NGSS and Nature of Science

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• Demystifying Nature of Science
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Lessons intended to develop all of the Next Generation Science Standards components must include the nature of science (NOS). But designing those lessons may not be easily accomplished; ways to infuse the NOS are often unclear. The resources in this issue of Science and Children will help deepen your understanding of the NOS and guide you as you cultivate this awareness in your students.

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Learning About the Nature of Science (NOS)

I doubt that Fleming could have obtained a grant for the discovery of penicillin on that basis [a requirement for highly detailed research plans] because he could not have said, ‘I propose to have an accident in a culture so that it will be spoiled by a mold falling on it, and I propose to recognize the possibility of extracting an antibiotic from this mold.’—Hans Seyle

I have never worked as a scientist, my parents weren’t scientists, and the only exposure I have had to scientists is through the media. I wasn’t taught anything about NOS, and I still don’t know if I fully understand all of the nuances involved in the ways to build that understanding. As I started my teaching career, I was among the group of teachers who thought it was not only appropriate to teach the Scientific Method but also graded my students on how well they kept everything they explained within the boundaries of that structure. As teachers, perhaps understanding NOS ourselves may be the place to start.

American Association for the Advancement of Science (AAAS), Project 2061, and Benchmarks for Science Literacy (1993) helped me understand NOS, and I finally began to realize the false structure I was teaching within. I scrapped my Scientific Method posters and started to revise the student investigations I had carefully crafted over the years to make them reflect a clearer picture of the true nature of science. I included investigations that would result in a variety of data that could lead students to different conclusions and then created opportunities for considering accuracy of analytics and argumentation. Students constructed their own strategies for discovery; beyond skill development, they were exposed to investigations that did not have a preconceived answer. I also expanded investigation time beyond the set class period and that false limitation on learning. It wasn’t easy, and it didn’t happen all at once. But I took it one step at a time, trying to design experiences that would help students explore, analyze analytics, and construct meaning with NOS consciously included. There are many resources available now that provide support to help teachers understand NOS as they provide strategies for students. One site you may find helpful is the University of California at Berkeley’s Understanding Science website (see Internet Resource).

I’m not a proponent of attempting to create a group of scientists in our classrooms. Nor am I interested in making students believe that they are scientists. What I am more interested in is providing a venue for them to develop understanding through exploration, asking and answering questions, being excited when they make discoveries, developing a knowledge base of disciplinary core ideas, and becoming lifelong learners. It just so happens that the best way to do that is through understanding the nature of science.

References

Internet Resource
Understanding Science
http://undsci.berkeley.edu
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The phrase “scientific literacy” has been around for over half a century and it remains a primary goal of science education throughout the world. In general, scientific literacy has always been at least partially associated with an individual’s ability to make informed decisions about scientifically based personal and societal issues. Meeting the stipulations of what it means to be scientifically literate requires that an individual understand subject matter as well as the nature of scientific knowledge and how it is developed. After all, without a knowledge of how scientific claims are made and their inherent limitations, how can an individual reach an informed decision on a scientifically based issue or concern? More specifically, as outlined in the Next Generation Science Standards (NGSS), the scientifically literate individual needs to have a functional knowledge of the disciplinary core ideas of science, science and engineering practices, and the crosscutting concepts of the sciences (NGSS Lead States 2013). The nature of scientific knowledge and how it is developed, often referred to as nature of science (NOS), is embedded within the dimensions of science and engineering practices and crosscutting concepts within the NGSS.

The connection between an understanding of nature of science and scientific literacy was, perhaps, most formalized by the work of Showalter (1974) and by a National Science Teachers Association position statement on science, technology, and society (NSTA 1982). Understanding NOS is critical to students’ and the general public’s ability to make informed decisions about scientifically based personal and societal issues. Traditionally, NOS has been difficult for teachers to teach and for students to learn (Lederman 2007). And, unfortunately, the current context of a typical science classroom places much more emphasis on the learning of subject matter than the nature and development of scientific knowledge. Consequently, when teachers are asked to integrate NOS into instruction, within an environment of high-stakes testing, there is a real, or perceived, concern that less time will be devoted to the learning of subject matter.

Conceptualizing science instruction as focusing primarily on science subject matter is familiar to us all. Alternatively, the meaning of NOS and how to teach NOS, as embodied in the NGSS, are not as familiar to science teachers or science teacher educators. Consequently, teachers have been limited in their ability to integrate attention to NOS in their science instruction. The purpose here, and in the rest of this issue of Science and Children, is to illustrate the importance of NOS to the NGSS and how it can be realistically integrated into the NGSS vision for science education.

Conceptualizing Nature of Science

Although teachers have been hearing the phrase “nature of science” for over 50 years, there is often confusion over its meaning. The following is a listing of the eight understandings of NOS specified in the NGSS (NGSS Lead States 2013).

- Scientific investigations use a variety of methods
- Scientific knowledge is based on empirical evidence
- Scientific knowledge is open to revision in light of new evidence
• Science models, laws, mechanisms, and theories explain natural phenomena
• Science is a way of knowing
• Scientific knowledge assumes order and consistency in natural systems
• Science is a human endeavor
• Science addresses questions about the natural and material world

The items on the list should seem familiar, as they have appeared before under the labels of NOS and scientific inquiry in the *Benchmarks for Science Literacy* (AAAS 1993) and the *National Science Education Standards* (NRC 1996). Some of the aspects of NOS included in the NGSS specifically relate to how scientific knowledge (e.g., concepts, theories, laws, models) are developed, while others refer to characteristics of the knowledge that stem from the way the knowledge is developed. For example, “scientific knowledge is open to revision in the light of new evidence” because “science is a human endeavor” and “science is a way of knowing.” Scientists are human beings with a variety of backgrounds, knowledge, and experiences, which causes different scientists to interpret data in different ways. This is why we constantly see scientists disagreeing about global warming, irradiated food, and the impacts of the extinction of certain animal and plant species. With time, the currently accepted scientific knowledge may change because new data is available or scientists interpret the same data in a different manner. “Scientific knowledge is based on empirical evidence” but we often do not have all of the potentially observable data, and inferences must be made. These inferences are made by humans and are subject to change. In the end, in science we never believe any knowledge is absolute with no chance of change, and this is a function of how science is done and the nature of the knowledge that is developed (Lederman and Lederman 2005). For a complete explanation of each of the aspects of NOS, please refer to the NGSS.

Although NOS is embedded in the NGSS dimension concerning science and engineering practices, it is important to note that NOS is specific to science practices. Engineering and science are closely related and influence each other, but they are different disciplines with different purposes. Engineering practices attempt to produce certain outcomes, while science simply tries to answer questions with no attempt to manipulate practices to produce a particular answer.

For many years it was assumed that students would understand NOS if they were simply engaged in “doing science.” This has been labeled the “implicit approach” by many science educators (Lederman 2007) and it assumes that the understandings elaborated by the NGSS do not need to be directly addressed during instruction. The research clearly shows that if you want students to understand NOS it must be emphasized during instruction as any other subject matter understandings you want students to learn. It is for this reason that the emerging support for teachers, provided by NSTA (Bybee 2013), makes it clear that NOS must be “visible” during instruction. This simply means there should be some discussion, not a lecture, with students as they reflect on the science activity they just completed. For example, the NGSS strongly emphasizes that students become engaged in authentic science practices as they learn science. One of the common misconceptions that students develop during their K–12 education is that all science must follow the same set and sequence of steps. This is often called “the Scientific Method” in textbooks, but it is not an accurate portrayal of how science is done. Space does not permit an example of how each aspect of NOS can be explicitly integrated into science instruction. However, two concrete examples follow. Additional examples are provided in the articles within this special issue.

The first aspect of NOS in the list previously provided is “scientific investigations use a variety of methods.” Even though students will do many investigations that do not follow the Scientific Method, they will not come to understand that “scientific investigations use a variety of methods” unless the teacher has students reflect on a single investigation that does not follow the steps in the textbook or a series of investigations completed in class that illustrates the variety of scientific investigations that make up the activities of scientists. Having students investigate the contents of an owl pellet is a common science activity in the upper elementary grades that is typically used to teach about form and function. Having students dissect the bones from the pellet is analogous to authentic scientific investigations performed by paleobiologists and ecologists. Having a discussion with students that compares this activity with the Scientific Method will clearly help students understand that “scientific investigations use a variety of methods.” Understandings of NOS must be made explicit as with any other subject matter you want your students to learn. Additionally, this very same activity could also involve students in a discussion of “science is a way of knowing” and “science is a human endeavor.” Students can discuss how they made inferences about how the bones dissected fit together and how the form of each bone was used to infer something about its function and location in the skeletal system.

In the early elementary grades students study the properties of matter and the difference between a liq-
uid and a solid. Following the vision of NGSS achieving these educational outcomes would emanate from students making numerous observations and comparisons among many examples of liquids and solids, preferably without knowing the differences in advance. You will want your students to arrive at the distinguishing attributes through their investigations. The labels of “liq-
uid” and “solid” would be provided after the students arrived at a conceptual understanding of the categories. Having students reflect on how they arrived at similarities and differences can be used to highlight “science is a human endeavor” (e.g., subjectivity, inference), “sci-
entific knowledge is open to revision in the light of new inference” (e.g., the categorizations of examples and their attributes might change during the investigation), and “science is based on empirical evidence” (e.g., the students made their inferences and conclusions based on direct observations and not on what they thought but did not see).

Hopefully, it is clear that once you have students experiencing authentic science practices they can be asked to reflect, in a natural way, on what they have done and why. It is these discussions that will facilitate students’ understandings of NOS. In the end, students will have a greater appreciation for the disciplinary concepts learned and they will have an understanding of how the concepts were developed. Students will “see” the connection between science practices, scientific knowledge, and NOS. And it really does not require that time be taken away from a focus on subject matter. Indeed it will help students develop a more in-depth understanding of the subject matter as well as science as a way of knowing about the world.

The primary goal of science education worldwide is scientific literacy, and the NGSS provides a new vision to achieve this elusive, but perennial, goal. It is an understand-
ing of NOS that provides the glue that holds together the dimensions explicated in the NGSS. NOS provides a context for the practices, disciplinary con-
cepts, and crosscutting concepts. Without this context, students’ abilities to make informed decisions about scientifically based personal and societal issues will be compromised. Elementary students are not necessarily making these decisions, but they eventually will be voting citizens and adults who will need to make such decisions on a daily basis. The vision of the NGSS is a K–12 endeavor and attention to NOS and the dimensions of the NGSS start in the elementary grades and continue until high school graduation. Students’ road to scientific literacy begins with you.

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References
Short news items of interest to the scientific community

Your Next Opponent in Angry Birds Could Be a Robot

With the help of a tablet and Angry Birds, children can now do something typically reserved for engineers and computer scientists: program a robot to learn new skills. A new project is designed to serve as a rehabilitation tool and to help children with cognitive and motor-skill disabilities.

The researchers have paired a small humanoid robot with an Android tablet. Children teach it how to play Angry Birds, dragging their finger on the tablet to whiz the bird across the screen. In the meantime, the robot watches what happens and records “snapshots” in its memory. The machine notices where fingers start and stop, and how the objects on the screen move according to each other, while constantly keeping an eye on the score to check for signs of success.

When it’s the robot’s turn, it mimics the child’s movements and plays the game. If the bird is a dud and doesn’t cause any damage, the robot shakes its head in disappointment. If the building topples and points increase, the eyes light up and the machine celebrates with a happy sound and dance. You can watch this process here: www.youtube.com/watch?v=wNrHwSfAJo.

“The robot is able to learn by watching because it knows how interaction with a tablet app is supposed to work,” said Ayanna Howard, who is leading the project. “It recognizes that a person touched here and ended there, then deciphers the information that is important and relevant to its progress.”

The robot analyzes the new information and provides appropriate social responses while changing its play strategy.

“One way to get robots more quickly into society is to design them to be flexible for end users,” said Hae Won Park, Howard’s postdoctoral fellow working closely on the project. “If a robot is only trained to perform a specific set of tasks and not able to learn and adapt to its owner or surroundings, its usefulness can become extremely limited.”

That flexibility is one reason Howard and Park see their robot-tablet system as a future rehabilitation tool for children with cognitive and motor-skill disabilities. A clinician could program the robot to cater to a child’s needs, such as turn-taking or hand-eye coordination tasks, and then send the machine home.

“Imagine that a child’s rehab requires a hundred arm movements to improve precise hand-coordination movements,” said Howard. “He or she must touch and swipe the tablet repeatedly, something that can be boring and monotonous after a while. But if a robotic friend needs help with the game, the child is more likely to take the time to teach it, even if it requires repeating the same instructions over and over again. The person’s desire to help their ‘friend’ can turn a five-minute, bland exercise into a 30-minute session they enjoy.”

In a recent study, Howard and Park asked grade-school children to play Angry Birds with an adult watching nearby. Afterward, the children were asked to teach a robot how to play the game. The children spent an average of nine minutes with the game as the adult watched. They played nearly three times as long (26.5 minutes) with the robot. They also interacted considerably more with the robot than with the person. Only 7% of their session with the adult included eye contact, gestures...
and talking. It was nearly 40% with the robot.

The next steps for the project team will include more games for the robot, including Candy Crush and ZyroSky. They will also recruit more children diagnosed with Autism Spectrum Disorder (ASD) and children with motor impairments to interact with the system. Their most recent study included two children with ASD. Their interaction times with the adult were significantly less than those in the typically developing group. They were about the same with the robot.

—Georgia Tech (www.news.gatech.edu/2014/07/10/your-next-opponent-angry-birds-could-be-robot)

How Octopuses Don’t Tie Themselves in Knots

An octopus’s arms are covered in hundreds of suckers that will stick to just about anything, with one important exception: They generally won’t grab onto the octopus itself; otherwise, the impressively flexible animals would quickly find themselves all tangled up.

Now, researchers report that they have discovered how octopuses manage this feat, even as the octopuses’ brains are unaware of what their arms are doing: A chemical produced by octopus skin temporarily prevents their suckers from sucking.

Binyamin Hochner and his colleagues had been working with octopuses for many years, focusing especially on their flexible arms and body motor control. There is a very good reason that octopuses don’t know where their arms are exactly, in the same way that people or other animals do.

“Our motor control system is based on a rather fixed representation of the motor and sensory systems in the brain in a formant of maps that have body part coordinates,” Hochner explains.

That works for us because our rigid skeletons limit the number of possibilities. “It is hard to envisage similar mechanisms to function in the octopus brain because its very long and flexible arms have an infinite number of degrees of freedom,” Hochner continues. “Therefore, using such maps would have been tremendously difficult for the octopus, and maybe even impossible.”

Indeed, experiments have supported the notion that octopuses lack accurate knowledge about the position of their arms. And that raised an intriguing question: How, then, do octopuses avoid tying themselves up in knots?

To answer that question, the researchers observed the behavior of amputated octopus arms, which remain very active for an hour after separation. Those observations showed that the arms never grabbed octopus skin, though they would grab a skinned octopus arm. The octopus arms didn’t grab petri dishes covered with octopus skin, either, and they attached to dishes covered with octopus skin extract with much less force than they otherwise would.

In contrast to the behavior of the amputated arms, live octopuses can

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Dr. Lara Croft, Veterinarian SeaWorld

High-Speed Solar Winds Increase Lightning Strikes

Scientists have recently found a link between increased thunderstorm activity on Earth and streams of high-energy particles accelerated by the solar wind, offering compelling evidence that particles from space help trigger lightning bolts.

Researchers found a substantial and significant increase in lightning rates across Europe for up to 40 days after the arrival of high-speed solar winds, which can travel at more than a million miles per hour, into the
Earth’s atmosphere.

A summary of the findings can be found in the associated video abstract: http://youtu.be/v-r-3qhE1s.

Although the exact mechanism that causes these changes remains unknown, the researchers propose that the electrical properties of the air are somehow altered as the incoming charged particles from the solar wind collide with the atmosphere.

The results could prove useful for weather forecasters, since these solar wind streams rotate with the Sun, sweeping past the Earth at regular intervals, accelerating particles into Earth’s atmosphere. Since these streams can be tracked by spacecraft, this offers the potential for predicting the severity of hazardous weather events many weeks in advance.

To arrive at their results, the researchers analyzed data on the strikes of lightning over the United Kingdom between 2000 and 2005. The record of lightning strikes was compared with data from NASA’s Advanced Composition Explorer (ACE) spacecraft, which lies between the Sun and the Earth and measures the characteristics of solar winds.

After the arrival of a solar wind at the Earth, the researchers showed there was an average of 422 lightning strikes across the United Kingdom in the following 40 days, compared to an average of 321 lightning strikes in the 40 days prior the arrival of the solar wind. The rate of lightning strikes peaked between 12 and 18 days after the arrival of the solar wind.

The solar wind consists of a constant stream of energetic particles—mainly electrons and protons—that are propelled from the Sun’s atmosphere at around a million miles per hour. The streams of particles can vary in density, temperature, and speed and sweep past Earth every 27 days or so, in line with the time it takes the Sun to make one complete
rotation relative to the Earth.

The Earth’s magnetic field provides a sturdy defense against the solar wind, deflecting the energetic particles around the planet; however, if a fast solar stream catches up with a slow solar stream, it generates an enhancement in both the material and the associated magnetic field. In these instances, the energetic particles can have sufficient energies to penetrate down into the cloud-forming regions of the Earth’s atmosphere and subsequently affect the weather that we experience.

—Institute of Physics (www.iop.org/news/14/may/page_63245.html)

In Brief:

• A fossilized tooth belonging to a fearsome marine predator has been recorded as the largest of its kind found in the United Kingdom, following its recent discovery. A team of paleontologists have verified the tooth, which was found near Chesil Beach in Dorset, as belonging to a prehistoric relative of modern crocodiles known as *Dakosaurus maximus*. The tooth, which has a broken tip, is approximately 5.5 cm long. *Dakosaurus maximus*, which grew up to about 4.5 m long, swam in the shallow seas that covered Europe some 152 million years ago. It belonged to a family of marine animals known as thalattosuchians, relatives of today’s crocodiles. The unusual shape of the animal’s skull and teeth suggests it ate similar prey to modern-day killer whales. It would have used its broad, short jaws to swallow large fish whole and to bite chunks from larger prey.

University of Edinburgh (www.eurekalert.org/pub_releases/2014-05/uoe-htf052914.php)
Uncovering Student Ideas in Physical Science, Volume 2
39 New Electricity and Magnetism Formative Assessment Probes

Grades K–12

Uncovering Student Ideas in Physical Science, Volume 2 provides formative assessment probes designed to uncover what students know—or think they know—about electric or magnetic phenomena or identify misunderstandings they may develop during instruction. Each probe offers field-tested teacher materials that provide “best answers,” along with distracters designed to reveal common misconceptions. The probes are short, easy-to-administer activities that come ready to reproduce. The teacher materials note links to national standards and suggest grade-appropriate activities to present material so students will learn it accurately. By helping you detect and then make sound instructional decisions to address students’ misconceptions, this new volume has the potential to transform your teaching.

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Translating the NGSS for Classroom Instruction

Grades K–12

With the release of the NGSS, you need a resource to help you answer pressing questions about how the standards fit with your curriculum, instruction, and assessments.

Rodger W. Bybee has written Translating the NGSS for Classroom Instruction to provide essential guidance for everyone from teachers to school administrators to district and state science coordinators.

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It’s Debatable!
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At the core of the exploration in It’s Debatable! is the Socioscientific Issues Framework. The framework gives students practice in the research, analysis, and argumentation necessary to grapple with difficult questions and build scientific literacy. After introducing the concept of the framework and explaining how it aligns with the NGSS, the book shows you how to implement the framework through seven units targeted to the elementary, middle, and high school levels. You even find out how to develop your own socioscientific issues curriculum.

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What Are They Thinking?
Promoting Elementary Learning Through Formative Assessment

Grades K–5

You don’t have to become a mind reader to understand the ideas young students bring to science class. This collection from award-winning author Page Keeley will help you draw out and then recognize what students know—or think they know—about the natural world. What Are They Thinking? is a compendium of 30 “Formative Assessment Probes” columns from NSTA’s elementary journal Science and Children.

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Uncovering Student Ideas in Primary Science, Volume 1
25 New Formative Assessment Probes for Grades K–2

What ideas do young children bring to their science learning, and how does their thinking change as they engage in “science talk”? Find out using the 25 field-tested probes in the newest volume of Page Keeley’s bestselling Uncovering Student Ideas in Science series, the first targeted to grades K–2. This teacher-friendly, ready-to-use book is tailored to your needs, focused on making your lessons more effective, and applicable to a range of science concepts. This age-appropriate book will help you teach more effectively by starting with students’ ideas and adapting instruction to support conceptual change.

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Introducing Teachers and Administrators to the NGSS
A Professional Development Facilitator’s Guide

Grades K–12

This book is full of activities and useful advice for guiding teachers and administrators as they put the standards into practice in the classroom. It introduces the vocabulary, structure, and conceptual shifts of the NGSS; explores the three dimensions of the Framework and how they’re integrated in the NGSS; provides classroom case studies of instructional approaches; and covers curricular decisions involving course mapping, designing essential questions and performance assessments, and using the NGSS to plan units of instruction.

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Member Price: $38.43 | Nonmember Price: $48.04
How Do We Know What We Know About the Universe?

By Emily Morgan and Karen Ansberry

Throughout history, people have made fantastic discoveries about the universe. Some of these stand the test of time; others are replaced by new ideas. As new technologies are developed, scientists are able to test and challenge previous findings. For students, understanding space science is not just learning what we know about the universe—it is also learning how we know what we know. This month’s lessons focus on how our understandings about the universe change as we develop technologies that allow us to gather new evidence.

This Month’s Trade Books

**Faces of the Moon**
By Bob Crelin
Illustrated by Leslie Evans
Charlesbridge. 2009.
ISBN: 978-1-57091-785-1
Grades K–2

Synopsis

In this unique book, innovative die-cuts and playful poetry introduce the names and shapes of the lunar phases and their repeating pattern.

**Boy, Were We Wrong About the Solar System!**
By Kathleen V. Kudlinski
Illustrated by John Rocco
ISBN: 978-0525469797
Grades 3–5

Synopsis

From the first humans wondering about the night sky to the demotion of Pluto to dwarf planet status, this book is an entertaining and informative look at how scientific theories change as new evidence is discovered.

Curricular Connections

This month’s lessons demonstrate understandings about the nature of science in the context of Earth and space sciences. In the K–2 lesson, by exploring the patterns of motion of the Sun, Moon, and stars in the sky (1-ESS1-1), students will be introduced to the basic understanding that “scientific knowledge is based on empirical evidence,” particularly that “scientists look for patterns and order when making observations about the world” (Appendix H, page 5). This lesson brings to the forefront the science and engineering practice of analyzing and interpreting data. The lesson for grades 3–5 explores the understanding that “scientific knowledge is open to revision in light of new evidence” (NGSS Lead States 2013, Appendix H, p. 5). Students will explore this understanding through a picture book that explains how our ideas about the solar system change as technologies advance and new evidence is uncovered.

Emily Morgan (emily@pictureperfectscience.com) and Karen Ansberry (karen@pictureperfectscience.com) are writers, educational consultants, and former classroom teachers. They are the authors of the Picture-Perfect Science series from NSTA Press.
Grades K–2: Patterns in the Sky

Purpose
Students will learn how scientists look for patterns when making observations of the Sun, Moon, and stars.

Engage
Ask students what they know about patterns. They may mention patterns they have generated in math activities or patterns they have made in their artwork. Next, ask them what patterns they have noticed in nature, e.g., spring is always followed by summer, summer is followed by fall, and fall is followed by winter. Then the pattern repeats. In whatever examples they provide, point out that in a pattern, you are able to predict what comes next. Ask students if they have ever noticed the different shapes of the Moon and the pattern they follow. Give each pair of students a set of Moon phases cards. Moon phases cards can be made by downloading a Moon phases calendar from the StarDate website and cutting them apart. You may consider limiting the number of cards to the named Moon phases for young students. Ask them to work together to put the cards in order, starting with the full Moon. Check with each group and ask them to explain why they put them in the order they chose. At this point, it is okay if they do not have them in the correct order. They will have an opportunity to reorder them later.

Explore
If time allows, have students keep track of the Moon phases for a month on a Moon journal (see Internet Resources). If not, give each pair of students a printout of the Moon phases for the current month from the StarDate website (see Internet Resources). Ask students if they notice a pattern to the Moon phases. Ask them what the Moon looks like at the beginning of the month and then at the end of the month. Then, give them some printouts of the Moon phases from the previous two months. Ask them what patterns they notice. Have them locate a full Moon on one of the calendars and notice what comes next. Have them do this for each of the printouts. Students should recognize that the Moon’s shapes appear in a certain order.

Explain
Show students the cover of the book *Faces of the Moon*. Tell them that this book will help them understand the pattern of the Moon phases and when they might be able to see each phase. Ask them to listen specifically for the order of the Moon phases and closely observe the illustrations of the pattern of the Moon phases. Be sure to point out the tabs on the center pages that show the order of the Moon phases (CC Connection: Reading Informational Text, Inte-
integration of Knowledge and Ideas).

After reading, allow them to reorder the cards based on what they learned from the book. Next, demonstrate the “Moon Calculator” feature of the StarDate website which allows you to enter a date from the past or future and see what the Moon phase was or will be. Invite some students to enter their birthdates. Then enter an important date in the future, like the last day of school. This feature demonstrates the predictability of the pattern of the Moon phases. Next, give each student a copy of the Moon Phases Flip Book from the American Museum of Natural History’s “Ol-ogy” website. Have students look at the Moon calendar printout for the current month, and then color in the darkened part of the Moon on each corresponding page of the flip book. Then, staple them together to make a flip book of this month’s Moon phases. (Note: At this grade level, it is developmentally appropriate for students to recognize the pattern and predictability of the Moon’s phases, but not understand the reason for the Moon phases.)

Elaborate

Tell students that observing the sky and recognizing patterns is the first step in understanding the universe. Scientists are always looking for patterns when they make observations. The ability to recognize these patterns helps scientists to better understand the universe. Ask students what other patterns they have noticed in the sky. Have they ever noticed where the Sun appears in the sky throughout the day? Tell them that on the next school day they will observe the position of the Sun in the sky as observed from the same location on the playground three times a day—first thing in the morning, around noon, and at the end of the day. Safety Note: Warn students to never look directly at the Sun because it can damage their eyes. Do this for several days in a row and record the position of the Sun by having students draw it or by taking a photograph from the same place each time. Be sure to have them label the time on each picture. After several days, have students analyze the pictures for a pattern. They should realize that the Sun is always in the same general place each morning (eastern sky), in the middle of the sky around noon, and in the same basic place each afternoon (western sky). It’s a pattern!

Evaluate

Assess student understanding of the observable patterns of the Moon, Sun, and stars in the following ways:

- Present an incomplete sequence of the Moon phases with the Moon phases cards and have students predict the next phase with their card set.

- Ask students to place a Sun cut-out in a photograph/drawing of the playground where they would expect to observe it in morning, noon, and afternoon.
Grades 3–5: Boy, Were We Wrong! (The Tentative Nature of Science)

Purpose
By learning the history of various scientific discoveries about space, students will recognize a fundamental understanding of the nature of science—scientific knowledge is open to revision as new evidence is discovered.

Engage
Tell students that you have a video for them to watch titled, “The Known Universe” by the American Museum of Natural History (see Internet Resources). After watching, ask students,

- How do we know what we know about the universe?
- How have our ideas changed over time?

Students may refer to instruments, such as telescopes, that help us learn about the universe. They may also discuss old ideas about the universe, such as people long ago thinking the world was flat.

Explore
Show students the cover of Boy, Were We Wrong About the Solar System! Read the first two pages aloud, ending with “…it took a long time and a lot of wrong guesses to learn what we now know today.” Give each pair of students a set of “Then and Now” T-chart. Tell them that some of the statements on the cards represent what people used to think about the universe and other cards represent what people now think about the universe. Have students read each statement and sort the cards on the “Then and Now” T-chart, placing what we used to think in the “Then” column and current understandings in the “Now” column.

Explain
Tell students that you are going to read the rest of the book aloud and as you read, you would like them to listen for the statements on the cards. After each statement is addressed, have students make sure they are placed in the correct column with the old idea directly across from the new idea. Students might think some of the statements on the “Then” cards were silly for anyone to ever believe, such as the Earth being the center of the solar system. So, ask them to think about what technology people had at the time—discuss what daily, monthly, and yearly patterns people must have observed that made them think that way. Then, discuss the technological advances and observations that led people to change that idea about the solar system (CC Connection: Reading Informational Text, Key Ideas and Details). For example, after reading pages 10–11, students should realize that the invention of the telescope allowed people to observe that the Sun and the Moon were not perfectly smooth spheres. Point out the various models people used to explain the universe that are depicted in the illustrations, such as the glass spheres on page 8 and the drawings on page 10 (CC Connection: Reading Informational Text, Integration of Knowledge and Ideas). Explain that with astronomy, or any other area of science, as we make more observations, our ideas and models can change. This is the tentative nature of science. Conclusions in science are not always final—that doesn’t necessarily mean they were wrong, it means that they can be modified or replaced when/if new evidence becomes available. Point out how the scientists in these books had to make arguments based on the evidence they observed in order to convince others to accept a new idea or model.
Elaborate

Reread page 30, which says, “Our ideas will change as we learn more. Scientists keep inventing better instruments. Every year more advanced probes are sent through the solar system.” Show students the Solar System Discovery Time Line on page 32. Tell them think about how the time line will progress into the future as we continue to explore. Tell students that you would like them to investigate the most current missions in space exploration. Have each student choose one current space exploration technology to investigate (e.g., Mars rovers, Hubble Space Telescope, radio telescopes, International Space Station, and so on. We have provided a list of current space exploration digital resources online; see NSTA Connection).

Evaluate

Have students present their findings to the class by sharing the following information about the space exploration technology they researched:

- A photo or drawing of the technology/mission they investigated
- An explanation of how it works
- A description of the type of information it collects
- A list of the discoveries that have been made by scientists using that evidence
- An explanation of how the technology/mission either changed or confirmed what we thought we knew about the universe (CC Connection: writing).

To conclude this lesson, show students “The Known Universe” video again. This time, ask students why they think the scientists at the museum decided to call this video “The Known Universe” and not just “The Universe.” They should realize that even though we have learned a lot about the universe, there is much we don’t know. Because our technology is limited, we have only seen so far into space. There is still so much to learn (CC Connection: Reading Informational Text, Integration of Knowledge and Ideas). Explain to students that this video was created by AMNH scientists in December of 2009. By the time the students are adults, the “known universe” will likely have expanded greatly and perhaps we will say, “Boy, were we wrong!” about some of our current ideas and models.

Internet Resources

- Ology: Astronomy
  www.amnh.org/explore/ology/astronomy
- StarDate
  http://stardate.org/nightsky/moon
- The Known Universe by AMNH
  www.youtube.com/watch?v=17jymDn0W6U
Connecting to the Common Core

This section provides the Common Core for English Language Arts and/or Mathematics standards addressed in this column to allow for cross-curricular planning and integration. The Standards state that students should be able to do the following at grade level.

**English/Language Arts**

**Reading Standards for Informational Text K–2:**
Integration of Knowledge and Ideas

- Kindergarten: With prompting and support, describe the relationship between illustrations and the text in which they appear (e.g., what person, place, thing, or idea in the text an illustration depicts).
- Grade 1: Use the illustrations and details in a text to describe its key ideas.
- Grade 2: Explain how specific images (e.g., a diagram showing how a machine works) contribute to and clarify a text.

**Reading Standards for Informational Text 3–5:**
Key Ideas and Details

- Grade 3: Ask and answer questions to demonstrate understanding of a text, referring explicitly to the text as the basis for the answers.
- Grade 4: Refer to details and examples in a text when explaining what the text says explicitly and when drawing inferences from the text.
- Grade 5: Quote accurately from a text when explaining what the text says explicitly and when drawing inferences from the text.

**Reading Standards for Informational Text:**
Integration of Knowledge and Ideas

- Grade 4: Interpret information presented visually, orally, or quantitatively (e.g., in charts, graphs, diagrams, time lines, animations, or interactive elements on Web pages) and explain how the information contributes to an understanding of the text in which it appears.
- Grade 5: Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently.

Writing across all content areas is emphasized within the common core, as seen by standard statement 10, which begins in grade 3 and states that students should “write routinely over extended time frames (time for research, reflection, and revision) and shorter time frames (a single sitting or a day or two) for a range of tasks, purposes, and audiences.

Furthermore the Common Core for ELA provide a standard related to the Range of Text Types for K–5 where it indicates that students in K–5 should apply the Reading standards to a wide range of texts to include informational science books.

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**Connecting to the Standards**

**Standard 1-ESS1 Earth’s Place in the Universe**

**Performance Expectation:**
1-ESS1-1 Use observations of the Sun, Moon, and stars to describe patterns that can be predicted.

**Science and Engineering Practice:**
Analyzing and Interpreting Data

**Disciplinary Core Idea:**
ESS1.A The Universe and Its Stars

**Crosscutting Concept:**
Patterns

**NGSS Table:**
1-ESS1 Earth’s Place in the Universe
www.nextgenscience.org/1ess1-earth-place-universe

**Standard 5-ESS1 Earth’s Place in the Universe**

**Performance Expectation:**
5-ESS1-2 Represent data in graphical displays to reveal patterns of daily changes in the length and direction of shadows, day and night, and the seasonal appearance of some stars in the night sky.

**Science and Engineering Practice:**
Engaging in Argument From Evidence

**Disciplinary Core Idea:**
ESS1.B: Earth and the Solar System

**Crosscutting Concept:**
Systems and System Models

**NGSS Table:**
5-ESS1 Earth’s Place in the Solar System
www.nextgenscience.org/5ess1-earth-place-universe

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NSTA Connection

Visit [www.nsta.org/SC1409](http://www.nsta.org/SC1409) for a list of space exploration resources and to download The Known Universe: Then and Now Sorting Cards.
The Nature of Science in Early Childhood

By Peggy Ashbrook

“It’s science! You’re going to learn some cool facts!” I often hear this from parents who are commenting with enthusiasm about part of the preschool curriculum. However, this outlook does not emphasize the nature of science, or how science works. I would like parents to say, “Go see what you can find out!” to encourage investigative behavior in their children rather than suggest that the teacher will tell them interesting facts.

Teachers of young children ask, “Should we only teach facts and offer experiences, or should we teach how science is conducted? Are children able to understand?” The Understanding Science website developed by the University of California Museum of Paleontology (see Internet Resources) states, “Kindergarten-, first-, and second-grade students can begin to understand what science is, who does science, and how scientists work through classroom activities, stories about scientists, and class discussions” (Janulaw 2014). Although “investigate questions and gather evidence through observations, and holding class discussions to share evidence and ideas” are listed as appropriate for first grade, beginning efforts in these tasks can start in preschool with developmentally appropriate expectations. Children who have an understanding of the nature of science may be able to apply it to many situations, not only in familiar situations.

The nature of science is usually described as having six to eight aspects, including understanding the difference between observation and inference (Lederman and Lederman 2004; Quigley 2011). The following activity provides practice making observations and inferences. Paired with children’s literature (see NSTA Connection) that directs children to make and discuss inferences based on the clues, and many additional opportunities to make observations, children will begin to tell you what they observed and what they think it means.

Peggy Ashbrook (scienceissimple@yahoo.com) is the author of Science Is Simple: Over 250 Activities for Preschoolers and teaches preschool science in Alexandria, Virginia.

References

Internet Resources
Understanding Science: Implications for Understanding the Nature of Science http://undsci.berkeley.edu/teaching/k2_implications2.php.
Observations and Inferences

Objective
To introduce the concept of creating inferences based on observations.

Procedure
1. Print two copies of a photograph or illustration that shows a locally common object or scene. Cut out some pieces so that the portion shown is not easily identifiable. For example, from a photo of a dandelion, you could cut out sections of leaves, flower buds, and stems.

2. With a small group of 3–6 children, show one piece from the larger photo, keeping the intact photo hidden. Say aloud, “I wonder what is shown in this picture?” The children may offer ideas about the object but say that you are describing only exactly what you see, such as, “I see a green shape with lines going through it.”

3. Say that you are now going to make an inference—to say what you think the picture might be. State an inference that will not give away the identity of the object and is slightly off track to allow you to model changing your understanding in light of new information later, such as, “It looks like a tree because it is green and I have seen a lot of green trees.”

4. Distribute pieces of the photo to each child and ask them to think about what they see in the picture. Use strategies such as “turn and talk” pairing or taking turns to have all children describe their picture.

5. After all children describe their picture, ask them to make an inference—to say what they think it might be—and why they think that. Tell children that sometimes scientists don’t know what something is, and that is okay. For example, children may say, “leaves,” “a tree,” or “something you blow” depending on which part of the plant is in their picture. The objective is not to guess what is shown in the whole picture but to teach children how to make observations that report exactly what they see, and then to make inferences about what the object might be based on previous knowledge and observations.

6. As children state their inferences, have them put their pieces in the middle of the work space. Encourage children to think about why they made a particular inference by asking, “What made you think of that?”

7. Show the intact photo and tell children that their pieces are not parts of a puzzle but just a few sections from the whole. Show where your piece matches the intact photo, and say, “Oh, it’s not a tree!” Ask children to find spots on the large photo for the picture they hold to help them see what part is pictured. If available, provide the actual object pictured in the photo and have children make more observations using other senses.

Materials
- Two copies of a photograph or illustration of a common object or scene (8.5 × 11 in. or larger for visibility)
- Pieces cut from one copy of the photo, but not cut into pieces as though a puzzle.
- The actual item pictured (optional)

NSTA Connection
Language is the way students and teachers communicate in the science classroom, but the language of science is not always the language children and adults use in their everyday life. As Michaels, Shouse, and Schweingruber put it, “In science, words are often given specific meanings that may be different from or more precise than their everyday meanings. It is important for educators to be clear about specific scientific usage to avoid confusion” (2008, p. 4). For example, consider the word *theory*. How many times have you heard someone say (or have you caught yourself saying), “That’s just a theory” or “I have a theory about that”? This colloquial use of the word *theory* usually implies a hunch, guess, belief, and even an unsupported prediction.

There are numerous theories in science—the theory of biological evolution, cell theory, plate tectonic theory, kinetic-molecular theory, theory of electromagnetism, germ theory, and many more. What each of these scientific theories has in common is that they are all solid explanations, based on a body of well-substantiated evidence that has gone through significant testing and is widely accepted by the scientific community. Sometimes theories change when new evidence becomes available, which then leads the scientific community to reconsider an existing theory and revise it to fit the new evidence that is available.

The formative assessment probe “Is It a Theory?” (Figure 1) is used to elicit ideas about the nature of science. This probe is designed to find out if students (and teachers) distinguish scientific theories from the common use of the word *theory* and if they understand how theories differ from laws. The statements included on this probe that best describe scientific theories are A, D, G, and I. For an explanation of these answer choices, and additional information to enhance your understanding of scientific theories, you may wish to read the teacher notes in the book chapter (Keeley, Eberle, and Dorsey 2008). This formative assessment probe was developed for use in middle and high school science, the grade levels when students become familiar with the historical and current developments that led to scientific theories and begin to distinguish between facts, hypotheses, theories, and laws.

Does this mean that we should not introduce or use the word *theory* in the elementary grades? Considering how pervasive middle and high school students’ misunderstandings are related to the word *theory*, as evidenced by responses to this probe, elementary teachers should begin using the word *theory* in their instruction around third grade. Prior to third grade, teachers should encourage students to use the words *claims* and *evidence* to construct and share their explanations as a precursor to using the word *theory* in later grades. Starting in grade 3, theory should be used to refer to ideas students have that are supported by data from their investigations and that help explain a phenomenon. If introduced purposefully, grade 3 is not too early to help students distinguish the science word *theory* from ways people use the same word in their everyday language.

You might begin by adapting the “Is It a Theory?” formative assessment probe for grades 3–5. The probe can easily be changed to an opposing views format—a format commonly used in the *Uncovering Student Ideas* series in which students consider two alternative views about an object, phenomenon, or concept. For example, using answer choices B and G from the original probe, you might tell students that people have different ideas about what the word *theory* means in science. These ideas are: idea #1: a theory is a hunch, guess, or a prediction or idea #2: a theory is an explanation strongly supported with evidence. Ask the students to decide which idea about the word *theory* is most like their own meaning of the word when they use the word *theory* in science class. Ask them to describe why they picked that idea and where they have heard the word *theory* used. If many students pick idea #1, that
is an indication of the need to begin using the word in their science experiences and developing an understanding that theories in the science classroom are the explanations students develop that are strongly supported by the evidence they collect from investigations or information they gather from valid sources. Their theories should explain the “why” and not just the “what” when they refer to their observations and evidence.

A fifth-grade case in Ready, Set, Science (Michaels, Shouse, and Schweingruber 2008) describes how students had a difficult time distinguishing between predictions and theories during a mass and density investigation (Note: Ready, Set, Science can be downloaded for free from the National Academy Press website). The teacher created a class “theory chart” to keep track of the different theories posed over time, with periodic review and revision of students’ theories. Listening carefully and probing further during science talk is a formative assessment strategy that reveals how students interpret the word theory. The following is a partial transcript of the discussion revealing different students’ ideas about theories and how the teacher uses talk moves to probe further (Michaels, Shouse, and Schweingruber 2008, pp. 139–140).

Mr. Wilson: “Does anybody have a theory about the wood? For instance, why the wood floats? Why did you predict the wood would float?”
Deana: “Because I’ve seen it float.”
Mr. Wilson: “So are you saying that just having seen something do something before is a reason, an explanation of why something would sink or float?”
Deana: “I think it is.”

Mr. Wilson: “You think it is? Can you say more about that?”
Deana: “Because if you’ve seen it before, then it’s a theory.”
Jody: “Wait, but didn’t we sort of decide that our experience is a good way of helping us make predictions but it doesn’t explain why something happens?”
Mr. Wilson: “Christina, do you have something to add?”
Christina: “Well, I sort of disagree with Deana because a theory’s kind of different from a prediction. A theory is why something happened. It’s not just a guess or a prediction.”
Caleb: “I know what a theory is. A theory is like ‘all wood floats.’ That means all wood has to float or your theory is wrong.”
Mr. Wilson: “Okay, so let me see if I’ve got what you’re saying. You’re saying that ‘all wood floats’ is a theory?”
Caleb: “Yep, a theory that’s been proven right.”
Mr. Wilson: “Does that tell me why wood floats though?”
Caleb: “Uh, not really.”
Mr. Wilson: “Okay, so can you give me an example? Let’s take wood. Some of us have seen in our experiments that wood floats. We have evidence that wood floats. But why does...
wood float? What makes it float? Can you give us a theory?”

The formative assessment probe and students’ discussions as they use the word theory can both reveal common misunderstandings students have about the word theory when it is used in science. By being aware of students’ misunderstandings, making instructional decisions to use the word theory to mean explanations supported with evidence that help us understand why something happens, and constantly monitoring how students use their evolving scientific language, elementary teachers can have a significant role in shaping students’ understanding of the nature of science and the specific language that it includes. ■

Page Keeley (pkeeley@mmsa.org) is the author of the Uncovering Student Ideas in Science series (http://uncoveringstudentideas.org) and a former NSTA President.

References
www.nap.edu/catalog.php?record_id=11882

NSTA Connection
Download the “Is It a Theory?” probe at www.nsta.org/SC1409.
American Museum of Natural History
Seminars on science, six-week online graduate courses in the life, Earth, and physical sciences, incorporate the museum’s resources plus interaction with scientists and educators. CEUs and graduate credits.

California University of Pennsylvania
Designed for elementary and middle level teachers, Cal U’s online masters degree focuses on teaching inquiry across the STEM disciplines. Each course in the 30-credit program also develops your teacher leadership skills so you can take your career to the next level.

Mississippi State University
Earn a Master of Science degree in geosciences via distance learning through the Teachers in Geosciences program. Curriculum includes courses in geology, meteorology, climatology, oceanography, astronomy, hydrology, and environmental geoscience.

Montana State University - Bozeman
Online graduate credit courses for K–12 science teachers through National Teachers Enhancement Network, as well as online offerings for Masters of Science in Science Education. NSTA member discount.

Penn State
Earn your Master of Education in Earth Sciences. Combine courses from multiple disciplines to enrich your practicing knowledge in the field of earth sciences while also enhancing your teaching and leadership skills—completely online.

University of Maryland
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http://learningcenter.nsta.org/onlinecourses
Call for Papers

Write for Science and Children!

Your 2000-word manuscript should describe a set of connected lessons or investigations that build an idea or content area. They should include assessments (pre-, post- and formative) as well as enough detail that another teacher could replicate the lessons in the classroom. Examples of student work are encouraged. Don’t forget to take photographs of students safely participating in the activities, and secure parent permissions for their publication. Handy with technology? Create videos, too! Don’t see a theme that fits your idea? Don’t let that stop you from writing! We always make room for good manuscripts on any elementary science topic.

October 2014–April/May 2015: Crosscutting Concepts

Seven crosscutting concepts are identified in the Next Generation Science Standards. The standards identify these crosscutting concepts in the grade level foundation box and connect them to disciplinary core ideas for specific grade levels. A Framework for K–12 Science Education considers crosscutting concepts as being fundamental to understanding the nature of science. This year in S&C, we examine each crosscutting concept. We are seeking manuscripts that explain how each crosscutting concept is deliberately developed and revisited.

Resources


March 2015: Structure and Function

Deadline September 15, 2014

A Framework for K–12 Science Education states that the way in which an object or living thing is shaped and how its substructure determines many of its properties and functions. Structure is what something is made up of; function is how it works. Young children can study how the structures they see serve a purpose. This includes the shapes of bridges, parts of animals that help them get food, and the structure of a bicycle and how wheels and axles work together. Early learners can begin by looking at mechanical functions, older upper elementary students are able to think about more complex systems and models such as systems in the human body and movement of small gas particles, things we can’t actually see. Elements of this cross cutting concept should be explicitly addressed and developed over the course of the lesson as described in your manuscript. Lessons should fit together, have a conceptual flow, and help students develop proficiency on a coherent set of performance expectations.

- What opportunities have you provided to support student understanding through a variety of experiences with varied durations?
- How do you develop an understanding of the components of structures and the properties of those components as they add to its shape and stability?
- What experiences do students have in the analysis the structure and function of natural objects?

April/May 2015: Stability and Change of Systems

Deadline October 1, 2014

A Framework for K–12 Science Education states that for natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study. It points out that the role of instruction in early grades is to begin developing accurate language for these concepts. Important in this understanding is asking questions about why something changes or why it remains the same. Systems have controls, sometimes in the form of feedback. The feedback may be positive or negative but it controls change or stability. Important in the identification of change or stability is the point of view. Within the system being studied, there are many components—some may be stable while others are changing. In early years it is important to begin using the vocabulary and discussing stability and change. As children mature they can discover patterns in change or stability. Elements of this cross cutting concept should be explicitly addressed and developed over the course of the lesson as described in your manuscript.
Lessons should fit together, have a conceptual flow, and help students develop proficiency on a coherent set of performance expectations.

- What opportunities have you provided to support student understanding through a variety of experiences with varied durations?
- What experiences do you provide for students that prompt them to ask and answer questions such as “What can be done to make this more stable?” or “How does a plant change as it grows?” or “What can be done to slow erosion?” and others that relate directly to the disciplinary core ideas being studied?
- What lessons have you used to develop the ideas concerning the impact the environment has on living things including those that lived long ago?

Summer 2015: Learning Progressions, see p. 65

September 2015: Engineering and Design
Deadline December 1, 2014
Mirroring the format of the popular Science and Children column Engineering Encounters, this issue will focus on engineering. Two basic types of submissions will be featured. One type will present classroom-tested, novel, and engaging lessons for preK–5 students. They should include all of the components necessary for an engineering investigation based on the NGSS to be completed and assessed, from design to implementation. Be sure to bring the voices of students and the teacher to the manuscript. In other words, focus on application of instruction that provides a peek into the classroom. The second type of submission should provide background information for the teacher that will support the teacher’s ability to construct his or her own engineering lessons. This might include suggestions as to where more information can be found concerning high-quality lessons, strategies for structuring lessons, resources that support teaching and learning, and strategies for use in evaluating lessons and materials. (NGSS: Appendices F & I and ETS1)

Find the complete Call for Papers at www.nsta.org/sandccall.

Not ready to pen a feature article?
Consider writing a column. These shorter, focused pieces are the perfect way to share your experiences with the wider elementary science community.

Early Childhood Resources Review
Science & Children has launched this column that provides reviews of some of the best resources designed specifically for teaching science to young children. Reviewers select resources that present relevant and appropriate science content and describe inquiry-based approaches to engaging young children in the practices of science and engineering, as described in the Next Generation Science Standards. For specific resource review criteria, more information concerning providing a review for publication consideration, or to suggest a review be provided for a specific resource, contact column editor Ingrid Chalufour at ichalufour@edc.org.

Science Shorts
This column shares your experiences with classic classroom activities and how they emphasize science practices. The lesson should be provided using the 5E instructional model—engagement, exploration, explanation, enrichment, and evaluation. Length: 1500 words

Methods and Strategies
We are considering this manuscript for the Methods and Strategies column. This column provides ideas and techniques to enhance science teaching. This is S&C’s “think piece” and connects science teaching with research on teaching and learning. This is done by sharing an account of a method or strategy used in the classroom and explaining how its use is supported by research. While the presentation of the method or strategy is often content-based, the method or strategy should be applicable to other settings and other content. Length 2000 words

Engineering Encounters
We are seeking column submissions that present classroom-tested, novel, and engaging lessons for preK–5 students. They should include all of the components necessary for an engineering investigation to be completed and assessed, from design to implementation. Be sure to bring the voices of students and the teacher to the manuscript. In other words, focus on application of instruction that provides a peek into the classroom. We are also interested in submissions that provide background information for the teacher that will support the teacher’s ability to construct his or her own engineering lessons. This might include suggestions as to where more information can be found concerning high-quality lessons, strategies for structuring lessons, resources that support teaching and learning, and strategies for use in evaluating lessons and materials. Length: 2000 words.
Fourth-grade students examine animal tracks to explore the nature of science.

By Amy V. Gilbert and Katherine E. Johns
In supporting students toward literacy, we must provide experiences that support the formation of informed understandings of the nature of science (NOS) as well as a structure for developing evidence-based explanations. Students were guided through this learning cycle to answer the essential question, “How do scientists work?” There is great potential for this learning cycle to transition students from the application of the NOS into other disciplinary core ideas. For this reason, we consider this learning cycle a benchmark experience for our students. The learning cycle presented aims to teach the NOS in explicit, reflective ways that support students’ abilities to resolve questions and solve problems across disciplines.

Engage

Students were engaged and preassessed with the probe “Doing Science” (Keeley, Eberle, and Dorsey 2008) (see Figure 1). This probe was used in two ways: to elicit students’ ideas about scientific processes and to group students heterogeneously based on their thinking. Students responded with explanations such as, “I believe that scientists don’t use just one method,” and “Sometimes scientists do use different methods for different questions.” Their points in the conversation showed that they had some understanding of various scientific processes. Several misunderstandings also emerged. When the students were asked, “So when you agree that all scientists use the scientific method, what kinds of scientists are you thinking about?” Students began to share careers such as doctors, chemists, and so on. When asked, “Why do you think some people might think Tamara’s step-by-step method was accurate?” one student stated, “I think that’s the way they work because last year when we went to see the science fair projects that the fifth graders did, they all had it stepped out like that, but I really don’t know if that’s the way real scientists do it. I am just guessing.” Another student then said, “That’s true. Because last year even when we would sometimes get to do science labs, they were always kind of written step-by-step for us to do. They were really easy though, so I don’t know if that was real science or not.”

**FIGURE 1.**

“Doing Science” formative assessment probe.

![Doing Science](image)

A student completes a preassessment before the lesson.
Transition from the engage to explore phase included discussion as to why Marcos’s response was the most correct way of thinking about how scientists work. We asked questions such as, “How many of you have had similar experiences to this? Following steps for science labs?” Many students raised their hands. “What are some of your other ideas for what doing science is like?” Students provided answers such as doing labs, testing ideas, finding cures for diseases, and helping to save animals that are in danger. It was then emphasized that students would now work with two other people to explore ways that scientists work.

**Explore**

For the exploration, students were grouped so that at least one student was informed or somewhat informed in their thinking, meaning they understood science could include a number of processes but perhaps lacked a depth in understanding. This might have been evident through the examples provided in discussion or in their writing on the probe. For example, an informed student who wrote, “Scientists don’t just do it one way. Like a marine biologist. He’s not in a lab,” was grouped with other students who agreed with Tamara’s step-by-step method or Avery’s “all” scientists. Within the new group, students were first encouraged to

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**FIGURE 2.**

Observation vs. inference T-chart.

<table>
<thead>
<tr>
<th>Observations</th>
<th>Inferences</th>
</tr>
</thead>
<tbody>
<tr>
<td>• gathering data from looking at evidence.</td>
<td>• an educated decision or prediction about an observation. Ex:</td>
</tr>
<tr>
<td>• something you see, not a guess</td>
<td>• a cow could be a mammal</td>
</tr>
<tr>
<td>• data from something you observe.</td>
<td>• an opinion, it might rain today.</td>
</tr>
<tr>
<td>• can be proven facts</td>
<td>• gather clues or evidence to determine</td>
</tr>
<tr>
<td>• Ex: a mammal has hair and fur.</td>
<td>• can be backed up by evidence, but not always proven true.</td>
</tr>
</tbody>
</table>

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Students share their ideas about the animal tracks.
discuss their strengths in relation to the roles and responsibilities of a reporter, recorder, and leader. The reporter was responsible for all oral communication, the recorder was responsible for all written communication, and the leader managed the group’s time on task and quality of work.

We encouraged students to choose a role that was consistent with their perceived strengths. If we heard discussion that was inconsistent with how we knew the students were able to perform, we offered guidance. For example, if we heard in their conversation that a soft-spoken student was chosen as the reporter, we would intervene with feedback like, “I hear that your group chose Juan as your reporter. As a group, make sure you help Juan practice giving the report and help him remember to speak loudly and clearly.” In these rare situations, occasionally students would restructure their group roles, but usually students were willing to accept the role and help their classmate improve in the performance of the selected responsibility.

After grouping, students were guided through a modified version of an isolated, explicit NOS activity titled “Tricky Tracks” (National Academy of Sciences 1998, p. 87–89; see Internet Resource). Tricky Tracks is a well-researched NOS curriculum that uses a series of intermingling animal tracks to guide students in distinguishing observations and inferences, using patterns and prior knowledge to propose explanations, analyze alternative explanations communicated by others, and communicate criteria for an agreed upon scientific explanation. We selected Tricky Tracks because it functions as a benchmark experience for students. It was our immediate intention to transition this first learning cycle into a second integrated, explicit NOS learning cycle that allowed students to determine and communicate patterns in the locations of Earth’s features. This is part of our fourth-grade standards and NGSS performance expectation 4-ESS2-2 Analyze and interpret data from maps to describe patterns of Earth’s features (NGSS Lead States 2013). However, as is the nature of benchmark experiences, we also knew that the content of this learning cycle would be referenced at multiple times throughout the year.

As mentioned above, Tricky Tracks was purposefully selected as a benchmark experience to set the context for non-experimental approaches to sciences as well as the kinds of empirical data used by scientists who study Earth systems. Before students collaboratively explored Tricky Tracks, they were guided through discussion to list distinctions between observations and inferences. As students provided what they considered an observation, it was listed on either the right or left side of a chart on the board (Figure 2). Once all students’ ideas had been exhausted, they were asked, “Why do you think I put your ideas in two lists?” A student said, “Because they’re not really the same kinds of things. Our observations are more like math and our inferences are more like our opinions.” At this time another student added, “Yeah, it’s like it’s really facts and opinions.” This was a perfect segue to making NOS explicit through the distinction between observations—those things directly accessible to the senses—and inferences, which are often based on prior knowledge. Students were then engaged in Tricky Tracks by being presented with their roles as a group of scientists who have recently come across a set of fossil tracks (National Academy of Sciences 1998, p.89).
As students explored the first set of tracks, they were encouraged to report observations, inferences, and predictions separately on a recording sheet (see Figure 3, p. 35, and NSTA Connection). The empirical, tentative, and observation-laden features of the NOS were made explicit by asking students questions like, “Why are you saying that these are animal imprints?” Students would respond with comments such as, “they have claws” and “because it looks like what you see when birds leave prints.” We then asked, “When you say that these are animal imprints, you are making an inference. What is it that you know about animals that is making you think this?” One student said, “There are predators and prey, and I have seen cats chase birds and actually I have even seen my dog chase the birds away. They leave those kinds of prints behind if it is muddy or something.” We responded, “It’s important to remember that when scientists observe these imprints, they might record measurements such as the distance between the prints, count the number of prints, or measure the depth of them. Let’s try to think more like a scientist. What kinds of observations like this could you add to our discussion?” As students were prompted in this way through each of the sets of imprints, their ability to distinguish observations and inferences improved.

As the next set of prints was unveiled, additional features of NOS were made explicit. This included the concept that scientists’ explanations change based on new data that is discovered and different perspectives that are shared. During our conversation, students also began to catch each other misrepresenting an observation. When the third figure of imprints was revealed, one student stated, “Well obviously, the bigger animal walked away, and the one with claws is gone.” Another student excitedly exclaimed, “Those are all inferences. You are just thinking that because there’s only the one set of prints left on that side, but we don’t know for real what happened, and we’re not supposed to be saying what we think about it yet. You have to say something like what I just said, that there’s just one of the prints left that we can see.” Students continued in this manner and seemed to even make a game of catching each other making inferences.

Explain

A template was provided to the group’s recorder (see NSTA Connection) to support the teams in collaboratively writing evidence-based conclusions that explained the fossils. While the teams worked on their explanations, we would ask them questions that allowed us to monitor carefully for accuracy in their use of evidence to support their various conclusions. We would ask them questions like, “Is there additional data to support this? Does any of this other data support what you are saying?” As the volume of the students’ discussions decreased, it became apparent that the group reporters were prepared, and thus students began to present to the whole class.
During presentations, students displayed a sense of pride and confidence in the conclusions they shared. One particular presentation was important due to the opportunity it allowed for other NOS tenets. The reporter began by saying, “We think that two animals, probably birds, enter where there is food, probably a school of fish, when it is high tide. They both eat as much of it as they can. As the tide goes back and the school of fish that are left over spread around, one of them walks away, and the other just flies off.” The reporter provided data to support the group’s conclusions, such as, “They had claws like other birds we have seen,” and “We have seen marks like this that birds leave behind and even seen all different kinds of birds swoop in for a big school of fish … and they didn’t fight or anything; they were just all getting food.” The points this reporter mentioned offered a perfect segue for discussion with explicit emphasis on how experiences influence the way we all think and draw conclusions. This NOS discussion was proven even more important when a different student commented, “Yeah, because I’ve never seen any of that kind of stuff, so I was just thinking about predator-prey stuff we learned last year in third grade.”

As recorders continued to share their data-based conclusions, the students’ ideas were collectively printed on the board. During transitions in the presentation, there was time allowed for students from other groups to provide additional support or refute data. Students really enjoyed arguing like scientists. On several occasions, their argumentation strategies were commended for their use of data and experiences to support their argument. As the presentations came to an end, with all of their ideas visible on the board, we made the NOS concept of reaching consensus explicit. To accomplish this, we informed students that final decisions needed to be based on the most logical and data-based conclusions. As the data and conclusions...
were discussed, students’ conversation reduced the ideas on the board to three possibilities. Students recorded their conclusions and answered questions (see Figure 4, p. 36, and NSTA Connection). Students were anxious to be told about what really happened, with consistent reinforcement that there is not an “all knowing being” in science, but again, a need for data-supported conclusions.

The students’ need for answers was seen as an opportunity to transition into a conversation about the tentative, empirical NOS. Students were asked, “Remember, you were working just like scientists in these Tricky Tracks. So, do you think that scientists have an answer key that tells them if they are right or not? Do you think that you might change your mind about the conclusions? What might make you change your mind? Would scientists be the same way?” Other questions, such as, “How is looking at these fossils similar to the kind of work scientists do?” “Did we do any experiments?” and “Were we still doing science?” were asked to allow students to openly reflect on how Tricky Tracks was similar or different from the way they were thinking about scientists’ work. Students agreed that scientists would study fossils like they had done, but “they would actually get to try to find the fossils.”

**Elaborate**

From this discussion, students moved into the elaborate phase. Through a slide show presentation, students were shown scientists’ discoveries of fossils of the same kinds of animals on different continents. Then, on 12 cards, separate illustrations of these fossils, known information about these animals, and the use of this data to support the interactions of plates were presented as a matching game. For us, this elaboration was specifically chosen as a way of transitioning into the associated disciplinary core idea of describing patterns of Earth’s features and the subsequent learning cycle for Earth’s Systems standards (ESS2.B; NGSS Lead States 2013). Again, however, it is important to note that as a benchmark experience, the elaborate phase of this learning cycle can serve as a transition in several ways.

Students were asked to quickly sort and match the fossils with their accurate data. Competitive in nature, the students worked quickly and quietly in their teams to sort the information cards. Afterward, questions such as, “What could explain how these fossils were found on different continents?” and “What would you think if I told you that our continents are always changing and moving around?” were used to pique their interest. In the summary of the presentation used, students were shown how the boundaries of the continental plates might be seen as puzzle pieces. Students were enamored by this explanation and began excitedly asking questions. One student asked, “Is this why we have earthquakes … because the land is moving?” At the end of discussion, students were posed with a challenge question to write about in their

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**FIGURE 5.**

Modified “Doing Science” formative assessment probe.

<table>
<thead>
<tr>
<th>Name: ____________________________</th>
</tr>
</thead>
</table>

**Doing Science**

Four students were discussing how scientists do their work. This is what they said:

- **Kelly:** “I think scientists try different things until something works.”
- **Gavin:** “I think there is a definite set of steps all scientists follow called the scientific method.”
- **Tyler:** “I think scientists use different processes depending on their question.”
- **Ashley:** “I think scientists use different processes. In these processes, they will do experiments.”

Which student do you most agree with?

Explain why you agree with that student and include why you disagree with the other students.
How Do Scientists Work?

journals. The question posed was, “If you were thinking like a scientist, then how could you be convinced that this is all possible?” In their writings, most students agreed that the explanation was logical, but they did not think that this was “enough evidence” to support a theory of continental drift. This idea of “enough evidence” was further discussed in the subsequent learning cycle.

Evaluate

As final summary and assessment, students transitioned from this isolated, explicit NOS exploration through formal reflection on their initial responses to the probe “Doing Science” (Keeley, Eberle, and Dorsey 2008). It is important to note that after hearing our students’ responses in the engage phase, we decided to modify the names of the students in the conversation and their choices in the probe. We directed our students’ attention to these changes (Figure 5). For example, we omitted the words “just” and “out” from Kelly’s (formerly Antoine) and Gavin’s (formerly Tamara) responses, and replaced the word “methods” with processes from Tyler’s (formerly Marco) and Ashley’s (formerly Avery) responses. In addition, we divided Ashley’s response into two sentences. Results from the probe showed remarkable gains in our students’ way of thinking about doing science. All students chose and explained how Tyler’s response was accurate. Students’ explanations included some variation of “Scientists use different processes depending on their question; there’s not just one set of steps they use that go in order,” or “The set of steps you use depends on the topic you’re working on, and it doesn’t always involve an experiment,” both showing deep understanding of the concept.

Conclusion

The students’ positive interactions with both the content and their classmates and overall gains in understanding this particular tenet of the NOS resulted in a positive teaching and learning experience. As our school year progressed, it was evident that the content of this learning cycle made a lasting impression on our students. At various unexpected but appropriate times during the year, students would participate in discussions by asking each other, “Well, how do you know that? … Is this your opinion?… Are you making an inference?… Is there data to back you up?” Furthermore, as we eluded to earlier, the learning cycle presented provided students with contextual practice in data analysis and interpretation that was applied in a subsequent learning cycle guided by the question, “How do we describe Earth’s features?” This sequencing positively reinforced the NOS made explicit in the presented learning cycle, an instructional approach we found instrumental in the positive outcomes we have shared.

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References


Internet Resource

Tricky Tracks Activity

http://msed.iit.edu/projectican/trickytracks.html

Connecting to the Standards

Standard: 4-ESS2 Earth’s Systems

Performance Expectation:
4-ESS2-2 Analyze and interpret data from maps to describe Earth’s features.

Disciplinary Core Idea:
ESS2.B Plate Tectonics and Large-Scale System Interactions

Crosscutting Concept:
Patterns

Connection to Nature of Science:
Scientific Knowledge is Based on Empirical Evidence

NGSS Table: 4-ESS2 Earth’s Systems

www.nextgenscience.org/4ess2-earth-systems

NSTA Connection

Visit www.nsta.org/sc1409 for the data recording sheet, conclusion template, conclusion questions handout, and modified formative assessment probe.
With the emergence of the Next Generation Science Standards (NGSS; NGSS Lead States 2013), it is apparent that teaching and learning about nature of science (NOS) continues to be an important goal of science education for all K–12 students. The understandings of NOS are included in the both the science and engineering practices and crosscutting concepts of NGSS as:

- Science is a way of knowing
- Science is a human endeavor
- Science addresses questions about the natural and material world
- Science models, laws, mechanisms, and theories explain natural phenomena
- Scientific knowledge is based on a variety of methods
- Scientific knowledge is based on empirical evidence
- Scientific knowledge is open to revision in light of new evidence
- Scientific knowledge assumes an order and consistency in natural systems
With this emphasis on NOS, early childhood teachers are asking how to design instruction to teach NOS within the context of these new standards. During a recent research project, we had the opportunity to teach NOS to 70 first-grade students in an urban midwestern city. For this study, our instruction focused on the learning of three aspects of NOS from the NGSS: Scientific knowledge is based on empirical evidence; science is a way of knowing; and scientific knowledge is open to revision in light of new evidence. However, it is important to note that other aspects of NOS, including “Science is a human endeavor,” were also addressed. The lessons were integrated into the science curriculum and augmented with literature connections. Interwoven throughout these inquiry lessons were reading, writing, and drawing activities. These multidisciplinary lessons allowed us to address topics found in both the Common Core State Standards for English Language Arts (CCSS-ELA) (NGAC and CCSSO 2010) and the NGSS (NGSS Lead States 2013).

To begin to develop an understanding of the aspects of NOS, we introduced the idea that scientific knowledge is based on humans making observations and inferences. Observations are descriptive statements about natural phenomena commonly obtained by young children through their senses. Inferences are statements about phenomena inaccessible to the senses (Lederman and Lederman 2004). Often, students confuse observations with facts and inferences with guesses. Teaching students at an early age explicitly about observations and inferences and that science is a human endeavor can prevent these common misconceptions from forming. In this article, we share examples of the lessons and activities we used in the study.

**Mystery Tube Activities**

This lesson opens by asking students to make observations of the classroom around them. We ask the students to share their observations (e.g., “Leaves are green and there are chairs”). Then the word *observation* is defined, introduced by the probing question, “What do we use to make observations?” Students begin to understand that they use their senses (sight, hearing, smell, taste, and touch) to make observations. Then we play a game to see how well the students can observe. We ask a student to volunteer and the other students make observations about the volunteer. Then we ask the student to leave the room and change one thing about their appearance. When the student returns, the remaining students make observations about the changes in that student. After a few rounds of the observation game, we bring out something else for students to observe. This is where the mystery tube is unveiled.

**When and How To Teach NOS**

In the past, many teachers wondered if it was even developmentally appropriate to introduce NOS to children this young. On the contrary, recent research is now showing that it is not only possible but also that in many cases young students are actually more open to these views of science than older students who may hold more absolute views and misconceptions about science. Young children’s natural curiosity and wonder about everything, coupled with their joyful questioning, provide their teachers with a perfect jumping-off point for inquiry-based science instruction and create an opportunity to explicitly teach about NOS.

Teaching about NOS, as with any other content, is most effective when explicit and reflective instruction is used. Explicit instruction simply means that specific objectives to teach NOS are planned for and taught. During and at the end of lessons, teachers guide students to reflect on what they just did and make connections between their inquiry-based science activities and the work of scientists. Explicit and reflective teaching emphasizes student awareness of the NOS aspects the teacher is targeting within the lesson (Khishfe and Abd-El-Khalick 2002). Explicit instruction makes NOS visible in the classroom, as opposed to the notion that students will come to understand science solely by participating in science activities. For example, during science investigations, teachers often have students collect and use data to form evidence-based conclusions. This is something students do repeatedly in their school careers. However, students may never understand that all scientific knowledge is empirically based if this is not explicitly taught to them. Scientific knowledge is based on observations from senses and data collected from the natural world rather than intuition or opinion. It is also important to note that the teaching of NOS should occur during the course of the school year and be considered a theme as opposed to an isolated unit.
“The Tube” (Lederman 1997) is often used to teach about scientific modeling in the older grades, but we have found it equally as effective in primary grades. It can be made from any type of cylinder (often a paper towel roll). See Figure 1 for a diagram of the tube. We made our tube from an oatmeal cylinder covered in bright paper. The strings were made of thick cord, and we used a plastic ring to connect the strings.

During science investigations, teachers often have students collect and use data to form evidence-based conclusions. This is something students do repeatedly in their school careers. However, students may never understand that all scientific knowledge is empirically based if this is not explicitly taught to them.

We first asked the students what they thought would happen when we pulled the various strings. They responded, “The other string will pull in,” indicating which string they were referring to, and they explained why they believed this. When a student pulled the top...
string on the left, the right string moved in. Then we asked another student to pull the right string and the left string moved in. We finally asked them what they thought the inside of the tube might look like. Some suggested it was one big string. But other students said, “No, there are four strings!” Others said there were only two. We then asked, “Do you know this? Did you actually see this or do you just think this?” Students said they didn’t know this for sure because they can’t see inside the tube but think that it is. We explained that thinking something based on an observation is called an inference. Inferences are a combination of what we observe and what we already know or have experienced. We then asked the students to pull one of the lower strings. When the lower string caused the top string to move in, the whole class was surprised! We then asked, “What did you observe?” and “What do you infer from this now?” As we continued pulling different strings, we asked students if their responses were observations or inferences, and followed up with why they thought so. Next, the students were told to draw a picture of what they thought was inside the tube (see Figure 2), saying that these drawings were also inferences. Students then shared their drawings with each other. We pointed out that although they all made the same observations, their inferred explanations (their drawings) were different. We explicitly discussed with the children that often people have different experiences and knowledge, so even though they observe the same things, they may make different inferences. We talked about this also being true for scientists when they do their work. One child drew a picture of tiny people in his tube pulling the strings (see Figure 3). We asked the children, “Is this possible?” and “Have you ever seen people that small?” Once the children agreed that this could not happen, we followed with a discussion of how science knowledge has to be based on data and what is possible in the real world.

After sharing, we asked the children how they could know if their models would work the same way as the original tube. They decided that they would have to make them! Students were provided with prepunched tubes from toilet paper rolls and precut lengths of string to build 3-D versions of their drawings. Students shared their models and demonstrated how they worked. It is important to note that there are a number of model designs that result in tubes that operate in the same way as the original. In our class, students came up with various ways of making the tube work as our tube did. We asked the students, “If your tube works like ours, does this mean that it is the same as ours inside?” After much discussion, they said this would not necessarily be true. We told them that often scientists make observations and inferences based on those observations but can never be absolutely sure and understand their inferences may change in light of new information.

As a follow-up to the tube activity, we read aloud Dr. Xargle’s Book of Earthlets by Jeanne Willis (1988) to the students. This book is a humorous story about a space alien describing human babies and their interactions with their parents. After reading a section, we stopped and asked students if the descriptions are observations or inferences and why. This served as a way to informally assess student’s understanding of observation and inference.

**Fish Activities**

Finally, we read Fish Is Fish by Leo Lionni (1970) to the students. This book is about how a fish infers his frog friend’s stories of the different living things he encountered on land. Much like the Earthlets book, this text serves as a platform for students and teachers to discuss observations and inferences and how they lead to conclusions. We asked students to close their eyes and visualize a fish. Then we told them to open their eyes and draw a picture of the fish they imagined (Figure 4, p. 44). Students were provided with prepunched tubes from toilet paper rolls and precut lengths of string to build 3-D versions of their drawings. Students shared their models and demonstrated how they worked.
udents were then divided up into groups of three and each group was given a cup of water containing a live goldfish. Again students were asked to draw pictures of their observations, then compare and contrast their two fish images. We modeled ways to write sentences to show two similarities and two differences between the students’ drawings. Students were also asked to compare their observation drawings with other students in their group who looked at the same fish and discuss the similarities and differences of their inferred drawings. A discussion of how scientists observing the same things may have different inferences followed.

A final text was used to bring home this unit on observations and inferences entitled Seven Blind Mice by Ed Young (1992). This book is an old fable about seven blind mice that venture out separately to investigate an unfamiliar object in a nearby pond. Each mouse makes observations and inferences about the new object based on the segment of the object they touch. Finally, the last mouse runs over the entire object and concludes that the unknown object is really a compilation of the separate observations of the other six mice. As we read the book, students were called on to explain what the mice were observing and inferring. We had the students reflect on the investigations they have been doing in science, and again we had a discussion about how it is necessary for scientists to talk to each other, share their observations and inferences, and perhaps as a result of these communications, rethink their inferred conclusions.

**Wrapping Up**

At the conclusion of these lessons, we used the Young Children’s Views About Science (YCVS) assessment protocol (Lederman 2010) to measure the students’ understandings about science and NOS. Because the YCVS is an oral protocol, it is capable of eliciting views of science from students who are not yet able to fully express themselves in writing. A copy of this assessment protocol and a scoring guide can be found online (see Internet Resource). The YCVS consists of six multipart questions. It assesses students’ understandings of what

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**FIGURE 4.**

Student drawings of imagined and observed fish.
science is and what scientists do, as well as their understandings about specific aspects of scientific inquiry and nature of science. Students are interviewed in groups of three to four. Small groups allow children to feel more at ease during the interview and for the students’ answers to build on each other. Students’ responses are evaluated as: inadequate, limited, and adequate. “Inadequate” views were students who had inaccurate understandings of the aspect. “Limited” was assigned for students who had a developing understanding of the aspect, and “Adequate” for students who had an appropriate view of the aspect for their age. We found that all of the students who participated in these lessons and the other lessons in our study gained greater understanding of NOS. The following is an example of one set of questions on the YCVS:

“How many of you know something about dinosaurs?” The children will immediately start telling everything they know! Get some control of the discussion by saying, “Each of you tell just one thing you know about dinosaurs,” and then go on to ask the following questions:

• How do scientists know that dinosaurs really lived since there are no dinosaurs around anymore and no one has ever seen them?
• What do scientists think dinosaurs looked like?
• Why do scientists think they look this way?
• Scientists don’t always agree on the reasons about what happened to make the dinosaurs all die away. Why do you think they don’t agree?

The only way to truly achieve the vision of the NGSS and develop scientifically literate citizens is to begin science instruction as early as possible. The results of our study offer compelling evidence that young students are very capable of learning nature of science. However, it is the responsibility of their science teachers to ensure that NOS is explicitly included in their students’ science instruction. It is reasonable to assume that whenever students are learning discrete science content, they should also be learning what this thing called science is as well!

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A traditional mystery-powders lesson is modified to emphasize argumentation.
By Eun Ju Lee, Suleyman Cite, and Deborah Hanuscin

Many teachers have developed “tried and true” lessons that they look forward to teaching—mystery powders is one of ours. Originally part of the Elementary Science Study curricula in the 1960s, there are now many different versions of this well-known activity in which students examine physical and chemical properties of several white powders (flour, cornstarch, baking soda, and so on) in order to identify a “mystery powder.”

With the release of the Next Generation Science Standards (NGSS Lead States 2013), some teachers may either fear they’ll have to let go of these cherished lessons (like us) or may think that their lessons already align with the NGSS. We noticed key differences between how we had implemented mystery powders and what is envisioned by the NGSS. For example, while the activity aligned with performance expectation PS1-3, Make observations and measurements to identify materials based on their properties, we realized we focused more on students correctly identifying the mystery powder than how they constructed arguments based on evidence. In doing so, we overlooked an important practice of science. In this article, we share how we adapted the mystery powders lesson for fourth and fifth graders using a 5E instructional model (Bybee et al. 2006) to emphasize the scientific practice of argumentation.

Engage

We began by asking students to think about the word property and what they thought it meant. Some students defined property as land and others, as things that belong to you. As students recognized multiple meanings, we explained scientists use the term property to refer to characteristics of a substance. We likened this to traits they have, such as eye color, hair color, and so on, noting that while each of them may share some characteristics, they are each unique.

We then showed students several containers of white powders—indicating the labels had fallen off after we filled them with flour, sugar, salt, and baking soda. Because they were the same color, we couldn’t determine which was which! We asked, “What other properties do you think we could use to tell the difference between these powders?” Students brainstormed in groups, identifying properties such as texture, whether it mixed with...
water, and taste. We differentiated between physical and chemical properties, explaining that chemical properties involve a change in composition of the materials. We told students they’d be able to test their ideas by comparing the properties of each unknown powder to a sample from the labeled product containers. Their goal would be to identify the unknown powder based on its properties.

Explore

Before distributing materials, we reviewed safety expectations—including wearing protective goggles and refraining from smelling or tasting the powders. We asked students why these precautions were necessary, and students agreed this would help avoid powder getting into their eyes and noses. We also emphasized that while flour, sugar, salt, and baking soda are edible and safe to touch, we couldn’t assume that any white powder would be safe to taste or touch.

Next, each group of four students received an unknown powder along with samples of the four labeled powders (flour, cornstarch, salt, and baking soda). We provided trays of materials including plastic cups, paper plates, spoons, stirring sticks, and hand lenses. We also had stations set up with digital microscopes that plugged into USB ports for student use. Each student was given a blank data table to record observations. Five task cards created for this lesson invited students to observe different properties of the powders, including a property of their choice (see Table 1). For example, some students noted whether the powders stuck to the inside of the plastic baggies—and the unique residue patterns each left. Others noted there were slight differences in the colors of the powders. As this was students’

<p>| TABLE 1. |
| Student task cards. |</p>
<table>
<thead>
<tr>
<th>Properties</th>
<th>Tasks</th>
</tr>
</thead>
</table>
| Texture (How does it feel?) | What do you notice when you rub a bit of powder in your palm?  
• How does it feel?  
• How is this alike or different from the other powders?  
What happens when you squeeze a bit of powder in your fist?  
• Does it make a ball? Stick together?  
• How is this alike or different for the other powders? |
| Appearance (What does it look like?) | Place a small amount of each powder on a paper plate. What do you notice when you look at powders with a magnifying glass?  
• What do the particles look like?  
• How is this alike or different from the other powders?  
What do you notice when you look at powders with a digital microscope?  
• What do the particles look like? |
| Chemical Properties (How does it react?) | Fill two small cups with one spoonful of each powder. What happens when you add several drops of iodine solution into each of the powders?  
• How is this alike or different from the other powders?  
What happens when you drop vinegar into powders?  
• How is this alike or different from the other powders? |
| Miscibility (Does it mix with water?) | Place a small amount of each powder in a cup. What happens when you mix water with each of the powders?  
• How is this alike or different from the other powders? |
| Your own property (How are they alike? Different?) | Are there any other properties you can think of that might be useful for examining the powders?  
• What did you find from your test?  
• How are the powders alike or different from each other in terms of this property?  
• Do you think this property is useful for distinguishing between the powders? Why or why not? |
first lesson on the properties of matter, our observations provided useful means of formative assessment both of their understanding of properties and their skills in investigating.

We noticed that even for the same task (mixing with water), what students did and observed varied. For example, some added a bit of water to the powders, mixing them and observing whether they formed a paste, while others added a bit of powder to water, observing whether it dissolved. We decided to follow up on this in the next phase of the lesson.

** Explain **

We held a jigsaw discussion, forming new groups comprised of students from each of the different teams so that each brought something different to the table. As students discussed the differences in their observations, their ideas were expanded—yet they all noticed that samples of each powder had the same properties (i.e., all groups observed baking soda “bubbled” when vinegar was added). They also agreed that no two powders had exactly the same properties. Based on this, there was consensus that they could match up their mystery powders to one of the four samples. While students were beginning to use their observations as evidence to support their arguments, we recognized they needed additional instruction to participate fully in scientific argumentation.

We next read a passage from *Why Do Scientists Disagree?* (Cervetti and Kessler 2010, p. 11) and asked students:

- Do you think arguing in science is a good or bad thing? Why?
- Why do you think scientists might have different explanations about the same data?

To our surprise, the majority of students did think argumentation was a good thing—and that it was inevitable because “different people have different ideas” and ways of seeing things. They explained that disagreements would cause scientists to question their ideas and would lead to better understanding, citing their own jigsaw discussions as an example. As one student put it, “I never thought of it the way [he] did!” As we read the rest of the book, students learned about how scientists disagree, compare their evidence, and test their claims using Galileo’s work as an example.

As we continued the lesson the next day, we reminded students of our discussion about how scientists argue, and explained that when scientists develop their arguments, they put lots of ideas together. We presented them with a card sort (drawn from our notes about their exploration activity), and asked them to sort these based on similarities and differences. As students recognized there were three different types of statements, we helped them identify each group of statements as claims (“The two powders are the same”), evidence (“They look the same under the microscope”), or reasoning (“Since all the grains in this powder have the same shape, and none of the others do, we can use the shape to identify it”). For this, we relied on the Connecting Claims Evidence and Reasoning framework (McNeill and Krajcik 2012), showing students how these different types of statements might be linked together to form a scientific argument (see Figure 1).

Students initially had difficulty distinguishing between claims and evidence but reached agreement that evidence states what happened or what results occurred (based on observations), while claims were what scientists thought the evidence meant (how they interpreted their observations). Not surprisingly, we found they were most unfamiliar with reasoning, or the linking of the interpretation of the evidence to scientific concepts. Researchers have also noted that this is a difficulty for students (Bell and Linn 2000; McNeill and Krajcik 2008).
Extend

To help students apply their ideas about argumentation, we set up a crime scene scenario and shared it with students:

Recently, a string of similar crimes have occurred. The newspapers call these the “White Powder Crimes” because at all of the crime scenes, an unidentified white powder was found. The police need your help! Your job as a forensic scientist is to investigate the properties of a mystery powder found at one of the crime scenes, using what you learned in your earlier explorations.

Each group was given a sample labeled with the number of the crime scene. Some samples were the same powders used earlier in the lesson, while others were new powders such as sugar, powdered sugar, and coffee creamer. Being familiar with the tests, students were able to get started (and were eager to do so!) easily and safely. As they recorded new observations of their mystery powders, they referenced their earlier data from the four known powders.

Evaluate

At the end of the lesson, we asked each group to write out their claims, evidence, and reasoning regarding the identity of the mystery powder on chart paper. We posted the chart papers around the room so that students could view each other’s work in a “gallery walk.” We then invited students to critique each other’s arguments. We set ground rules for this activity, emphasizing the importance of questioning others’ ideas versus criticizing the person, and provided sentence starters (see Figure 2) as a scaffold for offering feedback to their peers. Students used sticky notes to attach their comments to each group’s poster. Groups then met to read through their feedback and based on the critiques, revised their arguments. Because this was the students’ first experience engaging in scientific argumentation, we were concerned with their “grasp of scientific practice” (Ford 2008). The ability to construct scientific claims and appropriate reactions to others’ scientific claims stems from knowing how, under what circumstances, and why to critique them. This is important in understanding the nature of science. Because students were still developing this understanding and would need multiple experiences to build expertise in argumentation, we did not assign grades. Rather, we used this as an opportunity to pinpoint specific difficulties that we could address in future lessons.

Lessons Learned

We found students encountered three main difficulties in crafting scientific arguments. These included making claims that go beyond the evidence, not providing enough supporting evidence, and focusing on evidence that supports their claims while ignoring evidence that does not.

First, we found students did not consider the limitations of their evidence and made claims that went beyond the available evidence. For example, one group initially claimed:

The mystery powder is a mixture of cornstarch and flour. It is white, clumps/sticks together, spreads into fingers, reacts with iodine, and vinegar caused it to bead, but it didn’t mix into “pancake batter.” Based on the evidence we observed from four different powders, this has the same properties as cornstarch and flour.

Comments from peers helped the group consider alternative explanations. For instance, one of the comments was, “I think you should also consider the possibility that this is a new powder that has properties like cornstarch and flour.” In response, the group discussed and eventually revised their argument to specify:

If this powder is one we already used, then the mystery powder is a mixture of cornstarch and flour. It’s possible though that this powder is not a powder we used before. In order to see if this was a new powder, we would need to know both the physical and chemical properties of other powders to identify it.

This refining process opened up the opportunity to discuss that scientists also make tentative claims based upon the available evidence, but identify and look for additional evidence to strengthen their arguments. It helped illus-
trate an important understanding about the nature of science emphasized in the NGSS—that scientific knowledge is open to revision in light of new evidence.

This experience also illustrated to students how the quality and quantity of evidence can result in a claim that is strong or weak. For instance, one of the groups claimed:

*Our mystery powder is salt. It changed color to yellow when mixed with iodine and stayed the same color when mixed with vinegar. When we mixed it with water, it settled on the bottom of the cup.*

Recognizing that this group was focused on only part of the evidence, peers responded, “I think you should also consider other properties. Does your mystery powder have the same physical properties of salt?” The group realized that even though the chemical properties were similar to salt, they needed to consider the physical properties as well. This discussion provided an opportunity to stress the importance of supporting claims with multiple lines of evidence. In this case, when students examined the appearance of the mystery powder under the digital microscope, there were differences between their mystery powder (which was sugar) and salt. They recognized eventually that their claim was not warranted by the evidence. Through this, we were able to emphasize the importance of scientists
Connecting to the Standards

**Standard: 5-PS1 Matter and Interactions**

**Performance Expectation:**
5-PS1-3 Make observations and measurements to identify materials based on their properties.

**Science and Engineering Practice:**
Planning and Carrying Out Investigations

**Disciplinary Core Idea:**
PS1.A Structure and Properties of Matter

**Crosscutting Concept:**
Scale, Proportion, and Quantity

**Connection to Nature of Science:**
Scientific Knowledge Assumes an Order and Consistency in Natural Systems

**NGSS Table: 5-PS1 Matter and Interactions**
www.nextgenscience.org/5ps1-matter-interactions

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**NSSTA Connection**
Visit www.nsta.org/SC1409 for a blank data table.

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References


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Using tools and technology to make accurate observations—a theme highlighted in the NGSS in relation to the nature of science—and how scientific knowledge is based on empirical evidence.

Another common difficulty was that students didn’t fully articulate their arguments and the evidence to support their claims. For example, one group claimed:

*Our mystery powder is flour. Because of the properties we observed and what happened when we mixed them with the liquids, we were able to identify the type of powder.*

A peer responded, “Can you explain what you observed and the properties of your mystery powder compared to flour?” Students had assumed that their peers, who had done similar investigations, would understand their arguments. After considering feedback, the group added:

*Although some properties like texture and color were similar to baking soda and cornstarch, this powder looked different. The powder looked the same as flour and under the microscope did not seem like a mixture of different powders. Since this powder has the same properties of flour and different properties from baking soda and cornstarch, we think it is flour.*

The gallery walk created a context through which students could understand the importance of being explicit and providing details. We found our sentence scaffolds effective in stimulating the conversation.

Conclusions

We found aligning our lesson with the NGSS greatly improved the learning experience for our students, encouraging their engagement as they developed skills for participating in scientific argumentation. The additional emphasis on claims, evidence, and reasoning helped our hands-on activity to be a minds-on activity as well. While our students grew in their ability to argue from evidence, we grew as well in our ability to teach scientific argumentation as we better understood the specific challenges and difficulties they encountered. Incorporating argumentation and aligning our instruction with the NGSS was less difficult than we anticipated, but also challenged us to take our teaching to the next level!

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THREE, TWO, ONE ...

BLAST OFF!

Third-grade students learn about the nature of science through a rocket engineering challenge.

By Susan Hawkins and Meredith Park Rogers
Given a packed agenda, how can you build a solid understanding of complex scientific concepts while promoting and maintaining student interest? In one relevant, substantive curriculum, how can you address the new national standards while targeting learning experiences that fulfill multiple objectives? This activity fits the bill. I can tell you from experience once you announce, “Today we are going to design and test straw rockets to see which design will go the farthest” and then shoot an example across the room, the students are hooked. They want to know and apply anything that may help them propel their rockets farther and faster than all the others.

The Next Generation Science Standards (NGSS) states that “an essential part of science education is learning science and engineering practices and developing knowledge of the concepts that are foundational to science disciplines” (Appendix A, NGSS Lead States 2013, p. 1). With respect to this goal, students need the opportunity to not only practice science but to understand how science is practiced. This relates to understanding the nature of science (NOS), which comprises a fundamental component of learning about science at all grade levels. Through explicit discussion about the nature of science with students, they will learn that scientific investigations can use a variety of methods, science is a human endeavor, new evidence can change what we know about the natural world, and much more.

The purpose of this article is to share an activity that teaches the nature of science to a third-grade class in an explicit and reflective way while incorporating aspects of the NGSS three dimensions for science learning. This activity focuses on the third-grade standard 3-PS2, Motion and Stability: Forces and Interactions, especially performance standards 3-PS2-1, investigating balanced and unbalanced forces, and 3-PS-2, observing and measuring an object’s motion and using evidence to predict future motion. Although the lesson specifically addresses these third-grade standards, it also builds toward the middle school standard for the same topic, Forces and Motion, so can be used to extend the lesson to challenge all students. MS-PS2-2 focuses on how the sum of forces and mass affects motion, a standard requires students to apply their understanding of Newton’s first and second laws of motion (NGSS Lead States 2013).

Teaching the Nature of Science

The pedagogical basis for this lesson is guided by research that suggests effective NOS instruction requires reflective but explicit strategies (Lederman 2007). Research supports the placement of NOS ideas within the context of inquiry-type activities (Smith et al. 2000). This way, the concepts can be experienced and applied—instead of just being presented as discrete facts to be memorized. Teaching the NOS in an explicit way doesn’t mean it should be taught didactically; instead, research advocates that NOS tenets be openly discussed and explicitly connected to activities (Crowther, Lederman, and Lederman 2005). Khishfe and Abd-El-Khalick (2002) suggest the best way to help students form a sophisticated understanding is to first specifically introduce NOS tenets and then provide multiple structured opportunities to reflect on the inclusion or applications of these ideas. In addition, an inquiry-based approach to teaching science that asks students to participate in science like a scientist (i.e., asking questions, collecting data, drawing conclusions based on their analysis of the data, and so on) can also afford students the opportunity to be explicit and reflective about the meaning of NOS (Lederman 2010). See Figure 1 for the NOS concepts as outlined in Appendix H of the NGSS.

**FIGURE 1.**
NOS concepts as outlined in the NGSS - Appendix H.

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge Is Based on Empirical Evidence
- Scientific Knowledge Is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms and Theories Explain Natural Phenomena
- Science Is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science Is a Human Endeavor
- Science Addresses Questions About the Natural and Material World


Activity Background

In this activity, students apply the scientific principles of motion relating to the NGSS disciplinary core ideas.
by designing and redesigning straw rockets. In doing so, they discover science as a creative human endeavor; it is based on empirical evidence with knowledge that is open to revision in the light of new evidence. This activity also involves students in the crosscutting concept of Patterns while they assess which aspects increase flight distance. By keeping track of and analyzing what elements are present in successful designs, both of their own and others in the class, students can learn the importance of respecting evidence and how identifying patterns in evidence can lead to useful generalizations. For instance, if students notice that rockets with more mass (clay added in nose cone) fly farther, they can use this information to improve their design. This activity highlights another crosscutting concept, Cause and Effect. As students learn to systematically test and change one variable at a time, they learn to design fair tests to determine the effects of their design changes. Asking them to design, test, and redesign straw rockets based on evidence from their trials helps them build the link between cause and effect. This activity also supports Planning and Carrying Out Investigations—an NGSS science and engineering practice—when they are asked to design, test, and redesign straw rockets based on evidence from their investigations. Students collaborate as a class to critically assess the scientific ideas behind the successes and to incorporate the best elements of designs based on the collective evidence. Additionally, students explicitly reflect on elements of NOS as they connect to their understanding of the engineering design process and this activity’s disciplinary core ideas (NGSS Lead States 2013).

The materials needed for this activity include:

- Plastic straws
  You will need straws of two different widths—a thicker type for the rocket portion (found at many fast food restaurants) and a thinner type for the shooter portion (found in many convenience stores)
- Scissors
- Index cards
- Tape
- Chart paper
- Metersticks
- Goggles
- Data and design sheets (see NSTA Connection)
- Rubrics for the explain and elaborate phases (see NSTA Connection)
- Modeling clay (optional, to add mass to nose cone)

I also suggest providing copies of the scoring rubrics discussed in the evaluation phase below (see NSTA Connection). Providing rubrics to the students at the beginning helps them to understand the expectations of the activity.

Engage

As I introduce the activity, students’ eyes widen. They can’t believe they are actually being required to shoot things across the room! After one demonstration, they are hooked. The excited murmuring begins as they realize this is not going to be a boring, sedentary school day. This is a good time to discuss the safe and appropriate use of investigating with projectiles. Although the straws are only being powered by the students’ breath, remind students that directing their projectiles at others is
not the objective and that they are to wear goggles throughout the testing portion of the activity.

As a class, have students brainstorm scientific or engineering design ideas that may affect the rockets’ flight. Record students’ ideas on chart paper so they can refer to them throughout the design process. This chart is also useful to refer to during the explain phase so that students can re-evaluate and possibly modify their thinking after they’ve had time to explore the concepts. My students have suggested variables such as the number, size, and shape of fins, the size of the nose cone and whether it should be weighted or not, how hard and fast they should blow, and the angle of trajectory. The aerodynamics concepts of thrust, drag, lift, and gravity may also come up if these ideas have been covered previously. Students might even bring up mass and its effects on inertia and momentum. Be sure to include a discussion about how some variables are easy to control, like the number of fins or the angle of trajectory, and that other variables are harder to control, like how hard or fast they blow. This is a wonderful opportunity to have students brainstorm what they could do to minimize this variability. Depending on time and the attention span of your students, you could also delve into the subject of the effects of human error in experimentation. I usually like to situate this lesson after a certain amount of the disciplinary core ideas have already been explored, so that it can serve as an application of the students’ knowledge and provide a forum for experiencing the engineering design process. In order to prompt the students’ thinking and tie the activity to their real-world experiences, you can ask the students what they know about what rockets look like and what aspects of real-life rockets they think will help them design a straw rocket that will fly the farthest.

Next, briefly elicit what NOS tenets they think would be applicable to designing and redesigning straw rockets. As with the content and process skills discussed above, it is probably better to have introduced the NOS previously so that the engage section of this lesson isn’t so drawn out that the activity loses its momentum. I start discussing the NOS at the beginning of the year when I have students consider what science is. I think it is important to have the NOS tenets displayed in the room so that students are continually reminded about the way science works. You can create a poster of the list of tenets from the NGSS presented in Figure 1 (p. 54).

**Explore**

Allow students to begin the challenge of designing a straw rocket that will fly the farthest using the materials listed above. Hand out the design and data table template (see Figure 2 and NSTA Connection) for students to record their data and drawings. At this point, I also hand the students the rubric I will use to assess their work so that they will know my expectations (see NSTA Connection for the explain phase rubric). You can have the students work individually or in collaborative pairs; the latter gives students the experience of science as a social activity. Hand out materials and allow the students to plan, construct, and test their initial designs. The beginning of the explore phase can only be described as mayhem as the kids excitedly chatter and gather their materials. Once they settle down and start the design and testing process, the atmosphere becomes much more focused—with only an occasional whoop or burst of laughter as a design works well or crashes into the wall. During the explore phase, I circulate to make sure everyone is clear on the directions and is getting their ideas and data recorded. When they get to the redesign, I push them to consider what issues they had with their rockets’ flight and how they could modify the design using the scientific principles we listed on our class chart.

Remind students to label their drawings, include a rationale for their design, record the distance their rocket flew for all three trials and the average, and to fill in their data chart. This will allow you to formatively assess their work accurately. It also helps to instill the habit of collecting and recording precise data and labeling scientific drawings. When students have all necessary data recorded, they should assess how their rockets performed and evaluate what variable they think should be modified. Remind them that science is based on evidence and that they need to have a justification for why they changed what they did. Then they should build, retest, and assess for rocket number two. Some of the students’ second designs work better and some worse, but I have never had a student that hasn’t been motivated by this activity to figure out how to improve their rocket’s performance by considering concepts from the disciplinary core ideas. I usually end the day with
FIGURE 2.
Student design and data table example.

Data and Design Sheets
Your task is to design and build a straw rocket that will fly the farthest distance possible.

Original Design:
Draw design here: Number of fins, size of fins, size of nose cone, if nose cone is weighted or not. Also make sure to enter information onto data chart. Label and include measurements.

Rationale for design decisions:

Issues with flight:

Redesign #1
Based on the issues you found and recorded above, revise your original design. Be sure to identify with a label the aspect of the original design you changed. (Only change 1 variable) Draw design here: Make sure to include number of fins, size of fins, size of nose cone, if nose cone is weighted or not. Also make sure to enter information onto data chart.

Provide an explanation for the design change. Use evidence from your data collection and analysis to support your argument.

Issues with flight:

After meeting with your classmates to compare flight distances and discusses design components employed. Redesign your rocket one last time.

Draw design here: Make sure to include number of fins, size of fins, size of nose cone, if nose cone is weighted or not. Also make sure to enter information onto data chart.

Provide an explanation for the design change. Use evidence from the class results and discussion.

What aspects of the nature of science (NOS) were applicable to the design and redesign of your straw rockets?

<table>
<thead>
<tr>
<th>Tests</th>
<th>Distance Traveled in cm</th>
<th>Average</th>
<th>Evaluation of flight and possible scientific contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
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<td></td>
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<tr>
<td>3</td>
<td></td>
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<tr>
<td>Original</td>
<td>Number of Fins</td>
<td>Size of Fins</td>
<td>Size of Nose Cone</td>
</tr>
<tr>
<td>1</td>
<td></td>
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<td></td>
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<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>Number of Fins</td>
<td>Size of Fins</td>
<td>Size of Nose Cone</td>
</tr>
<tr>
<td>1</td>
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<tr>
<td>3</td>
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<tr>
<td>Final Design</td>
<td>Number of Fins</td>
<td>Size of Fins</td>
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<td>2</td>
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</table>
small group discussions of NOS tenets applicable to the day’s design and redesign process.

**Explain**

Start the second day by reviewing the design task and having students have a “fly off” to determine which rocket designs fly the farthest. Then have the students discuss the design and launch features they felt were the most instrumental in the success of the rockets’ flights, encouraging them to consider the scientific principles that effected the performance. This is the time to bring up the disciplinary core ideas surrounding how balance and mass affect the motion, as well as remind students to use evidence to back up their redesign decisions if students haven’t already done so. By finding patterns in the data, they can make informed modifications of their designs. For example, students may say, “I used three fins to stabilize my rocket so it would fly straighter and therefore farther.” Next, turn students’ attention to the aspects of the NOS they experienced in the explore phase. Direct students’ attention to the NOS tenets poster. NOS tenets that are particularly applicable and have been identified by my students in the past are: Scientific Investigations Use a Variety of Methods, Scientific Knowledge Is Open to Revision in Light of New Evidence, and Science Is a Human Endeavor. All of these tenets relate to the notion that scientific knowledge is both tentative and subjective, ideas that are critical to understanding how science knowledge evolves over time. At this point, I allow students some time to go back and look at their design and data sheets and add any additional details or explanations before I assess them using the rubric I gave them at the beginning of the explore phase (see NSTA Connection).

**Elaborate**

Allow the students to apply what they’ve learned from their community of scientists by having them redesign their rockets once more using the most successful rocket designs and the information from the class discussion. At this time, have them complete page 3 of the design and data table template. They will need to justify their design changes, using evidence to back up their decisions, and discuss any applicable relevant concepts from the applicable disciplinary core ideas. Students will also record the aspects of the NOS they experienced through the design and redesign process. You can use another rubric (see NSTA Connection) to assess them. This rubric includes evaluation of NOS understanding, process skills, and how thoroughly students’ rationales are rooted in disciplinary core ideas. As I do with the other rubric, I give the students a copy of the rubric before they fill out the final portion of their design and data sheet so they will know what my expectations are.

**Evaluate**

I assess both the disciplinary core ideas and NOS understanding throughout every phase of the lesson using a combination of formative and summative assessments. I use the whole class discussion and class chart generated during the engage phase to formatively assess current
student understanding to guide the trajectory of the lesson. During the explore phase, I use the design and data sheets first as a formative and then as a summative assessment to evaluate the students’ understanding of the design and redesign process. As students work through the explore phase, I circulate the room, checking their rationales, justifications, and use of evidence for modifications in order to formatively assess areas where students may be experiencing problems. I also listen in on the small group discussions of NOS tenets during the engage phase to formatively assess student understanding. This allows me to gauge how I may need to scaffold their ideas in this area. The discussion during the explain phase and the final page of the design and data sheets serve as summative assessments to help determine the students’ attainment of science and engineering practices, their understanding of disciplinary core ideas as evidenced in their rationales for design changes, and their understandings of NOS tenets. The rubrics can help you assess students during both the explain and elaborate phases while also informing them of your expectations.

**Conclusion**

This lesson addresses the three dimensions of science learning as laid out in the NGSS—science and engineering process skills, crosscutting concepts, and disciplinary core ideas—in addition to embedding practical exposure to NOS tenets in an inquiry-based activity. In addition to the efficiency component, combining ideas helps build the connections that form a solid framework of understanding of science and how it works. Straw rockets provide an easy, inexpensive way to address multiple learning objectives. The setup of this activity lends itself beautifully to differentiation, allowing all students to achieve at their highest level. It is also a lot of fun! When you have an activity that motivates students to apply their knowledge, teaching becomes a joy.

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**References**


The nature of science (NOS) describes what science is and how knowledge in science is developed (NSTA 2013). To develop elementary students’ understandings of how scientists explore the world, we—an education professor and a third-grade teacher—endeavored to integrate NOS into a third-grade life science unit. The lesson is based on the “Variation in Population” Environments Unit (FOSS 2013) and Next Generation Science Standards (NGSS) performance expectation 3-LS4-3: Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well, and some cannot survive at all (NGSS Lead States 2013). In this lesson, colored paper “organism” models demonstrate how varied colors can result in different levels of camouflage in the environment, and thus differentially benefit the population. A Framework for K–12
Science Education states, “Modeling can begin in the earliest grades, with students’ models progressing from concrete ‘pictures’ and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades” (NRC 2012, p. 58). We recognize that this is only one type of model and that models in general “serve the purpose of being a tool for thinking with, making predictions, and making sense of experience” (NRC 2012, p. 56). Working with a science education professor who has dedicated her scholarship and practice to NOS allowed us to identify where to emphasize NOS in the lesson and to create a NOS poster to reinforce these concepts (see Figure 1).

Using Models to Investigate Ecosystem Dynamics

Throughout the lesson, we emphasized the students acting as scientists; however, our main focus was on how and why scientists use models. This aligns with the Next Generation Science Standard science and engineering practice Developing and Using Models, as the “organisms” served as models of live animals. Thus, we infused NOS by discussing that scientists collect empirical data by making observations and inferences and use models to represent natural phenomena.

The school has been emphasizing using a “claims, evidence, reasoning” (CER) framework to support students’ explanations about their investigative data (Zembal-Saul, McNeill, and Hershberger 2013). Thus, our third-grade students had already experienced a couple of science lessons that incorporated CER although explanations from data were generated as a class. In this lesson, our goal was to scaffold the CER framework so that students could generate individual explanations.

We began the lesson with a question adapted from FOSS: How do variations within a population benefit some organisms over others? In previous lessons in the unit, students had explored populations, inherited traits, and learned behaviors. We had discussed with students throughout those investigations how they were acting like scientists, collecting empirical data through observation and inference, and constructing explanations from their data. This supported the NGSS science and engineering practice of Engaging in
Argument From Evidence. For this lesson, we reviewed these concepts and introduced the word *variation*, which we described as differences within a population. We started a word wall to keep track of the new and reintroduced vocabulary.

Next, we introduced the “organisms.” Because organisms blend into or provide contrast in different environments in nature, our paper “organisms” were brown, green, gray, and red. We asked the students how the different colored papers were similar to (real organisms also vary in color) and different from (real organisms move) the live organisms they represented. We also asked students what variations existed within the population. Students noted that live organisms were different sizes (small and large). We then described their habitat, modifying the FOSS text to our context:

“These organisms are members of a population called ‘twittles.’ They live in several habitats in school yards, including the school garden and the stream. They eat the leaves of plants and their predators are birds. They protect themselves by trying to blend into the environment.”

We then explained that each team would have its own habitat in which to place equal numbers of organisms (and equal numbers of each color), and that the teams would switch habitats and act as predators trying to find the organisms placed by the other team.

To make a NOS connection, we asked students how we might act like scientists to answer our question. We displayed the NOS poster (see Figure 1) and discussed with students that scientists ask questions about the world, work in teams, use models to represent things, and collect data. We said, “Today we are going to act like scientists by using a model to gather data. The twittles are not real organisms but models. Why is it better to use a model of real organisms?” One student responded, “We will use models because real organisms might move around and we wouldn’t be able to find them.” Another student added, “Models will be better because it is cold outside and we might not find real organisms.” We noted that our data would be the observations of these models and that we would look for patterns once we’d collected our data. Students received eight twittles (two of each color) and worked in two teams of 10, thus each habitat had 20 twittles of each color. We put these starting numbers for each population in our results table. Students were very excited to go outside and begin the lesson; however, we reviewed the school’s expectations for outdoor learning to ensure focused student engagement (see NSTA Connection):

- Use quiet voices
- Walking only
- Respect people, plants, and animals
- Ask before using tools or harvesting crops
- Pull up plants only with permission
- Stay on paths

When we got outside, each team worked within the garden or stream area to find good hiding places within sight of their peers. The students were hesitant about where to hide the twittles at first, yet once they began hiding them, they realized that some of them were very difficult to see due to their coloration. Students used their creativity to hide the twittles—they hid them in trees, bushes, near rocks, in groups, and individually. The students then switched “habitats” and were given two minutes to find as
Integrating the Nature of Science

many organisms as they could. When looking for twittles as “predators,” the students looked in places where they knew twittles might be camouflaged. Once back inside, we calculated how many of each organism was found in the two habitats. We tabulated the data for both the garden and the stream habitats on the class chart (see Figure 2).

Constructing Data-Based Explanations

On the second day, we returned to our focus question: How do variations within a population benefit some organisms over others? We reviewed the vocabulary from the previous day’s lesson, and students stated that variations meant differences, and populations were groups of the same organisms. We then reviewed the NOS poster, and students determined that we were indeed acting like scientists. Our guiding question for the lesson served as the question about the world around us. The students easily identified that they worked in teams when placing and hunting for the twittles. They explained that they used the paper twittles to model organisms that would occur in nature. We noted that scientists use different types of models, and that although we were using models like scientists, we were learning about something that scientists had already studied. We then noted that, just as scientists need to understand their data, we needed to do the same, so we were going to look for patterns in our data and think about what this means through cause and effect. Students recorded the data from the class chart into their science notebooks. According to the FOSS lesson, we asked the following questions to understand our observations and inferences and to support the NGSS crosscutting concept of Cause and Effect:

• Which colors and which sizes of organisms were easiest for predators to find? (Students responded, “The red ones and grey ones were easiest to find. We found the most of these.”)
• What does the data tell us? (Students responded, “The brown ones and green ones are the best colors to be because we found the fewest of these … They blend in with the leaves and dirt.”)

Example of claims, evidence, and reasoning from a student’s notebook

• If that variation was passed on from parents to offspring, what might we infer that means for the survival of the future generations? (The future generations can blend in better—and survive more—if the coloration continually passed on from parent to offspring.)

To begin our CER, we looked back at the data table to make a claim based on our data. We asked students to discuss the data in their table groups, just as scientists do to answer questions about the natural world. Students said, “It was good to be a small twittle because they were harder to find.” Another student added, “It was really hard to find the green and brown twittles. I even had a hard time finding the ones I had just hidden.” We noted that scientists must communicate their findings, and often do so through writing; therefore, we needed to record our
CERs in our science notebooks. We asked the students to write their thoughts directly from their table group discussions into their notebooks. However, we quickly realized that students were struggling to get these complex thoughts into written sentences. To scaffold students’ thinking and writing, we provided them with the following frame, “The ________ benefits the population because __________.” Students stated, “The color benefits the population because it can be camouflaged from predators” and “The color benefits the population because it helped it blend in.” Next, we had to support our claim with evidence from our data. Zembal-Saul, McNeill, and Hershberger (2013) note that by third grade, students should be able to make a claim and support the claim with multiple pieces of evidence. For our students, we provided two sentence frames, one for each habitat: “We know this because out of __ brown organisms, we found only ___ in the garden/near the stream.” A few students needed support to read our data chart, therefore we verbally clarified our thinking and darkened the lines separating each place that data was collected in the school yard. Once the students recorded the two evidence statements, we orally reviewed the statements for the green twittles. We did not expect third-grade students to come up with their own reasoning, but we discussed the content recommended by FOSS with them, stating that “adult organisms that have the advantage might reproduce, and their offspring might have those characteristics (inherited traits) that allow them to survive and thrive in their environment (survival of the fittest).” Finally, we concluded that, “we just explored a model to understand how variations like this one benefit a population.”

Assessment and Conclusion

Overall, we think this lesson went very well. We assessed students’ engagement in science investigation through a formative checklist (Pearce 1999) as well as their written explanations in their science notebooks. Most students wrote a version of what we articulated as a whole class.

With scaffolding, the students were able to collect and analyze data to answer a question about the natural world. Students recognized the components of NOS that corresponded to the lesson, especially why models are needed to represent concepts or objects. For example, one student said, “The twittles helped us figure out how different-color organisms blend in since we couldn’t see the real ones.” Our next steps would be to ask students to identify from the NOS poster the ways they act like scientists in future lessons and investigations. We also plan to gradually release the scaffolds for students so that by the end of their year they can come up with their own written claims and evidence.

Connecting to the Standards

**Standard 3-LS4: Biological Evolution: Unity and Diversity**

**Performance Expectation:**
3-LS4-3 Construct an argument with evidence that in a particular habitat some organisms can survive well, some survive less well and some cannot survive at all.

**Science and Engineering Practices:**
Analyzing and Interpreting Data
Engaging in Argument from Science

**Disciplinary Core Idea:**
LS4.C: Ecosystem Dynamics, Functioning, and Resilience

**Crosscutting Concept:**
Cause and Effect

**Connection to Nature of Science:**
Science Is a Human Endeavor

**NGSS Table:** 3-LS4 Biological Evolution: Unity and Diversity
www.nextgenscience.org/3ls4-biological-evolution-unity-diversity

**NSTA Connection**
Download a list of outdoor field trip safety tips at www.nsta.org/SC1409.

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**References**
Learning progressions is an important initiative identified in the Next Generation Science Standards. Providing coherence in K–12 science instruction is vital to the success of any science program. As the Framework states:

“... children continually build on and revise their knowledge and abilities, starting from their curiosity about what they see around them and their initial conceptions about how the world works. The goal is to guide their knowledge toward a more scientifically based and coherent view of the natural sciences and engineering, as well as of the ways in which they are pursued and their results can be used.”

The development of disciplinary core ideas is the focus of this progression discussion. The NGSS provides us with appendices that summarize these progressions, while the Framework provides the full explanation of progressions.

Communicating progressions to Science and Children readers will be a challenge. It will require a creative approach to providing our readers with a clear understanding of how a progression is developed, supported, and assessed, while also revealing specifics concerning what occurs in the classroom. This is complex because a progression may span several disciplinary core ideas and incorporate many practices across grade levels.

Be creative. Consider ways you can illustrate strategies for providing progressions as they are used successfully in your school. Illustrate how a disciplinary core idea is developed as students approach it from one grade to another, using a minimum of two grade levels; explain how students at one grade level encounter a core idea at various points throughout the year, developing and adding on to their understanding; show how the progression of disciplinary core ideas are developed alongside the increasing complexity of practices; and/or provide a view of how crosscutting concepts are developed as students develop understandings.

To discuss your ideas or for more information, contact Science and Children Editor Linda Froschauer: fro2@mac.com

For this special issue will allow the acceptance of manuscripts with a 3,000 word limit, surpassing our usual 2,000 word limit. We will also accept a series of up to three manuscripts that are closely linked from a team of authors, showing how disciplinary core ideas are developed from one grade level end point to another.

Find manuscript guidelines and submission instructions at www.nsta.org/elementaryschool.

Submit manuscripts at http://mc.manuscriptcentral.com/nsta.

See our complete call for papers at www.nsta.org/sandccall.
Q: How Do We Use Calculus in Science?

By Bill Robertson

That might seem like an odd question to answer in a magazine intended primarily for elementary school teachers. After all, how much calculus do we use in elementary science? For that matter, I’m going to guess that quite a few readers of this column don’t know a whole lot about calculus and haven’t taken a course in calculus. I’m addressing the question for a few reasons. First, the basic concepts of calculus, minus the complicated-looking math, aren’t that difficult to understand. Second, calculus is behind many of the science concepts we do cover in elementary school. Third, every elementary school teacher will, at some time or another, get student questions that have something to do with calculus and its applications in science. If those three reasons are good enough for you, then keep reading.

As is often the case in these columns, I’m going to have you do an activity to start. Stand about five feet from a wall, facing the wall. Take a step that covers half the distance between you and the wall. Then take another step that covers half the remaining distance between you and the wall. Keep taking steps that cover half the distance between you and the wall. Do you ever reach the wall? Well, there are two answers—one according to the mathematics behind what you’re doing, and one that reflects reality. In reality, you run into the wall, right? But mathematically, if you keep halving the distance between you and the wall, you’ll get really, really close to the wall, but you’ll never touch it.

Why do that silly exercise? To illustrate that science models (these are often mathematical models) don’t always mesh with reality. Our model in this case (moving half the distance between you and the wall each time) says we’ll never reach the wall. In reality, we run into the wall. Another reason to do that silly exercise is to help you understand what’s going on in the next exercise, an exercise that will help us understand a basic concept in calculus.

Get yourself a ball (just about any size, from marble to tennis ball) and find a carpeted surface. Mark a starting point on the carpet (use a pencil or anything similar) and start the ball rolling toward that point. When the ball hits that point, start counting out seconds (as in “one thousand one, one thousand two, one thousand three...”). Count until the ball stops. Do not start counting until the ball hits the starting point—we’re interested in the time measured from the starting point rather than the time measured from the moment you get the ball rolling (see Figure 1).

Estimate the distance (in meters) the ball traveled (anything approximately close to the actual distance is
fine) and estimate the time (in seconds) it took to travel that distance (obviously an estimate since you were simply counting out seconds). Once you have those two numbers, divide the distance in meters by the time in seconds. What you have calculated is the speed at which the ball traveled.

\[
\text{speed} = \frac{\text{distance traveled}}{\text{time to travel that distance}}
\]

Let’s suppose your ball traveled 3 meters and it took one and a half seconds. Then the speed you would calculate is

\[
\text{speed} = \frac{3 \text{ meters}}{1.5 \text{ seconds}} = 2 \text{ meters per second}
\]

Did the ball travel at 2 meters per second the entire time? Was it moving at 2 meters per second at the beginning? How about as it stopped? If you answered no to all three questions, good for you. That speed you calculated doesn’t tell you how fast the ball is moving at each point in time, but rather gives you the average speed of the ball for the entire trip.

Let’s say you want to know how fast the ball is traveling 1/4 of the way along its trip, meaning you want the instantaneous speed at that point. Note that this is not 1/4 of the average speed for the entire distance; in fact, it will be a speed greater than the average speed for the entire distance. One way to get an answer for that is to measure the distance the ball moves for the first half of the trip and divide it by the time it takes the ball to travel the first half of the distance, as shown in Figure 2. Just for kicks, try that with your ball, attempting to roll it at about the same speed as before. This time, divide half the total distance by the time it took the ball to travel to the halfway point.

That gives us the average speed of the ball for the first half of the trip, but does it give us the exact speed at the 1/4-way point? Nope. We’re closer, though. The average speed for the first half of the trip is closer to the exact speed at the 1/4-way point than is the average speed for the entire trip. Okay, so let’s try a smaller distance right around the 1/4-way point, say the one shown in Figure 3.
Will that give us the exact speed at the 1/4-way point? Again, no.

In fact, we can take smaller and smaller distances around the 1/4-way point and measure the time it takes for the ball to go those distances, but we’ll never get the exact speed at that point. The speed we get will be closer and closer to the exact speed at that point, because we’re narrowing in on that spot by using smaller and smaller distances. But our result will always be an average speed for a certain distance, because we can’t determine the speed without a distance and a time to travel that distance. At exactly the 1/4-way point, the ball doesn’t move any distance at all, because by definition, there is no distance involved in an exact point!

However, we often talk about the speed of an object at exactly one point—we call that the object’s instantaneous speed. But how can we do that if we can never measure an object’s instantaneous speed? This is another case of our scientific model (calculating speed by dividing a distance by a time) not quite describing our notion of reality (the object is moving at a specific point, and it’s moving at a certain speed).

Sometimes we can calculate instantaneous speed, such as when the object is moving at a constant speed. Then the instantaneous speed at any point is always equal to the average speed because the speed never changes—unchanging speed is what we mean by the term constant speed. If a ball is moving at 2 meters per second throughout its motion (constant speed), then its instantaneous speed at any point is 2 meters per second. The speed never changes because it’s constant, not because we’re calculating it in a certain way. But in most instances, objects change speed, and do so at different rates of change.

The mathematics known as calculus comes to the rescue. We can use it to calculate instantaneous speed even when the speed is always changing.

That’s where a lot of introductory resources stop. “We use calculus and you won’t understand it, so just trust us.” Well, calculus really isn’t any different conceptually from what we just went through with the rolling ball. We couldn’t measure the speed of the ball at exactly one point, but we could take smaller and smaller distances, measure the average speed for those smaller and smaller distances, and get closer and closer to the instantaneous speed of the ball at one point. We can’t measure the exact value at an exact point, but we can approach that value by using smaller
and smaller distances (see Figure 4).

Calculus goes through that process of approaching a value by taking smaller and smaller intervals for speed calculation (remember—we need an interval of distance and time, calculating an average speed for that interval because we can’t calculate speed at an exact point), and does so mathematically. In calculus, we call that “approaching the limit” of a value. To see that more clearly, let’s graph the distance a ball moves versus the time it takes to go that distance. For a ball moving at constant speed, the graph looks like Figure 5.

Notice that the ball covers the same distance in equal time intervals, so the calculated average speed—the distance traveled divided by the time to travel that distance—is the same no matter what the interval. That means that the instantaneous speed at any point and the average speed for any interval have the same value. Now recall, if you will, how to determine the slope of a line. In case you don’t recall it, the slope of a line plotted on an set of x-y axes is equal to the change in value on the y axis divided by the change in value on the x axis. You might have learned this as “rise over run” (see Figure 6). The slope of a line tells you how “steep” the line is or \( \frac{\Delta y}{\Delta x} \).

Comparing Figures 5 and 6 will tell you, then, that the speed of a ball rolling at constant speed is simply equal to the slope of the graph of distance versus time. Figure 7 should make that somewhat clear.

No calculus needed in the above case, because the slope of our graph of distance versus time is constant; no matter what two points you use for determining the slope (the average speed), you’ll always get the
same answer. Now, though, let’s look at a graph of what your ball did rolling on the carpet. It started out moving fast and then slowed to a stop. Figure 8, page 69, shows a graph of distance versus time for this motion. Take a moment and convince yourself that this graph shows an object moving slower and slower, and finally stopping.

The speed of the ball is changing, and the slope of the graph representing the motion is changing. No surprise, because when you plot distance versus time, the slope of the graph is the speed. Because the slope of the graph is always changing, you can’t determine the slope the way we did with Figures 5 and 6. If you want the slope (or speed) at a particular point on the graph, you have a problem. You need two points to determine the slope. So, we start approximating the slope at a particular point by figuring out the slope for smaller and smaller intervals. As we do that, we get closer and closer to the answer we’re after. We “approach the limit” of the value of the slope, and get an answer even though it’s impossible to get the answer directly (remember, you want the slope at a single point, but you can’t calculate slope without two points, so you can’t get a direct answer). Check out Figure 9, where the two points are labeled A and B. As B gets closer to A, the slope of the line between A and B gets closer to being the slope at point A.

For those of you who have taken a calculus course before, what I just described is known as finding the derivative of the graph. With a mathematical expression that describes the graph, finding the derivative is a mathematical process. It can get pretty complicated and ugly, but the basic idea is relatively simple.

Okay, so what? We need calculus just to find the instantaneous speed of things? If that were all we could do with calculus, it might not be worth the trouble, but science is full of situations where something is changing continuously, and we want to find an instantaneous value of the something. Examples are the voltage and current in an electric circuit, the energy in a sound wave, the heat input or output of a system, the rate of a chemical reaction, and even the population of a species (not really constantly changing, but changing so fast that it’s almost constantly changing and you can use calculus to describe things). By using calculus in our scientific
models, we’re able to help bridge the gap between our models and reality. And the better our models represent reality, the more valuable the models.

In this column, I’ve only covered a portion of what calculus is good for. It’s useful for calculating all kinds of things that change continuously. For example, you probably know that the area of a circle is given by the formula $\pi r^2$, where $r$ is the radius of the circle. But think about what area is. The area of something tells you how many square meters or square centimeters or square anythings fit inside a shape. A bunch of little squares fits nicely into a rectangle, but not into a circle. When you put little squares near the curved surface of a circle, there are always little gaps at the edge. See Figure 10.

To take care of this problem, we add up little squares in the limit at which the size of each square approaches zero. That is, you add up tinier and tinier squares (the tinier they are, the better they fit into the gaps near the edge), getting closer and closer to the answer, until you arrive at the answer mathematically. I say “mathematically,” because you can’t add up things that have zero size! When you do the math, though, you end up with the answer of $\pi r^2$.

As before, I’m not going to go into any detail on actual calculations. I’m just trying to give you a basic conceptual understanding of what calculus is all about, and how it helps us develop scientific models that more closely approximate reality. Of course, I could write about 20 columns on what we mean by “reality,” but the editors wouldn’t like that, and not that many people would care.

Bill Robertson (wrobert9@ix.net com.com) is the author of the NSTA Press book series, Stop Faking It! Finally Understanding Science So You Can Teach It.
Pet birds, fish, reptiles, and mammals—all are often found in elementary classrooms because of the wide variety of opportunities they provide for exciting teaching and learning experiences. Applications of the opportunities these organisms can provide is reflected in the NGSS Life Science progression of disciplinary core ideas, specifically LS1.A, Structure and Function: “All organisms have external parts. Different animals use their body parts in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water, and air” and LS1.B, Growth and Development of Organisms: “In many kinds of animals, parents and the offspring themselves engage in behaviors that help the offspring to survive” (NGSS Lead States 2013).

Although a popular addition to the classroom, pet adoption comes with safety and responsibility issues. The NSTA position statement Responsible Use of Live Animals and Dissection In the Science Classroom notes, “NSTA encourages districts to ensure that animals are properly cared for and treated humanely, responsibly, and ethically. Ultimately, decisions to incorporate animals in the classroom should balance the ethical and responsible care of animals with their educational value.” The position paper recommends that teachers “educate themselves about the safe and responsible use of animals in the classroom. Teachers should seek information from reputable sources and familiarize themselves with laws and regulations in their state.” In this column, I share things to consider when bringing animals into the classroom as well as resources for caring for them, with student and animal safety in mind.

Before Introducing Animals to the Classroom

Before adopting and bringing pets into the classroom, make sure the basic care and safety requirements can be met. The NSTA book Exploring Safety: A Guide for Elementary Teachers (Kwan and Texley 2002) provides insight; see Figure 1 for thoughts to consider. The book also contains a handy chart about how to select the appropriate organism or pet for the classroom, featuring type of organism, level of required care, and potential problems.

A component of animal care that you may not have considered is that some local health departments may require (or advocate for) veterinarian examination of certain classroom pets, including administration of vaccines. All animals, including service animals, housed on school property on a regular basis must meet every veterinary requirement set forth in state law and county or local regulation/ordinance.

It is essential to have a parental notification form go home so parents are aware of the new classroom additions, learning objectives for having the pets, request for allowing students to be directly involved with pets (handling, care, and cleaning), and most important, any health concerns (allergies). A great resource for this information and much more is the Columbus Public Health Department booklet titled “Classroom Pets: Safely Caring for Animals in the Classroom” (see Internet Resources). Another excellent guide for safety tips is “Science & Safety: Making the Connection” from the Council of State Science Supervisors (see In-
ternet Resources). One should never assume everyone knows the obvious, such as only allowing students to touch animals after they have been given handling instructions, and not disposing of animal waste in sinks.

More In-Depth Information

Teachers looking for a more detailed resource, especially in the area of specific pet care and health issues, should check out a guide by the American Association for Laboratory Animal Science called *Caring for Animals: A Guide to Animals in the Classroom* (see Internet Resources). The resource first addresses the idea of having animals or pets in the classroom, with consideration given to school policies, pet care, parent concerns, and health issues. Specific attention is given to allergy and asthma considerations for students, along with additional resources. Species-specific animal care sheets provide information on biology and husbandry for the types of animals found most commonly in school classrooms. Each care sheet provides information on housing requirements, feeding, handling, diseases, human health concerns, and resources. The section that deals with potential signs of pain and distress in animals (discharge from eyes, changes in facial expression, sores, changes in respiration rate, change in posture, isolation, and restlessness) helps to ensure that the animals are properly cared for and treated humanely, responsibly, and ethically—as advocated in the NSTA position statement on this topic. The last section of this resource shares 10 basic principles in consideration of animals for classroom use.

**FIGURE 1.**

**Thoughts to consider before bringing animals into the classroom.**

- Is there dander, mold, or other allergens being brought into the classroom with the pets?
- Can student behavior be monitored and controlled to ensure the pets would not be placed in harm’s way?
- Are plans in place to schedule animal feeding and cage cleaning?
- What would you do with the progeny should they arrive?
- What about care plans for weekends and vacations?
- What happens to them at the end of the school year?
- Can you help students deal with the death of a classroom pet?

<table>
<thead>
<tr>
<th>Type of Organism</th>
<th>Level of Care</th>
<th>Potential Problems</th>
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| Plants                            | Low: need light and water, can be left for vacations | • Molds bother some sensitive students  
• Some plants are toxic          |
| Aquarium fish, protists           | Low: can be left for vacations       | • Slight risk from bacteria in tank  
• Temperature controls may be required during vacations |
| Crustacea and snails              | Moderate: simple foods, intolerant of heat | • Moderate risk of bacterial contamination |
| Insects, butterflies              | Moderate: cultures can become moldy | • Stings  
• Exotic species endanger the environment |
| Reptiles (snakes, lizards, turtles)| High: require live food, intolerant of cold | • Bites  
• Salmonella infections  
• Moldy food  
• Sensitive to temperature change |
| Rodents and rabbits               | High: can’t be left unattended during vacations | • Allergenic dander  
• Odor from droppings and bedding  
• Bites and scratches  
• Human disease carriers |
Final Safety Thought

Feather, feet, and fin pets in the elementary classroom provide exciting educational opportunities to which students can easily relate. However, this comes with work and responsibility for the health and safety of both pets and students. Be prepared by looking into the components of pet care and checking out the resources provided before adopting any pets for the classroom.

Ken Roy is Director of Environmental Health and Safety for Glastonbury Public Schools in Glastonbury, Connecticut, and NSTA’s Chief Science Safety Compliance Consultant. If you have questions or an issue dealing with safety that a future column might help address, send an e-mail to Royk@glastonburyus.org.

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Internet Resources
American Association for Laboratory Animal Science
Animal Science
www.aalas.org/resources/classroom_animals.aspx

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Perfect Pairs
Using Fiction & Nonfiction Picture Books to Teach Life Science, K–2
Melissa Stewart and Nancy Chesley
Perfect Pairs, which marries fiction and nonfiction picture books focused on life science, helps educators think about and teach life science in a whole new way. Each of the twenty-two lessons in this book is built around a pair of books that introduces a critical life science concept and guides students through an inquiry-based investigative process to explore that idea. Bringing high-quality science-themed picture books into the classroom engages a broad range of students and addresses the performance expectations outlined in the Next Generation Science Standards.
Grades K–2 | TS-0958 | $28.00

Also available from Stenhouse
To Look Closely
Laurie Rubin
Grades 1–6 | TS-0992
$22.50

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Elementary science experiences help develop students’ views of science and scientific interests. As a result, teachers have been charged with the task of inspiring, cultivating, recruiting, and training the scientists needed to create tomorrow’s innovations and solve future problems (Business Roundtable 2005). Who will these future scientists be? The Next Generation Science Standards (NGSS) support science as a human endeavor and propose that men and women from different social, cultural, and ethnic backgrounds choose careers as scientists (NGSS Lead States 2013, Appendix H). In other words, the culturally and ethnically diverse elementary school children in our current classrooms are the scientists of the future.

We wondered what fourth-grade students thought about scientists, science careers, and the contributions of scientists. Did they share the NGSS view that anyone could be a scientist and choose a science career? Or did they hold stereotypical views
Engage: Look in the Mirror

To create interest, we told students that we had just discovered something remarkable on a mirror while preparing the lesson. We told them we were wondering if we were the only ones who had seen it because, if we were the first to discover it, we needed to contact the National Science Foundation to see if we could win an award. We projected the NSF home page (see Internet Resources) to show them the large "Awards" and "Discoveries" tabs.

Next, we gave students small mirrors and encouraged them to look closely to see if they could spot the discovery. We had them make predictions as to what the remarkable thing was and without giving it away, we provided a few clues to keep their curiosity high. Sample clues included: This thing could change the world! It could save lives! It could be famous!

No one connected the mystery discovery, “scientists,” to the reflections in the mirrors. We told the students that we would revisit the discovery challenge later in the lesson.

Explore: Sculpt-a-Scientist

Sculpt-a-Scientist (Jackson 2008) is a fun tactile activity that we decided to use to discover what our class of fourth graders thought about scientists and to activate any negative stereotypes students might hold regarding scientists and scientific careers. Modeled after the Draw-a-Scientist test (Chambers 1983), “Sculpt-a-Scientist uses modeling clay or play dough as the medium for creative expression” (Jackson 2008, p. 50). Sculptures and brief narratives explicate student perceptions regarding scientists and scientific endeavors. Farland-Smith (2011) notes that children’s illustrations have long been accepted as their representation of how they view the world and therefore their pictures are filled with information they are trying to convey. Jackson (2008) suggests that student-generated sculptures may do the same thing.

Each student received a stick of modeling clay, a piece of wax paper for them to put their sculpture on, and an index card for the student to write a brief paragraph describing their sculpture. If you do not have modeling clay, you can make your own play dough. Figure 1 contains a play dough recipe that makes about a pound of dough and is enough for 8 to 10 students.

Next, students were asked to use the modeling clay to sculpt a scientist at work. It took a few minutes for the creative juices to kick in, and we needed to offer a few words of encouragement to reluctant sculptors. We motivated them by suggesting a competition among the students for the

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**FIGURE 1.**

Traditional play dough recipe.

- 1 cup flour
- 1 cup warm water
- 2 teaspoons cream of tartar
- 1 teaspoon oil
- 1/4 cup salt
- food coloring (paste food coloring creates intense, vivid colors)

Combine food coloring and warm water. Mix all ingredients. Stir over medium heat until smooth and the play dough does not stick to the sides of the pan. Remove from pan and knead until blended smooth. Place in plastic bag or airtight container when cooled. Will last for two weeks.
FIGURE 2.
Descriptions of student sculptures.

“He has goggles to protect his eyes and a lab coat to protect his body.”

“My scientist has crazy hair because they stay up for days focusing on their crazy project and don’t have time to take care of their hair.”

“My sculpture is a boy because I see boys on TV doing science all the time.”

“My scientist looks evil because he creates weapons to destroy the world.”

most detailed and accurate sculpture. We encouraged them to think about what clothes scientists wear, what tools they use, what environment they may work in, and so on. As the students finished sculpting their scientist, we asked them to write a short narrative that described their sculpture. Students were asked to describe their completed sculpture and to explain why they included anything extra in their depiction of their scientist.

Explain: Our Data vs. the Stereotype

When all of the students were finished, they shared their scientist sculptures and their descriptions with each other in small table groups and then they moved around the classroom (gallery walk) to observe the remaining sculptures and read the accompanying descriptions. We used “two stars and a wish” to structure student feedback. As the students moved from table to table, we encouraged them to write at least two positive comments (two stars) for each sculpture as well as list any questions they had regarding the sculpture (a wish) on an index card or sticky note. The two stars and a wish format provided students with a structured peer review template. A quick two stars and a wish search on the internet will provide multiple examples and images of this instructional strategy. Following the gallery walk, we held a class discussion regarding what the students had learned during their gallery walk. This gave students a chance to respond to any questions their peers had after the gallery walk. Next, the students compiled a class list of the descriptions the class had used to describe their scientists. We noted which descriptions were common among the scientist sculptures and which descriptions were unique.

We thought that student sculptures would reflect students’ ideas about scientists and science careers. They did! Forty-eight fourth graders participated in this activity. Their finished sculptures included a mix of two- and three-dimensional shaped scientists, and the narratives were brief but informative (see Figure 2 for a sample). Of the 48 students that participated in this activity, only three of them sculpted a representation of science that was outside of typical stereotypes. These three included statements such as:

“I made a table. I always see science experiments happening with a bunch of stuff on a table that you look at and touch.”

“I made a bird in her nest with her eggs. Scientists watch birds and how they nest.”

“I made a shark with a tag spear. I see scientists on Shark Week tagging sharks in the ocean and tracking them.”

We read the results of Mead and Metraux’s (1957) study and Chambers’s (1983) study (described in the “Studies of Stereotypes About Scientists” sidebar) to the class and created a list of the descriptions of scientists included in Mead and Metraux’s and Chambers’s results. We compared the list of our descriptions to the list of descriptions included in the two studies and highlighted the scientist characteristics that were common among our descriptions of scientists and those provided by the students in the studies. Many of the fourth-grade students’ scientist sculptures and descriptions included elements of the stereotypes reported by Mead and Metraux (1957) and Chambers (1983). We also noted differences in the lists. We discussed the sources of all of the beliefs. Were they based on scientists viewed in movies, cartoons, video games, or television shows? Were they based on factual sources? It is important to help students separate fact from fiction.
Elaborate: Internet Resources and Research

We reviewed the mystery discovery from the engage activity. We informed the students that the remarkable thing we were looking for was the reflection of their faces in their mirrors: the reflections of scientists! We wanted them to realize that they are scientists and that they could choose to pursue scientific careers. Negative stereotypes and modern ideas about scientists became topics of classroom discussion and were validated or refuted with the help of internet resources and books. We wanted students to understand that some of their beliefs were tenacious negative stereotypes that could not be substantiated in real life.

To focus their research efforts, students were assigned specific tasks. They could conduct research and write a report about a particular scientist or a specific scientific career. Research was conducted using the internet and books about science and scientists, including biographies found in the school library. Local scientists could also be invited to speak to students about their careers and what sparked their interest in science. Research is a key feature of Common Core for Literacy Standards. When students participate in a short-focused or longer research project, they meet elements of the writing strand.

Evaluate: First We Thought, But Now We Know...

There are several ways to evaluate this lesson. To evaluate student understanding, we showed pictures of various scientists at work in a variety of fields, both stereotypical and non-stereotypical. As we displayed the slide show, students gave a “thumbs up” or “thumbs down” to show whether or not they believed the person was a scientist. After several slides, the stu-

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Studies of Stereotypes About Scientists

**Historical Studies**

In 1957, Margaret Mead questioned 35,000 high school students to find out what they thought of science and scientists. They were asked to respond to one of the following questions:

**Boys:** If I were going to be a scientist, I should like to be the kind of scientist who...

**Girls:** You may either complete the sentence above or this one: If I were going to marry a scientist, I should like to marry the kind of scientist who...

Participants described scientists as elderly or middle-age white males who wore glasses and white lab coats, and worked in a laboratory surrounded by equipment: bubbling liquids in test tubes, flasks, and bottles. They believed that scientists were probably bald, stooped, tired, unshaven, and should never marry. They pictured scientists peering through microscopes and telescopes and writing notes neatly in a black notebook (Mead and Metraux 1957).

In 1983, Chambers developed the Draw-a-Scientist assessment. To complete this two-part activity, students drew a picture of a scientist at work and then wrote an explanation of their drawing. The historical descriptions of scientists gathered by Mead (1957) and Chambers (1983) reveal that the perceived image of how scientists look and what a scientist does has remained reasonably constant for decades (Chambers 1983; Barman 1997; Thomas, Henley, and Snell 2006; Steinke et al. 2007).

**Sources of the Stereotype**

Perpetuated by books, magazines, comics, television, movies, and video games, the scientist stereotypes reported by Mead (1957) and Chambers (1983) have proven to be pervasive and extremely resilient. Because children gather progressively negative images of scientists throughout their childhood, Knight and Cunningham (2004) stress the importance of confronting negative stereotypes early. Images of scientists developed during childhood play a role in shaping perceptions of scientists and may influence career choice (Steinke et al. 2007).
students started to notice their thumb kept staying up! After awhile, with big smiles on their faces, they started shouting, “These are ALL scientists!” There are several other ways of evaluating whether the objective has been met for this lesson. Students could conduct research on other classes or their parents to see if they maintain stereotypes about scientists. They could graph the results to figure out the percentage or fraction of students in the school or adults with stereotypical views of scientists. Student could write a short play that highlights the transformation of their thinking. Dialogue sentence stems could be provided for the students to complete: “At first we thought scientists … But now we know scientists ….” Teachers might use this activity at the beginning and end of the year, to see whether attitudes have changed. Finally, they could ask students to create a bulletin board that displays pictures of scientists, and put a mirror in the center. Throughout the year, teachers could emphasize the role of students as scientists, actively engaged in scientific inquiry, thinking like scientists. Just look at yourself in the mirror. You are a scientist!

Conclusion

Elementary school is the perfect place to introduce science careers, discuss contributions of scientists, and highlight science as a human endeavor. The Sculpt-a-Scientist activity helped us uncover what 48 fourth-grade students believed about scientists and scientific careers. It highlighted the existence of tenacious negative stereotypes of scientists while providing opportunities to explore and challenge the validity of these stereotypes. It provided us with a focused research project that prompted a dialogue that presented scientists as men and women from various cultural and ethnic backgrounds. We discovered that modern scientists mirror the demographics of our diverse classroom. ■

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Getting Your Own Lab Coat (careers in science and research) http://kids.niehs.nih.gov/explore/ehs/labcoat.htm

Pictures and brief biographies of notable women scientists
www.factmonster.com/spot/whmbios2.html

Project NOVA (biographies of notable female and minority scientists)
www.csupomona.edu/~nova/scientists/index.html

National Science Foundation
www.nsf.gov

The Institute of Environmental Health Sciences: Meet the scientist
http://kids.niehs.nih.gov/explore/ehs/meet_the_scientist.htm

The 20 Most Influential Scientists Alive today
www.superscholar.org/features/20-most-influential-scientists-alive-today
Creating a classroom culture for engineering

The Tightrope Challenge
When confronted with a robotics engineering task, fourth-grade students develop growth mindsets.

By Bill Burton

In truly authentic problem-solving challenges, teachers may not know what will happen or how a final project will look. When teachers give up some control of an engineering project and hand it over to students, some amazing things can happen.

In order to prepare our students to become our next innovators, teachers need to provide real-world challenges that allow children to exercise their innovation muscles. The real-world innovation process doesn’t happen on a worksheet, and it doesn’t come with a detailed set of directions. Innovation starts with a problem and innovators work to solve a problem by planning, creating, and testing. Along the way, there may be successes and setbacks, joy and frustration, teamwork and friction.

Often, the setbacks and frustrations in a project lead to the greatest successes and the most meaningful learning. Thomas Edison tested over 1,600 materials for the filament of the lightbulb before he found one that worked (Smithsonian.org). As innovators, our students need to have Edison’s resiliency.

In her book Mindset, Carol Dweck (2008) coined the terms growth mindset and fixed mindset. Dweck states that people with fixed mindsets believe that certain personal qualities are static. They cannot grow beyond who they are. When met with a challenge that doesn’t offer initial success, they may be quicker to make excuses, assign blame, or simply give up. On the other hand, Dweck describes people with growth mindsets as having resilient characteristics. They relish a challenge. When faced with a setback, they think of ways to improve their performance. They have a resiliency that innovators need.

When my students are given an engineering challenge, the key word is challenge. Challenges that aren’t challenging don’t help students learn new skills or try new things. It can quickly become clear which type of mindset a student has during a particularly difficult challenge. But what’s great about Dweck’s mindsets is that they can change. As educators of innovators, it is our role to nurture the growth mindset.

Background
Lego Mindstorms robotics sets offer endless opportunities for students to complete engineering and programming challenges. Before entering fourth grade, students at our school have had significant experience with both Mindstorms and WeDo Lego systems and programming. In addition, classes have spent time discussing the steps of the engineering or innovation process. While this article demonstrates the engineering process through the lens of Lego products, there are certainly other activities that require less investment in materials (see “Alternatives to Legos,” p. 83).

The Engineering Process
There are many resources that discuss the engineering process. The steps of the engineering process can take on many forms. In many cases, the engineering process itself depends on the problem being solved. While the process isn’t bound by any rules, it generally includes the following six steps (in some varied order or detail):

- Problem Statement
- Research
- Design
- Create
- Test
- Improve

These steps are often cyclical in nature. A design may be built and tested. Then, improvements need to be made that require more building and testing. Several websites offer great kid-friendly graphics describing the engineering process (see Internet Resources).
Setting Up the Challenge

In fourth grade, students are given several open-ended robotics challenges. For the purpose of this article, the tightrope challenge will be discussed. In the tightrope challenge, a length of rope was suspended at student height and secured at each end of the room. A teacher-designed Lego device secured at one end of the rope held a plastic ball (see Figure 1 and NSTA Connection for directions). The ball holder can also be made from materials such as cardboard and tape, as long as it serves the purpose of holding a ball without fully enclosing it.

Before dividing the students into smaller groups, the class discussed a range of possible achievement levels for the challenge. At minimum, each group was required to design and build a vehicle that could suspend from the rope and move in some way. The most ambitious achievement level challenged students to design, build, and program a robot to traverse the rope, stop at a designated point, retrieve a plastic ball, stop at another designated point, and then drop the ball. Students were also given the option to create a project aimed somewhere between the two extremes of the achievement spectrum. For example, some groups might choose to spend more time designing a project to retrieve the ball more efficiently. Or, others decided to try unique designs to traverse the rope in a fun way. The initial task was set with the potential for students to make it their own.

Planning for the Challenge

While students often want to dive right into building, project planning is helpful. For the tightrope challenge, fourth-grade students did basic project planning. For the first step, each student defined the problem that had been presented. Students wrote a problem statement on an engineering planning sheet (see Figure 2, p. 82, and NSTA Connection). This was a great way to assess if they understood what was expected and what their final project should accomplish. This aligns with the Next Generation Science Standards Engineering Design performance expectation 3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost, as well as disciplinary core idea ETS1.A: Defining and Delimiting Engineering Problems.

Students were then expected to draw a sketch of what their project might look like (Figure 2, p. 82). Their sketches were another step toward planning a physical project. Students were aware they would not be bound to their sketches; it was simply a way to explore ideas before building (disciplinary core idea ETS1.B: Developing Possible Solutions).

Before digging through Lego pieces and starting construction,
students were put into teams of two or three. To do this, the teacher surveyed the class and determined which students were eager to attempt a complex achievement level or which students felt more comfortable working on a less complex design. Some students wanted to reach the highest achievement level. And some wanted to try just the basics. Organizing the students into teams based on shared achievement goals helped avoid larger conflicts during the project. Later, it would be easier for the teacher to offer differentiated instruction and encourage each group to reach for a higher achievement level.

In their groups, students needed to complete one more task before the building process. Each person in the group had come up with a different sketch. The small groups discussed their sketches and built consensus around a final design and achievement level they would pursue. In many cases, individual students had similar features in their design that the group decided to keep. For example, most students sketched a hanging vehicle and all final designs for this project ended up suspended beneath the rope. The claw that retrieved the ball had different designs. Some students proposed a pincer method. Others proposed a scoop method.

When building consensus, students made comments like, “The aim would have to be perfect for that to work” for a pincer design or, “There’s more room for error” for a scoop design.

Keep in mind that part of the planning process should include determining of safety precautions to be taken during the building stage. Before beginning to build, remind students to wear eye protection. Ensure that the rope is secured at the ends before testing and that no fragile materials or equipment are in the rope’s path. Advise students to work carefully around ropes and other potentially hazardous building materials.

**Engineering Encounters**

Students had nearly three hours over three class periods to construct their designs. During the building period, students were able to test their creations on the rope. Because the larger tightrope challenge had several smaller challenges to overcome, designs changed during the construc-

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**FIGURE 2.** Engineering planning sheet, student example.
tion and testing process.

Nearly every group was fully engaged in the engineering process. Students created and tested one solution and continued on to another. However, one of the groups that had chosen to build a simpler design said, “We’re finished,” about halfway through the building time. It was a simple vehicle that could move on the rope. The teacher watched a brief demonstration of the project and agreed that they had accomplished part of the challenge, “But,” he said, “think about the challenge as a whole. What can you add to this project to make it even better?” There was a moment of silence as the group stared at their project. Then, one of them said, “Oh, we can make something that carries a ball.” The group re-entered the engineering design process.

During the three hours, students were very self-directed as they continued to create, test, and improve. There were several trial balloon comments between group members such as, “What if we tried this?” and “Maybe it would work better if we did that.” However, this was also a time when setbacks and frustration occurred. In many cases, when confronted with a design problem, students demonstrated very good resiliency. Some students encountered setbacks and quickly dove back into a redesign. Some student groups needed teacher prompts like the example above. In some groups, however, individual students had varied responses to setbacks.

One particularly interesting group had someone with a particularly strong growth mindset and another with a strong fixed mindset. After some setbacks, one group member had clearly become frustrated and was on the verge of giving up. Another student in the group began coaching him through the frustration. “Sometimes problems happen,” she said. “What can we do to fix it?” After exploring some possible options, she was able to use her growth mindset and leadership skills to bring the student back into the design process.

**Completing the Challenge**

On the final day of the tightrope challenge, student groups demonstrated their projects for the class. While they all didn’t work exactly how they did during testing, all projects successfully completed some aspects of the challenge. Although some groups initially chose to do the simplest aspect of the challenge, none of the final projects were limited to the simplest form. Each of these groups added at least one additional challenge feature to their project. Despite difficulty and time constraints, one group managed to create a project that fulfilled all aspects of the project.

**Assessing the Challenge**

Throughout this engineering challenge, various formative assessments were implemented. Beginning in the early planning stages, the engineering planning sheet helped demonstrate a basic understanding of the design challenge. In addition to this basic sheet, students might also be asked to provide detailed labels and descriptions of each component.

In small groups, formative peer- and self-evaluation took place. Students considered multiple solutions, communicated and negotiated a final group design based on the merits of individual ideas.

During the construction process, student work was relatively self-directed. This allowed the teacher to act more as a facilitator by asking...
questions such as, “What else can you try?” or “Would another part make a difference?” By circulating through the room, the teacher could determine who was fully invested in the engineering process and who might need some encouragement.

Once the challenge was complete, students completed a written self-assessment rubric (see NSTA Connection). While some components of the projects were assessed, much of the rubric referenced the quality of students’ interpersonal interactions.

On the rubric, students ranked themselves somewhere within three levels of achievement. The “starting” level was described to the students as not quite working up to your ability. The “building” level was on target for fourth-grade work. The “performing” level was above and beyond. Because students were able to choose the complexity of their design before beginning the challenge, the same assessment tool could be used for all student groups.

In addition to the written assessment, students discussed some of the challenges and successes of the project. For this challenge, we discussed limiting factors. Frequently we are limited in what we can do. We don’t have everything we need to make things work the way we imagine them. Students were given the question, “What limited your group from making a perfect robot?”

Several hands went up. One student said, “We only have these Lego pieces, and sometimes they don’t fit together the way I want them to.”

The teacher did a quick survey, “Lego makes tons of pieces. How many people could have made a better project if we had every piece we wanted?” Most hands went up.

Another student said, “Time.” Another quick survey. “How many people could have made a better project if they had another hour or even five hours?” Most hands went up.

Then, a student gave a very astute response. “Experience,” he said. When asked to elaborate he said, “We’re only in fourth grade. If we practice and keep learning, we’ll be able to build better things” (Common Core K–5 Speaking and Listening; NGAC and CCSSO 2010). Clearly that last student has a growth mindset.

**Conclusion**

Just like other academic disciplines, learning to become an innova-
Connecting to the Standards

Standard 3-5-ETS1 Engineering Design

Performance Expectations:
3-5-ETS1-1 Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
3-5-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
3-5-ETS1-3 Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Science and Engineering Practices:
Planning and Carrying Out Investigations
Constructing Explanations and Designing Solutions

Disciplinary Core Ideas:
ETS1.A Defining and Delimiting Engineering Problems
ETS1.B Developing Possible Solutions
ETS1.C Optimizing the Design Solution

Crosscutting Concept:
Cause and Effect

Connection to Nature of Science:
Science Is a Human Endeavor

NGSS Table: 3-5-ETS1 Engineering Design
www.nextgenscience.org/3-5ets1-engineering-design

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www.legoeducation.us
NASA Engineering Design Challenge
www.nasa.gov/audience/foreducators/plantgrowth/reference/index.html#
Utml6PbnbWI
NSF Engineering Classroom Resources
www.nsf.gov/news/classroom/engineering.jsp
NSTA Science Store
www.nsta.org/store

NSTA Connection
reviews

Uncovering Student Ideas in Physical Science, Vol. 2
By Page Keeley and Rand Harrington.

Some people couldn’t wait for the last Harry Potter book to come out. Still others look forward to the next installment of Downton Abbey or Game of Thrones. I, on the other hand, jumped for joy the day Uncovering Student Ideas in Physical Science, Vol. 2 arrived at my door. I can now say that my collection is, for the moment, complete.

The sections in this volume include three substantive formative assessment probes on electric charge, including “Where does the charge come from?” “Does it matter if the wire has knots?” and “How would a magnet work on the Moon?” This great book is well-worded with well thought-out questions that truly pull the misconceptions out of my students so they can be addressed. This newest book in the Uncovering Student Ideas series is a must-have book, and if you yourself struggle to critically think about topics such as the effects of magnetism on the Moon, the book provides detailed explanations, advice for administering the probe, suggestions for instruction, and references.

I am continually amazed by how my students take a concept and either bundle it with several unrelated ones, or apply the one-size-fits-all method to explaining it. Being aware that students will have misconceptions is one small step; having a copy of an exceptional assessment probe that quantifies that misconception is the giant leap.

Teri Cosentino

It’s Debatable!

It’s Debatable! Using Socioscientific Issues to Develop Scientific Literacy is a new book that allows science teachers to enrich their classes and increase science literacy by posing real-world questions to their students. The book presents scenarios that could be used in biology, chemistry, and physics classes. The various topics described in the book will help teachers make cross-curricular connections and will allow students to begin to develop a social conscience as they prepare to become active members of society.

Each activity is designed to make implementation a snap for teachers. The authors present convincing research to support the value of incorporating socioscientific issues into the science curriculum. The book outlines a variety of activities covering various topics, from the need for a speed limit to whether or not society should charge a “fat tax” for unhealthy foods. Several units in the book are designed for each grade level. The units provide the complete materials that teachers will need to implement the activities in their classrooms, from a description of the objectives to ideas for assessment. Most of the activities require simple materials that are obtained with little difficulty and at a minimal cost. A strong point of the book is that the activities could be adapted to additional socioscientific issues beyond the ones described in the various units. Teachers could use the strategies, pro-
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Thomas Brown

It’s Debatable! is designed to provide a foundation for teachers at all levels to enrich their curriculum with challenging and thought-provoking topics. This book would be an outstanding resource for science teachers who desire to increase their students’ awareness of the scientific challenges facing our society. Hopefully, the book will also spur educators to develop their own units on additional topics beyond those illustrated in the book in order to further demonstrate to students the relevance of science to their daily lives.

procedures, and assessments as bridges to build more activities to engage their students and help them to become scientifically literate.

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Hey, Mom, do we have anything I can use to make a volcano? Dad, could you help me with a model of the solar system? Science projects of these types, typical of many found in our schools, are not examples of what is meant by project-based science (PBS).

The project-based approach is an engaging technique where students learn by mimicking what real scientists do. They learn to develop appropriate questions, identify problems, share ideas, and make predictions. They design and collaborate on investigations, often using technology from which they collect and analyze data. Finally, they create products that address their questions. By doing these things, students are involved in the processes of science and engineering, from which they can acquire both knowledge and skills. PBS is relevant to students’ lives and helps them develop scientific literacy.

This thoroughly researched, well-organized, and highly detailed book, a “how-to” guide to PBS teaching, provides a wealth of information for teachers and schools. Its eleven chapters, among other topics, follow the process from asking questions to developing assessments. Emphasizing the importance of science in children’s lives, it makes numerous connections to A Framework for K–12 Science Education. Each chapter begins with “Chapter Learning Performances,” a set of objectives to be met by the users of the book (preservice or inservice teachers). After an introduction, nearly all chapters present several scenarios that reflect learning situations in which different teaching techniques are used. These are followed by comprehensive and practice...
Try this TOPS IDEA!

**clock pendulum** ...adapted from GLOBAL TOPS #91 by TOPS Learning Systems

1. Tie an arm's length of thread to a paper clip.
2. Lightly fold a small piece of masking tape over the middle.
3. Slide the thread through the tape until you find the length where your pendulum swings exactly one cycle each second.
4. Measured to the center of the bob (the paper clip), how long is your pendulum clock? Can you accurately time one minute with it?

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**OBJECTIVE**
To make a pendulum that ticks like a clock, at 60 cycles per minute.

**SET-UP**
Cover wall clocks. Ask students to be seated and put away all timepieces (you will be the only timekeeper). Announce a contest: students should stand up when they guess that one minute has passed from the moment you say “GO!” Note who stands closest to the mark, but don’t announce the winner until all are standing. Then hand out copies of the lab above. Students might repeat this contest at the end of this lab (see wrap-up).

**LAB NOTES**
Copy the lab for each student or lab team.

**NOTES 2-3.** Tape folded over thread makes an ideal pendulum pivot: hold it while the pendulum swings beneath. The thread stays put until you slide it to a new pendulum length. By trial and error, students find the length that counts 60 seconds with 60 swings.

**ANSWERS**
4. A one-second pendulum measures 24.8 cm from the edge of the tape tab to the middle of the clip.

**WRAP-UP**
Have students sit again, then ask them to stand at precisely one minute by counting their pendulum cycles. They will likely all stand together.

**EVALUATION**
Q. A grandfather clock runs too slow. How would you adjust its pendulum bob to improve its timing?
A. Shorten the pendulum to speed up the clock. An adjustable nut on the bob generally allows this.

**EXTENSION**
Develop a pendulum that makes 1 swing (half a cycle) each second. How many times longer is this than your 1-cycle-per-second pendulum? Ideal pendulums 4 times longer swing at half the frequency.

**MATERIALS**
- Thread, scissors, a paper clip, masking tape, and a centimeter ruler.
- A clock or timepiece that shows seconds.

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TOP 10 REASONS TO ATTEND

1. PERFORMANCE: You and your students deserve to be excellent in science.
2. LEADERSHIP: New skills, knowledge, and activities help build educational leaders who influence others to do extraordinary things.
3. DISCOVERY: Looking at the world with a new perspective brings innovation and creativity in the classroom.
4. MOTIVATION: Expert speakers, educators, and scientists serve to inspire and stimulate.
5. PASSION: Sharing it with your peers, your mentors, and the leaders in science education is contagious.
6. EXPERTISE: Educators are the best when they are well-versed in their field.
7. INSPIRATION: You’ll hear stories from renowned authors and presenters that will move you to act.
8. GROWTH: Your conference experience will expand your world personally and professionally.
9. FREEBIES: Exhibiting companies from across the nation will offer you hundreds of classroom giveaways, new products, and samples.
10. CONNECTIONS: You’ll meet peers, mentors, leaders, and acquaintances for support and friendship.

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- Partnerships and Collaborations: Learning Inside and Out
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- Elementary Science — Early and Often
- Environmental Explorations: Indoors and Outdoors
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