growth or animals eating plants. They think the processes involve creating and destroying matter rather than transforming it from one substance to another. Other students recognize one form of recycling through soil minerals but fail to incorporate water, oxygen, and carbon dioxide into matter cycles. Even after specially designed instruction, students cling to their misconceptions. Instruction that traces matter through the ecosystem as a basic pattern of thinking may help correct these difficulties.

The National Science Digital Library (NSDL) is an open-access online library and collaborative network of disciplinary and grade-level focused collections that was established by the National Science Foundation in 2000. The NSDL serves as a point of access for many resources, one of which is research on student learning progressions and areas of student misconceptions.

Connections to the *Common Core State Standards*

Table L1.3 lists the literacy and mathematics skills (*CCSS ELA* and *CCSS Mathematics*) outlined in the *Common Core State Standards* (NGAC and CCSSO 2010) that are addressed in this lesson.

TABLE L1.3

Alignment With the *Common Core State Standards*

LITERACY CONNECTIONS (*CCSS ELA*)	
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
WHST.9-10.2 and WHST.11-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
MATHEMATICS CONNECTIONS (*CCSS MATHEMATICS*)	
MP2	Reason abstractly and quantitatively
MP4	Model with mathematics
HSN.Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
HSN.Q.A.2	Define appropriate quantities for the purpose of descriptive modeling.
HSN.Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

References

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010. *Common core state standards.* Washington, DC: NGAC and CCSSO.

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*.

B-POCALYPSE RUBRICS

Engineering Rubric

	DEGREE TO WHICH EXPECTATION WAS MET				
COMPONENT OF THE ENGINEERING DESIGN PROCESS	**EXEMPLARY**	**PROFICIENT**	**BASIC**	**MINIMAL**	**NO EVIDENCE**
Defining the problem (HS-ETS1-1; ETS1.A)	**5 points:** The nature of the essential problem of decreasing natural pollination was clearly described. A rationale for an engineering solution of a manual pollinator was described.	**4 points:** The essential problem and engineering need were described but without sufficient detail or with minor errors.	**3 points:** The engineering need was described but with little or no connection to the underlying problem of decreasing natural pollination.	**1–2 points:** Some minimal understanding of difficulties with pollination was shown.	**0 points**: No evidence was provided to show understanding of the essential problem or engineering solution.
Identifying constraints and criteria (HS-ETS1-1; ETS1.A)	**5 points:** At least two constraints on the solution were identified. At least three realistic criteria for evaluating potential solutions were also identified.	**4 points:** Sufficient constraints and criteria were identified but could be more completely explained or more focused on the most important features.	**3 points:** Fewer than two constraints and three criteria were identified. or Constraints and criteria were confused with each other.	**1–2 points:** One or two general limits or goals for a solution were described.	**0 points:** No constraints or criteria were identified.
Developing engineering solutions (HS-ETS1-2; ETS1.B)	**8–10 points:** At least three potential solutions were considered. These solutions were refined using research and experimentation on pollination. A leading solution was selected using the criteria identified earlier.	**5–7 points:** At least three solutions were considered and evaluated against the project criteria. The solutions would be more effective if there were greater variety and/or better application of science content knowledge.	**3–4 points:** Multiple solutions were considered, but one was chosen without relying on research or experimentation.	**1–2 points:** Only one solution was seriously considered, and little or no refinement of that solution was evident.	**0 points:** No evidence was provided to show any process of refining ideas into a potential solution.

Continued

B-Pocalypse Engineering Rubric *(continued)*

COMPONENT OF THE ENGINEERING DESIGN PROCESS	EXEMPLARY	PROFICIENT	BASIC	MINIMAL	NO EVIDENCE
Prototyping and revising a proposed solution (HS-ETS1-2; ETS1.B, ETS1.C)	**8–10 points:** The hand pollinator prototype essentially met the goals of the intended design. Revisions were made as needed to address shortcomings in the design.	**5–7 points:** The prototype met most of the design intent. It had minor shortcomings that were not addressed and may affect the usefulness of the prototype.	**3–4 points:** The prototype followed the major theme of the intended design but had serious shortcomings that were not addressed and that limit the usefulness of the prototype.	**1–2 points:** The prototype was largely incomplete or vastly different from the design intent. It was unusable for evaluating the proposed solution.	**0 points:** No prototype was produced.
Testing and evaluating a proposed solution (HS-ETS1-3; ETS1.C)	**8–10 points:** The hand pollinator prototype was tested to determine how well it met the engineering need. Test results were analyzed and used to identify strengths and weaknesses of the proposed solution in terms of project constraints and criteria.	**5–7 points:** The prototype was tested and results were analyzed against the constraints and criteria of the project. Conclusions made in the analysis could be more thorough or better connected to the data.	**3–4 points:** The prototype was tested and the results were recorded. Analysis was minimal and focused only on major performance of the prototype.	**1–2 points:** The prototype was tested and general visual observations were made, but no further analysis was performed.	**0 points:** No evidence was provided to show testing of the prototype or analysis of its effectiveness as a solution.

Comments:

Life Science Rubric

	DEGREE TO WHICH EXPECTATION WAS MET				
TOPIC	**EXEMPLARY**	**PROFICIENT**	**BASIC**	**MINIMAL**	**NO EVIDENCE**
Structure of the flower (Cause and Effect, Structure and Function)	**8–10 points:** Detailed and accurate information on the following structures and their role in pollination and reproduction was included: 1. Petals 2. Anther 3. Pistil 4. Stigma, style, and ovary 5. Pollen	**5–7 points:** Any four of the five topics were addressed. or Topics were addressed but without sufficient detail or incorrectly.	**3–4 points:** Any three of the five topics were addressed. or Many details were missing. and/or The information contained was somewhat incorrect.	**1–2 points:** Any two of the five topics were addressed. and/or Significant amounts of detail were missing. and/or The information contained was incorrect.	**0 points:** There was no evidence of learning.
Role of bees in pollination (LS4.C, LS4.D; Obtaining, Evaluating, and Communicating Information)	**16–20 points:** Detailed information was provided to address the following topics: 1. Types of bees 2. Structure of bees and how it is used with flower structure in pollination 3. Role of sonication in pollination and why it is important 4. Effects of inadequate pollination 5. Role of farming on the decreased number of pollinators	**11–15 points:** Any four of the five topics were addressed. or Topics were addressed but without sufficient detail or incorrectly.	**6–10 points:** Any three of the five topics were addressed. or Many details were missing. and/or The information contained was somewhat incorrect.	**1–5 points:** Any two of the five topics were addressed. and/or Significant amounts of detail were missing. and/or The information contained was incorrect.	**0 points:** There was no evidence of learning.

Continued

B-Pocalypse Life Science Rubric (*continued*)

TOPIC	EXEMPLARY	PROFICIENT	BASIC	MINIMAL	NO EVIDENCE
Hand pollinator mitigation: (LS4-6; ETS1.B; Cause and Effect, Obtaining, Evaluating, and Communicating Information)	**8–10 points:** Detailed information was provided on the following topics: 1.Timing of hand pollination 2.Impacts/effectiveness of hand pollinators 3.Role of hand pollination to increase crop yield	**5–7 points:** Any two of the three topics were addressed. or Topics were addressed but without sufficient detail or incorrectly.	**3–4 points:** Any two of the three topics were addressed. and/or Many details were missing. and/or The information contained was somewhat incorrect.	**1–2 points:** Any one of the three topics was addressed. and/or Significant amounts of detail were missing. and/or The information contained was incorrect.	**0 points:** There was no evidence of learning.

Comments:

Poster and Presentation Rubric

	DEGREE TO WHICH EXPECTATION WAS MET				
FORMAT	**EXEMPLARY**	**PROFICIENT**	**BASIC**	**MINIMAL**	**NO EVIDENCE**
Preparation (Obtaining, Evaluating, and Communicating Information)	**5 points:** All of the following requirements were met: 1. Neat 2. Organized 3. Colorful 4. Fewer than five spelling or grammar errors 5. Contains relevant pictures or diagrams	**4 points:** Any four of the five requirements were met.	**3 points:** Any three of the five requirements were met.	**1–2 points:** Any one or two of the five requirements were met.	**0 points:** There was no evidence of learning.
Delivery (Obtaining, Evaluating, and Communicating Information)	**5 points:** All of the following requirements were met: 1. All team members participate 2. Team members do not read directly from poster or PowerPoint presentation 3. Describes how the prototype works 4. Includes data and evidence from research and testing to justify choices 5. Provides a rationale for why the data and evidence are important to inform the design choices	**4 points:** Any four of the five requirements were met.	**3 points:** Any three of the five requirements were met.	**1–2 points:** Any two of the five requirements were met.	**0 points:** There was no evidence of learning.

Comments:

B-POCALYPSE MATRIX FOR LESSON DEVELOPMENT AND ASSESSMENT

NGSS ALIGNMENT

Performance expectations:

HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

6E FRAMEWORK STAGE	LESSON COMPONENT	SCIENCE AND ENGINEERING PRACTICE(S)	DISCIPLINARY CORE IDEA(S)	CROSSCUTTING CONCEPT(S)	EVIDENCE STATEMENT ALIGNMENT
Engage	• Introduction of design challenge	• Asking Questions and Defining Problems 6–8		• Influence of Engineering, Technology, and Science on Society and the Natural World	• HS-ETS1-1 (1ai)
Explore	• Flower structure • Sonication/Pollination	• Developing and Using Models • Planning and Carrying Out Investigations	• LS4.C: Adaptation • LS4.D: Biodiversity and Humans • PS3.A Definitions of Energy • PS3.B Conservation of Energy and Energy Transfer • PS4.A Wave Properties	• Patterns • Cause and Effect • Energy and Matter	• HS-ETS1-2 (1b, 1c) • HS-LS4-6 (1ai, 1c)

Continued

B-Pocalypse Martix for Lesson Development and Assessment (*continued*)

6E FRAMEWORK STAGE	LESSON COMPONENT	SCIENCE AND ENGINEERING PRACTICE(S)	DISCIPLINARY CORE IDEA(S)	CROSSCUTTING CONCEPT(S)	EVIDENCE STATEMENT ALIGNMENT
Explain	• Reproductive strategies • Significance of structure-function phenomena	• Developing and Using Models	• LS1.A: Structure and Function	• Systems and System Models • Structure and Function	• HS-ETS1-2 (1b, 1c)
Engineer	• Design of hand pollination prototype	• Constructing Explanations and Designing Solutions	• ETS1.B: Developing Possible Solutions • PS3.A Definitions of Energy • PS3.B Conservation of Energy and Energy Transfer • PS4.A Wave Properties	• Cause and Effect • Systems and System Models	• HS-ETS1-2 (1b, 1c)
Elaborate	• Redesign for improvement or redesign for a different species of flower	• Constructing Explanations and Designing Solutions			• HS-ETS1-2 (1b, 1c)
Evaluate	• Sharing of design solutions with attention to effectiveness and design justification	• Obtaining, Evaluating, and Communicating Information		• Structure and Function	• HS-ETS1-3 (1ai, 1aiii)

Bluebell Inc. Memorandum–Confidential

Date: 3/10/18
To: Engineering Department
From: Kenneth Cohen, CEO
Re: Challenge Response to Declining Pollination

Blueberries remain the primary crop for this company, along with tomatoes and cherries. However, colony collapse among wild bee pollinators has devastated the blueberry industry, leading to a large decline in crop yields for our company. A similar situation is present in other areas of agriculture such as apple crops. The leadership at Bluebell Inc. wishes to explore the potential benefits of manual pollination of our blueberry crops with a handheld device that uses sonication for pollen transfer. A similar approach is successfully being applied to apple crops in China, but the structural differences between apple blossoms and blueberry flowers limit the feasibility of relying on the technology developed in China. Your team is tasked with exploring the feasibility of this type of solution for blueberry crops and designing a prototype pollinator that utilizes sonication as the strategy to collect pollen and redistribute it in one of the target crops.

Before beginning your design, your team should explore the concept of sonication as well as the structure and function of both flowers and their pollinators. Crop data related to fruit yield, pollen production, and management strategies are to be used as resources to generate evidence to support your recommendation. Testing of sonication materials and pollination transfer materials will be necessary to support your solution designs.

Your team will present your final recommendations at the next department meeting. Be prepared with a prototype model and either a PowerPoint presentation or poster that summarizes supporting evidence from your materials testing and research that informed your design choices.

Your department head will provide details regarding the timeline and other considerations. I look forward to seeing your creative solutions to this challenge.

Name: ______________________________

Team Members: ______________________________

Memorandum Debrief

Describe some of the background information from the memorandum you received.

1. What is the main problem described in the memo?

2. Why do you think the company wants to develop a handheld pollinator instead of trying other possible solutions?

3. List three *constraints* on the design of a handheld pollinator. (Constraints are limits or restrictions on a design.)

4. Describe two *criteria* for a successful pollinator design. (Criteria are ways of judging how good a design is.)

5. What additional questions about the project does your team have?

Research

From the resources provided, summarize information that will support your design decisions and recommendations related to developing a hand pollinator using sonication. Include information related to, but not limited to, the following:

1. What are the unique features of plant structures involved in pollination? Describe the structure and the role in pollination.

2. Describe the role of bees (both honeybees and bumblebees) in pollination.

3. What is a fruit set, and what is the impact of poor pollination on fruit yield and the fruit set? What is the scale of this issue?

4. What is the evidence of the impact of hand pollinators?

5. Do you think that using wild pollination and managed colonies is an effective strategy to increase fruit yield?

6. Which strategy, use of honeybees or use of wild bees, is closely associated with fruit production?

Investigations

Tuning Fork Station

At this station, you will be testing tuning forks and electric toothbrushes. Your goal is to determine which toothbrush will be the best for your hand pollinator based on the data that you collect. You will consider these important questions:

1. How do the frequencies compare in regard to vibrations creating movement? Is this relationship present in toothbrushes? How could you use the toothbrush data to support a cause-and-effect relationship between frequency and the resulting motion of water?
2. What do the splattering water molecules serve as a model for in the design of your hand pollinator? (i.e., What do the water molecules represent in your pollination system?)

After you conduct the tests of the tuning forks and the toothbrushes, answer the questions at the end of this section.

PROCEDURE FOR TESTING TUNING FORKS

1. Put a bowl of water in the center of a piece of paper.
2. Record the Hertz level (Hz) of each tuning fork in the data table on the next page.
3. Hold one tuning fork by the stem and tap the open end on the table. Place the open end of the tuning fork to the surface of the water.
4. Record observations in the data table.
5. Circle the splatter marks from the tuning fork. Record the distance (in centimeters [cm]) to the farthest splatter.
6. Repeat steps 1–5 for two more trials, then calculate the average.
7. Repeat steps 1–6 for each tuning fork.

ⓘ SAFETY NOTES

1. Wear personal protective equipment during setup, the hands-on activity, and takedown.
2. Immediately wipe up/pick up any water and other spills off the floor to avoid a slip or fall hazard!
3. Keep clear of electrical receptacles and other electricity sources when working with water to avoid a shock hazard.
4. Wash hands with soap and water after completing the lab.

TUNING FORK HZ	OBSERVATION OF SPLATTER	DISTANCE OF SPLATTER TRIAL 1	DISTANCE OF SPLATTER TRIAL 2	DISTANCE OF SPLATTER TRIAL 3	AVERAGE

PROCEDURE FOR TESTING TOOTHBRUSHES

1. Record the brand/type of toothbrush being tested.
2. Turn the brush on and note the tone of the brush (i.e., how it sounds).
3. While the brush is on, place the head of the brush into the water bowl. Record data as you did with the tuning forks.
4. Repeat for each toothbrush.

BRAND OF TOOTHBRUSH	OBSERVATIONS	DISTANCE OF SPLATTER TRIAL 1	DISTANCE OF SPLATTER TRIAL 2	DISTANCE OF SPLATTER TRIAL 3	AVERAGE

QUESTIONS

1. Which fork creates the biggest splatter? Which toothbrush creates the biggest splatter?

2. How do the frequencies compare in regard to vibrations creating movement? Describe the relationship between the frequency of the tuning fork and the distance of the splatter produced.

3. Is this relationship present in toothbrushes? How could you use the toothbrush data to support a cause-and-effect relationship between frequency and the resulting motion of water?

4. What do the splattering water molecules serve as a model for in the design of your hand pollinator? (i.e., What do the water molecules represent in your pollination system?)

5. Make a decision about which toothbrush you think would be best to use for your hand pollinator. Then, using the evidence that you have collected at the tuning fork station, explain your rationale for the choice you have made. In your rationale, address frequency (wavelength), energy, and the distance that water traveled.

Toothbrush chosen:

Evidence:

Rationale:

Pollinator Materials Station

At this station, you will be testing different materials for the head of your hand pollinator. The goal is to determine what materials you will use to pick up and drop off the pollen. Before testing any of the materials, your team should discuss how you will verify a "fair test" for pollen pickup and dropoff. Clarify how you are comparing pollen pickup and dropoff across materials (i.e., what aspects of the procedure and materials need to be considered to conduct a fair test?). Describe your testing approach in the space below.

Record your data on pollination materials in the data table, including observations regarding the effectiveness of the material. You should examine a minimum of three materials as possible pollen transfer candidates.

MATERIAL	OBSERVATION: POLLEN PICKUP	OBSERVATION: POLLEN DROPOFF

Decide which material you think would be best to use for your hand pollinator. Then, using the evidence that you have collected, explain your rationale for the choice you have made. Specifically address how the properties of the chosen material allow it to pick up and drop off the pollen. How do the features of these materials support the team's design goals, and how will they be incorporated into the structure of the designed solution?

Material(s) chosen:

Evidence:

Rationale:

Summarize the knowledge you have gained from exploring materials and research, focusing on flower structure, how pollination happens, the role of sonication, and how frequency is connected to the pollination process. Provide at least one example of how a structure within a pollinator enhances its ability for pollination.

Planning: Individual Sketches

Provide four possible solutions for developing a hand pollinator based on sonication.

View your team members' individual sketches. Based on their designs and your own, write down which elements you feel are most important to incorporate into a group design and explain why those features are important.

On a separate piece of paper, design one team solution that is ready for building. Label all parts of the sketch. Have your teacher sign off on the design before getting your building materials. Build and test your prototype.

Teacher's initials: ____________

Prototype/Model Testing

Record observations and data collected during the prototype/model development of the hand pollinator. You will need to test the effectiveness of your hand pollinator in picking up and dropping off the "pollen" to your flower. Use additional pages if needed.

TYPE OF PROBLEM (DESIGN OR CONSTRUCTION)	PROBLEM DESCRIPTION	SUGGESTED IMPROVEMENT

Sketch and label your final prototype and prepare your presentation as described in the memorandum.

Design Review

1. What scientific data did you use to make decisions about the design of your pollinator?

2. Summarize the testing that you conducted on the finished pollinator prototype. What conclusions can you make about its effectiveness in transporting pollen?

3. How well does your pollinator prototype satisfy the other design criteria that you listed at the beginning of the project?

4. List the constraints on a pollinator design from the beginning of the project. Does your prototype meet each of them?

5. How could you improve the method of how you evaluate your prototype? Is there a way to quantify the data that your team obtains so that the data could be used to design another revision?

Reading Guide

Answer the following questions about the resources. These will help you in your development of your hand pollinator.

"Decline of Bees Forces China Apple Farmers to Pollinate by Hand"

1. Insufficient food supplies have emerged as a worldwide concern. What changes have occurred that have created this issue?

2. How have modern agricultural practices affected the environment and contributed to the decrease in pollination/pollinators?

3. How have hand pollination strategies been used to combat the loss of bees? What other strategies could be used?

“What’s the Buzz About? The Ecology and Evolutionary Significance of Buzz-Pollination”

1. Why are buzzes used in pollination?

2. What features do *Solanum*-type flowers have that characterize them for buzz pollination? Make a list.

3. Which sex of bees uses buzz pollination?

4. Explain the process a bee goes through to collect pollen. (See p. 2, highlighted section.)

5. What three things characterize a buzz?

6. Explain the differences in buzzes and how these differences impact pollination. (See p. 2, highlighted section.)

7. What is the range of frequency for typical bee species? (See Figure 3.)

8. Why would buzz pollination have evolved? (See p. 5.)

“Hand Pollination of Cherimoya Practical Method for Improving Fruit Set for Better Yields”

1. What is one of the limiting factors of a commercial production of cherimoya? Why does this happen?

2. Why is cross-pollination necessary for the cherimoya?

3. Explain the timing of hand pollination and the process used.

REPRODUCTIVE GROWTH AND DEVELOPMENT OF BLUEBERRY (PP. 1–3)

1. What impact does temperature have on flower buds?

2. What is pollination? What factors affect pollination?

3. Explain the structure and function of the following anatomical parts of the blueberry flower:
   a. Corolla tube (stigma, style, and ovary)

   b. Pistil

   c. Anthers

4. How does the structure of the blueberry flower make insects essential for pollination?

5. How do the sonicating insects accomplish the process of pollination?

6. Why can’t honeybees pollinate blueberry flowers?

ENGINEERING IN THE LIFE SCIENCES

9–12

When the authors of this book took part in Project INFUSE, the National Science Foundation–funded teacher development program, they noticed something. Life science teachers were highly receptive to engineering ideas related to everything from genomic testing to biofuels. But they also saw that teachers struggled to develop age-appropriate, standards-based lessons. The teachers asked for help facilitating the kind of open-ended design challenges that are useful to presenting engineering concepts in quick, engaging ways.

Out of that intensive interaction came *Engineering in the Life Sciences, 9–12*. It is designed to help you understand both what to teach and how to teach it. The authors created it specifically to be

- **Content-rich.** Six fully developed lessons show how to use engineering concepts to enhance life science courses. The lessons draw on each of the major content areas in biological sciences, including structures and processes, ecosystems, heredity, and biological evolution.
- **Standards-based.** This book will help you see how to weave the engineering thread from the *Next Generation Science Standards* into and throughout your content.
- **Engaging.** Lesson titles include "Designer DNA," "Ecosystem Board Game," and "B-pocalypse," which is about battling the decline of bees needed to pollinate crops.
- **Practical.** Inspired by extensive field testing, the authors made the lessons easy to use in diverse settings. The book is packed with detailed advice on managing engineering-oriented activities and conducting assessments. You also get idea-starters, teaching tips, and case studies to inform your own lessons.

Full of both sound science and innovative approaches, *Engineering in the Life Sciences, 9–12* brings fresh meaning to the terms "teacher-tested" and "classroom-ready." It is specifically designed to address the curriculum and pedagogical needs of life science educators.

Grades 9–12

NSTA press
National Science Teachers Association

PB433X
ISBN: 978-1-68140-477-6
9 781681 404776