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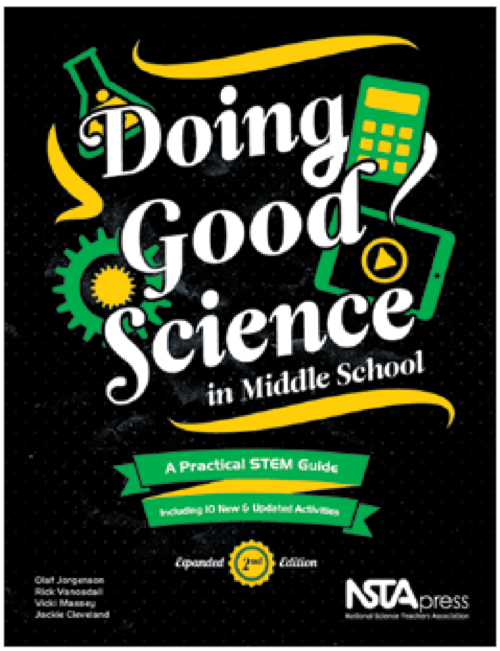
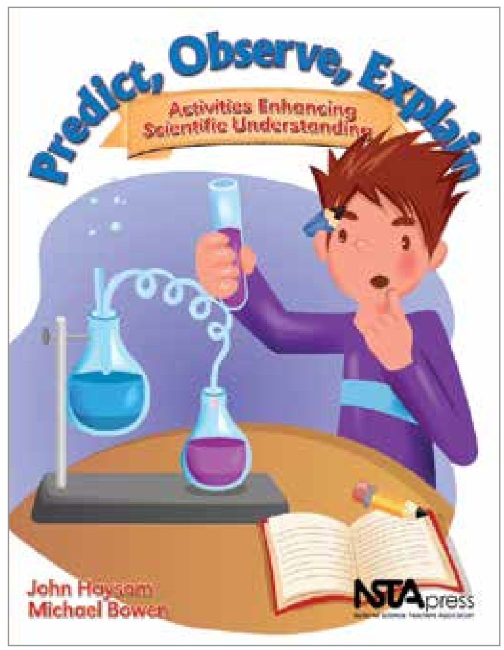
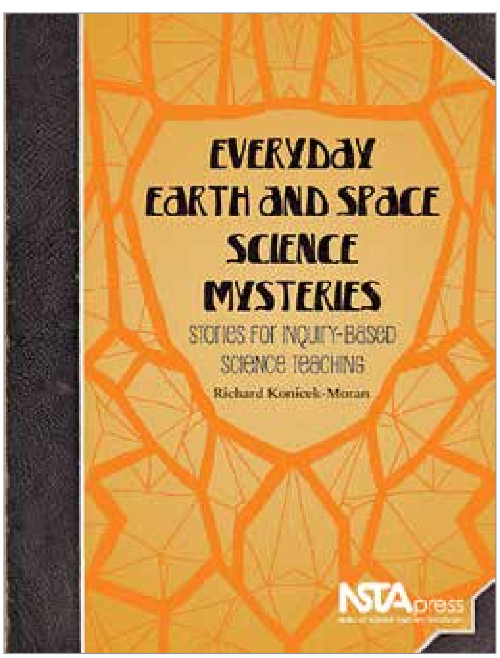
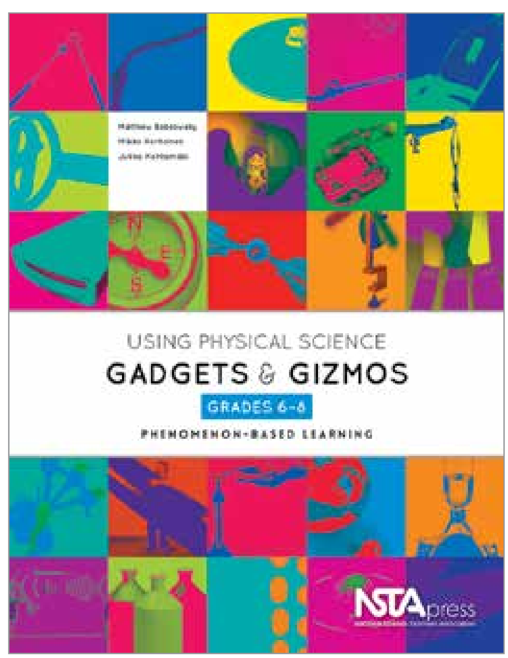
Middle School Sampler









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Dedication

For Juliette, Wesley, Grant, and children everywhere who benefit from good science and great teachers; and to Kash, Krew, and Paige, who are part of the next generation of science learners.

About the Authors

OLAF (OLE) JORGENSON served as director of K–12 science, social sciences, and world languages in the Mesa Unified School District in Mesa, Arizona. Previously he was a teacher and administrator in U.S. and international schools, mostly at the middle school level. Ole is past president of the Association of Science Materials Centers (ASMC) and served on faculty with the National Science Resources Center's Leadership Assistance for Science Education Reform (LASER) strategic planning institute, with a focus on middle school science issues. He has presented on middle school science reform at the National Science Teachers Association's annual meeting and at ASMC's Next Steps Institute, and is a past member of NSTA's National Committee for Science Supervision and Leadership. Ole's other publications focus on topics in instructional leadership. He holds a doctorate in educational leadership from Arizona State University. Ole lives with his wife, Tanya, and their daughter, Juliette in San José, California, where he is head of school at Almaden Country School. He can be reached via e-mail at *olafjorgenson@yahoo.com*.

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Teachers Association, director of NSTA Division XIV and NSELA Region D, and board member for the Arizona Science and Engineering Fair. Vicki received her Masters of Arts in Science Teaching from NAU. Her experience as a curriculum developer and professional-development specialist deepened her appreciation for science teachers and the tremendously important job they do each day. Vicki lives in Mesa, Arizona, with her husband, horse, and ever-loyal pug and border collie dogs. She can be reached by e-mail at *vickimassey@cox.net*.

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Background

This book grew out of the authors' experiences while they worked in the Mesa Public Schools (MPS) in Mesa, Arizona. MPS is a metropolitan district serving 70,000 students and 90 schools, K–12. Mesa has used learner-centered methods, inquiry principles, and hands-on science units since 1974, with a science resource center for kit development and distribution starting in 1979. Mesa's science program has earned praise from the National Science Teachers Association, *Harvard Educational Review, Newsweek, American School Board Journal, Parenting* magazine, *American Scientist*, and *The Executive Educator*. In the past two decades, the district has celebrated five awardees of the Presidential Award for Excellence in Science Teaching.

The district's science program and resource center was developed by longtime director Dr. Susan Sprague, now a semiretired science consultant living in northern Arizona. Mesa's resource center refurbishes and distributes more than 10,000 kits annually to its 55 elementary schools. The middle school program also includes two self-contained fifth-grade flight centers with aircraft and helicopter simulators and night-vision goggle stations, serving all of the district's approximately 4,000 fifth graders each year. To find out more, please visit the MPS Science and Social Sciences Resource Center (SSRC) website at *www.mpsaz.org/ssrc*.

Introduction

Changes, Changes, Changes!

Talk about an explosive decade for teachers and learners! When we wrote the first edition of this book, YouTube and Facebook had not preoccupied America's waking hours, and "Google" was not yet a verb. As teachers across our nation recognize, the rapid proliferation of digital technology and concurrent accelerated "flattening" globalization of the world's economy have reshaped the potential and purpose of American education in profound ways.

Middle school teachers today serve a new generation of children weaned on social media that didn't exist in 2004. They instantly access information in and out of the classroom that was previously hoarded, protected, and strategically dispensed by their teachers. It is, to say the least, a very different classroom world today compared to 10 years ago, when we wrote the first *Doing Good Science*.

And these seismic shifts—combined with the emergence of distance and blended learning, flipped instruction, interactive digital textbooks, the furious rise of standardized testing, the popularity and widespread embrace of robotics, development of the Common Core Initiative and the *Next Generation Science Standards* (*NGSS*)—all called us to revisit our work and evaluate how we might make the book more useful in the context of 21st-century skills that teachers today are expected to cultivate in their students.

We realized quickly that improving the second edition would require more than updating and freshening our original book. We've added chapters and sections to help teachers assimilate STEM principles, understand and apply the *NGSS* and *A Framework for K–12 Science Education* (including the new expectations for engineering design), and integrate the *Common Core* literacy and writing standards. We've also learned from teacher feedback about some holes in our first version, such as advice about how to arrange and conduct collaborative table groups and about the critical role of scientific argumentation that we've addressed in this new book.

Most important, since teacher-friendly, ready-to-use STEM activities are the core of this second edition, we've gathered more teacher feedback to provide 10 new and updated investigations aligned with the revised standards and reflecting the emergent emphases on engineering design, STEM, and the 5E method that were present but less pronounced in the original 10 activities.

Based on reader reviews from the first edition, we've also sought to *deepen* the activities as well—beyond explaining what each activity is about, we aim in the new set of activities to help teachers engender productive conversations with students about the investigations and their resulting data.

Throughout our work in rewriting the book, though, the same basic goals that motivated us to create *Doing Good Science* have guided our efforts in this version:

1. Provide a useful resource for science teachers of varying ability and experience levels, staying focused on colleagues in their first years of teaching middle school science, who serve students in a wide range of school and community settings and with differing levels of resources and support.
2. Keep the book readable and user-friendly, addressing the demands teachers face concerning integration of STEM and literacy skills.
3. Provide activities that address the standards, engage students (good science is *fun!*), and are neither costly nor dependent on access to science kits or expensive technology.

Above all, we want *Doing Good Science in Middle School* to be a book by teachers, for teachers, that can make what you do for your students a little easier, richer, and more enjoyable.

We hope you agree that we achieved our objectives. Enjoy!

—Ole, Rick, Vicki, and Jackie

Preface

A middle school science classroom was once described to us as "a nuclear reaction about to happen, on an hourly basis." At the time, that description was meant to illustrate the unstable, unpredictable, and at times irrational behavior of a group of middle schoolers. Years later, we know that the behavior in question is pretty typical, but it can be significantly more challenging to deal with when middle-grade students are confined to neat rows of desks and numbed by textbooks, teacher-centered instruction, and lack of meaningful interaction with peers or their teachers.

In this book, we propose opportunities for learning and teaching amidst the sound and fury of a different sort of explosive (but productive) middle school science classroom. In our experience, good science—by which we mean activity-based STEM instruction—promotes the unexpected and delightful development of adolescent middle school students.

For us, good science constitutes a shift away from the textbook-centered direct instruction that emphasizes discrete factual knowledge claims and passive observation of science phenomena toward active, learner-centered, hands-on and minds-on investigations conducted to some degree by students themselves. Good science and middle school learners are very compatible, as we'll explain in Chapter 1.

Who are we? We are four educators who worked together in Mesa, Arizona, in a school district that has embraced good science instruction since 1974. We are among those who have come to enjoy the blossoming intellects, often comical behaviors, and insatiable curiosity of middle schoolers and who *choose* to work with them! With more than 130 years' combined experience in the profession, we've gathered a lot of ideas to share. We know from our interactions with educators around the country that relatively few quality resources exist to assist science teachers "in the middle," and this was a central impetus for writing and then updating *Doing Good Science in Middle School*.

Our book is aligned with *A Framework for K–12 Science Education* (2012) and the *Next Generation Science Standards* (2013), which set forth eight practices that are fundamental to understanding the nature of science:

- Asking questions (for science) and defining problems (for engineering)
- Developing and using models
- Planning and carrying out investigations

- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

We've used the *Framework* (2012), *NGSS* (2013), and the *Common Core State Standards* (2010) as the basis for recommendations to assist middle-grade science teachers, while unpacking the *NGSS* to make them more easily accessible. Throughout the book, we kept in mind teachers who work in self-contained team formats as well as departmentalized middle school configurations.

Our work here is meant to meet other important objectives but above all, we intend it to be teacher-friendly. We wrote *Doing Good Science* as practitioners, for practitioners. In this book, you will find

- a comprehensive overview of science and engineering practices, STEM, and inquiry-based middle school science instruction, aligned with the *Framework* and the *NGSS*;
- a conscious connection to the *Common Core* literacy and math skills embedded in the *NGSS* that help determine—and are fostered by—student success in good science instruction;
- 10 teacher-tested activities that integrate STEM with literacy skill-building (with emphasis on safety in the science classroom);
- information on best instructional practices including argumentation and formative assessment, along with useful print and Web-based resources, science associations, workshops, and vendors;
- a solid foothold for new teachers to help them teach science and engineering practices while better understanding their often enigmatic middle-grade students; and
- an opportunity for veteran teachers to reaffirm that what they do is "good science."

We hope readers will find this book easy to use. It can be read in its entirety or perused section by section as a reference for lesson and unit planning and as a basis for evaluating and modifying existing lessons. It will help teachers explain to their principals why their classes at times need to be noisy, bustling, and "social" to be effective.

We also hope this book is for some readers a point of departure from relying solely on teacher-centered methods with passive text- and worksheet-dependent curricula and in favor of the active learning potential and rich teaching opportunities that good science makes possible in the middle grades.

Let the journey begin!

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CHAPTER 14

Activity 7: Only the Strong Survive!

Biology: Population Dynamics and Natural Selection

Every organism uses resources to grow and reproduce, and, every organism lives in relationship with the other living organisms and inanimate objects in their local area. This area is called an ecosystem.

In every ecosystem, there are limits to one or more of the resources that are required for an organism to live: limits to the availability of food, for example, or to the space available for shelter and security. As organisms consume food and other resources to survive, grow, and reproduce, other organisms compete for the limited resources.

Understanding the dynamics of this competition, and the effects of the competition on population growth and decline, is fundamental to understanding issues humans contend with as we interact within our Earth's ecosystems. This activity puts students in the roles of ecologists and wildlife biologists as they discover the principles of population dynamics and the role of genetic variation within a population of prey species.

Safety First

In every activity, we remind you to be certain that you understand the potential risks involved and are confident you can ensure your students' safety. Before attempting any of these activities in class, we recommend completing them yourself, and optimally with a teaching partner.

STEM

This activity capitalizes on the patterns in nature and models population dynamics and genetic variation within a species over time. As with all models, there are limitations and assumptions that allow the model to work. And, as with all models in the STEM disciplines, this model consistently demonstrates a major scientific concept that has been established through repeated observations across multiple areas and over a long period of years. Additionally, as with all models in STEM disciplines, this model will be continually improved upon over time.

This activity introduces students to a process in which they experience how scientific knowledge is developed and tested. Then, students use the scientific knowledge to predict and test additional questions and applications related to environmental quality, drinking water, and food sources. Opportunities to apply math standards emerge in the activity's use of statistics, tables, and graphing.

Tying It to *NGSS*

Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem. (MS-LS2-1)

[Clarification Statement: Emphasis is on cause and effect relationships between resources and growth of individual organisms and the numbers of organisms in ecosystems during periods of abundant and scarce resources.]

Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems. (MS-LS2-2)

[Clarification Statement: Emphasis is on predicting consistent patterns of interactions in different ecosystems in terms of the relationships among and between organisms and abiotic components of ecosystems. Examples of types of interactions could include competitive, predatory, and mutually beneficial.]

Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. (MS-LS2-4)

[Clarification Statement: Emphasis is on recognizing patterns in data and making warranted inferences about changes in populations, and on evaluating empirical evidence supporting arguments about changes to ecosystems.]

Construct an explanation based on evidence that describes how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment. (MS-LS4-4)

[Clarification Statement: Emphasis is on using simple probability statements and proportional reasoning to construct explanations.]

Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in populations over time. (MS-LS4-6)

[Clarification Statement: Emphasis is on using mathematical models, probability statements, and proportional reasoning to support explanations of trends in changes to populations over time.] [Assessment Boundary: Assessment does not include Hardy Weinberg calculations.]

Science and Engineering Practices

Analyzing and Interpreting Data

Analyze and interpret data to provide evidence for phenomena. (MS-LS2-1)

Constructing Explanations and Designing Solutions

Construct an explanation that includes qualitative or quantitative relationships between variables that predict phenomena. (MS-LS2-2)

Plan for safety by determining which engineering controls, safety procedures and personal protective equipment will be needed.

Engaging in Argument from Evidence

Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. (MS-LS2-4)

Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-LS2-5)

Connections to Nature of Science

Science disciplines share common rules of obtaining and evaluating empirical evidence. (MS-LS2-4)

Analyzing and Interpreting Data

Analyze and interpret data to determine similarities and differences in findings. (MS-LS4-1)

Using Mathematics and Computational Thinking

Use mathematical representations to support scientific conclusions and design solutions. (MS-LS4-6)

Constructing Explanations and Designing Solutions

Apply scientific ideas to construct an explanation for real-world phenomena, examples, or events. (MS-LS4-2)

Construct an explanation that includes qualitative or quantitative relationships between variables that describe phenomena. (MS-LS4-4)

Connections to Nature of Science

Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-LS4-1)

Disciplinary Core Ideas

LS2.A: Interdependent Relationships in Ecosystems

Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. (MS-LS2-1)

In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. (MS-LS2-1)

Growth of organisms and population increases are limited by access to resources. (MS-LS2-1)

Similarly, predatory interactions may reduce the number of organisms or eliminate whole populations of organisms. Mutually beneficial interactions, in contrast, may become so interdependent that each organism requires the other for survival. Although the species involved in these competitive, predatory, and mutually beneficial interactions vary across ecosystems, the patterns of interactions of organisms with their environments, both living and nonliving, are shared. (MS-LS2-2)

LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (MS-LS2-4)

ETS1.B: Developing Possible Solutions

There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (secondary to MS-LS2-5)

LS4.B: Natural Selection

Natural selection leads to the predominance of certain traits in a population, and the suppression of others. (MS-LS4-4)

LS4.C: Adaptation

Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes. (MS-LS4-6)

Crosscutting Concepts

Patterns

Patterns can be used to identify cause and effect relationships. (MS-LS2-2)

Graphs, charts, and images can be used to identify patterns in data. (MS-LS4-1), (MS-LS4-3)

Cause and Effect

Cause and effect relationships may be used to predict phenomena in natural or designed systems. (MS-LS2-1)

Stability and Change

Small changes in one part of a system might cause large changes in another part. (MS-LS2-4), (MS-LS2-5)

Connections to Nature of Science

Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. (MS-LS2-3)

Scientific knowledge can describe the consequences of actions but does not necessarily prescribe the decisions that society takes. (MS-LS2-5)

Tying It to *Common Core State Standards, ELA*

RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (MS-LS2-1)

RST.6-8.9 Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (MS-LS4-3), (MS-LS4-4)

WHST.6-8.1 Write arguments to support claims with clear reasons and relevant evidence. (MS-LS2-4)

WHST.6-8.2 Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content. (MS-LS2-2)

SL.8.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly. (MS-LS2-2)

SL.8.4 Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation. (MS-LS2-2)

Tying It to *Common Core State Standards, Mathematics*

MP.4 Model with mathematics. (MS-LS2-5)

6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems. (MS-LS2-5)

6.EE.C.9 Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation. (MS-LS2-3)

6.SP.B.5 Summarize numerical data sets in relation to their context. (MS-LS2-2)

Common Misconceptions

One common misconception in this subject area is that natural selection is the same as evolution. Evolution is the word used to describe change over time, and it is considered a theory. Biologists agree that there are five distinct and different processes that result in evolution. While there are passionate debates regarding how and what is taught regarding biological evolution in schools, there is less debate over teaching processes such as natural selection and population dynamics.

Another common misconception is that individuals within a species may adapt to an environmental factor. Adaptations are the result of genetic variation and are passed on to future generations if the adaptation will help the individual with that variation survive and reproduce. Some of the common misconceptions are related to nonscientific beliefs and a lack of understanding the scientific principles and data regarding natural selection and population dynamics.

If you search the internet, you will find abundant websites that provide a range of explanations and representations regarding genetic variation and natural selection. However, caution should be exercised regarding evaluating the sources of the information. NSTA offers excellent resources on natural selection and the other principles associated with evolution. Obviously we don't have the space in this book to provide all the information you may desire regarding this topic. Therefore, we suggest seeking additional information from the NSTA website (*www.nsta.org*) and the NSTA Learning Center (*learningcenter.nsta.org*; search for "natural selection" and "evolution").

Once again, for more on helping students break through scientific misconceptions, consider the resources developed by Dr. Philip Sadler and others associated with the Harvard-Smithsonian Center for Astrophysics: see "Minds of Our Own" and other free online resources and video resources at *www.learner.org/resources/series26.html*.

In each activity, regardless of subject matter, we also urge readers to consider Page Keeley's series about identifying the prior knowledge your students bring to your classroom: see *Uncovering Student Ideas in Science* (*http://uncoveringstudentideas.org*).

Objectives

By the end of this activity, students will have demonstrated the ability to

- collect, analyze, and pool data;
- compare data and data analyses to look for patterns;
- role-play as predators in a model ecosystem and also as ecologists and wildlife biologists as they collect and analyze data and make claims based on evidence regarding the population dynamics across varieties of a prey species;
- analyze data and use data tables and graphs to describe patterns in nature (e.g., the variation in the number of individuals across multiple generations of a population in the model ecosystem); and
- implement procedural consistency and emulate research teams working collaboratively to process large sets of observations.

Academic Language

Trend, cycle, population, specie, prey, predator, population dynamics, carrying capacity, offspring, generation, natural distribution, biostatistics, forceps, model, variation, genetic factors, environmental factors, resources, limits

Focus Question(s) (Scientific Inquiry)

- How will a population of a prey specie vary across a variation and multiple generations?
- What living and nonliving factors appear to affect changes in the population dynamics in successive generations?
- How much variation is there among individuals of the same species?
- How do scientists and engineers collect large data sets?
- What advantages do large data sets provide scientists and engineers, compared with small data sets?
- When do you know you have enough data to have a high degree of confidence to make a claim based on evidence?

Framing the Design Problem(s) (Engineering Practice)

A sample problem for students might be "Design a plan to enhance an environment to optimize the survival of an endangered species or to optimize the survival of humans." (The variation among humans could be geographic location, potable water, or food for good nutrition, for example.)

Refer to Figure 4.3 "The Engineering Design Process" (p. 45) for more information about how to frame the design problem for this activity.

Teacher Background

This activity requires careful data collection and provides a rich opportunity to explore and elaborate on the limitations of models and simulations by having students compare their activity data to real data sets available on the internet.

We suggest teachers research various internet resources starting with the NSTA Learning Center's information on natural selection and evolution; there also are many decent YouTube and Khan Academy videos, as well as TEDed resources to review content knowledge associated with natural selection, population dynamics, and evolution.

Preparation and Management

This is an activity that can be set up with minimal cost, be stored in a small space, and last for years. There are computer simulations for this concept. However, we suggest this "hands-on" role-play as the entry point to the concept. After completing this activity, students will be better able to appreciate and understand the simulations that are available on the internet. One potential extension of this lab would be to have students analyze simulations for strengths and weaknesses compared to their "hands-on" role-play activity.

The Prey

The prey species is a paper dot (the punch out from a paper hole punch used for 3-hole punching paper for a 3-ring binder). If you have access to an electric punch, it will make the set up much easier.

You will want to use construction paper or simply various colors of copy paper. Pastel colors work best, or match the colors that are similar and that contrast well with the environment (piece of cloth). We suggest you use colors that are found and that contrast to colors in the environment (fabric square described in the following section on the "environment").

Having a variety of prey variations is important. The number of variations determines the complexity of the activity. At a minimum, we suggest five different colors; at a maximum you could use up to 10 colors, but the analysis becomes significantly more complicated.

You will want to use sandwich-size resealable bags to hold the "stock" for each color variation of the prey species.

The Predators

Students play the role of predators in this modeling game. Allowing students to use only a tool such as forceps or tweezers to pick up the prey makes the process work consistently. In the Differentiation section, we provide a list of increasingly complex variations among the predators.

The Environment

The teacher will need to get a set of multicolored fabrics in the same sizes. (The size of the cloth determines the size of the ecosystem. We recommend a minimum size of 50 cm × 50 cm, and a maximum size of 1 m × 1 m. The level of "busy-ness" in the pattern and size of the pattern elements also plays a role in this setup.

Prep Time

30 minutes to gather materials

Schedule time for students to use computers for internet access

Teaching Time

90–100 minutes, or two or three teaching periods

Materials

- Environment (1 piece of multicolored cloth to lay down on the tabletop)
- Prey organisms (1 resealable plastic bag per variation of prey; each bag needs a minimum of 100 pieces—if you use 5 variations, then you will have 5 bags, with each bag containing 100 paper punches of a single color.)
- Forceps or tweezers (one pair per student who is role-playing a predator)
- 1 stopwatch (or a wall clock with a second hand to time predation periods)
- Lap notebook (to record population of each prey variation per generation of play)
- Whiteboard, markers, and eraser for each group of three students (large chart paper and felt pens can be used in place of whiteboards)
- Safety glasses or goggles

5E Instructional Model

Engage

Show PowerPoint slides of places that profile the effects of human activities and diminishing habitat, and therefore the growing number of endangered and extinct species, and also the effects of proper management to save some species (for example the recovery of the bald eagle populations in North America).

Preassessment

Ask students to do the following:

1. Share what they've heard about endangered species and the recovery of some populations.
2. Describe what they know about invasive species and their effects on the health of the environment and any impact on human populations.

These two questions may be given as writing or discussion prompts to assess student prior knowledge about natural selection and population dynamics. Another suggestion is to have students develop individual explanations, share them, and ask other students to determine what seems correct and incorrect and what evidence supports their stances. The goal is to determine students' familiarity with the content as well as their ability to use evidence to support their positions (i.e., basic argumentation skill); this helps you shape the rest of the activity and subsequent lessons according to student ability and needs.

Explore

Table group teams are ideally four students each, but not any larger. Each team member has a role, and the roles should rotate with each "generation" of play. (When the hunting session is completed for a generation, all students participate in counting and establishing the appropriate number of each variety of species to be set up in the environment for the next hunting season.)

The roles include

- one student who is the time keeper and environmental steward (this student sets up the environment with the proper number of each prey species, while other players look away to keep them from seeing the arrangement prior to the beginning of the hunting session), and
- three students who are predators (these students look away while the time keeper/environmental steward sets up the environment for another hunting session).

Generation 1

1. All students work together to count out 20 of each variation of prey organisms.
2. When a set of 20 organisms for each fur coat color has been set in piles on the edge of the environment (the fabric square), students identify each role and who will play the roles in the first generation of play.
3. The predators will look away as the timekeeper/environmental steward mixes all the various colored punches and distributes the "prey" fairly evenly across the environment.
4. When the timekeeper is ready, the predators will pick up a set of forceps or tweezers, and the predators begin hunting for a specified time limit. This is predetermined by the team, and could be 20 or 30 seconds or a time limit that seems appropriate for the size of the environment and other conditions that

might exist in your classroom. Limit the time such that the predators cannot collect 100% of a particular prey species variation in the first hunting session.

5. After the timed hunting session, all hunting ceases. All team members work on collecting the data. They count the total number of each variation still alive in the environment. Then, they calculate that every pair of survivors will produce 3 offspring. So, if there were only 10 of a particular color, that is 5 pairs, and each pair will add 3 new offspring, so the team could count out the original 10 survivors plus 15 new offspring for a total of 25 organisms in the environment for that color variation.
6. The previous timekeeper/environmental steward becomes one of the predators, and one of the predators becomes the timekeeper/environmental steward.
7. Typically, you will want to have 5–7 generations of play to begin to see patterns emerge.

Explain

Each team of scientists should produce a whiteboard explanation of the process they completed across the generations. These should be shared with the class. The teacher facilitates this discussion, and each group defends its information using evidence from the simulation. (This is an excellent opportunity to implement formative assessment practices for clarifying and reteaching topics and information that may be needed to improve the accuracy of what students learned.)

Each group creates a written analysis of what happened in its simulation; teams will compare the results with other teams and environments (fabric squares with different colors and patterns).

Elaborate

Students extend their claims and evidence to look at issues of habitat management across the various environments. Students can design a plan for protecting the vulnerable species. One real-life example we've used is the discussion of deer hunting season and its purposes from an ecosystem and population management perspective.

Evaluate

Students will be evaluated on their ability to complete the series of generations and remain consistent with the model. Additionally, students will analyze the variations between team results based on the data and observations. How did the different teams' experiences vary, and why?

Discussion and Argumentation

Students should be given multiple opportunities to voice their claims and evidence, as well as the opportunity to refine their claims based on class-pooled evidence. This dialogue may be facilitated by the teacher and should focus on the nature of scientific ways of knowing (systematic review of data and the processes used to collect the data). We are not pursuing one correct answer here! Instead, we suggest the students stay focused on exploring and articulating what they "know" and the evidence they have. If the students need to go back to the activity to run additional tests, that should be encouraged, time permitting.

This activity again invites students to evaluate whether the more data we have, the better and to critically review these questions:

- Is there a point at which you have enough data to make a claim, and a diminishing return on the investment of time and energy to continue collecting data?
- If there is a point of diminishing returns, how do you know when you are at the point where you don't need to collect additional data?

If Time Allows

One of the many important opportunities provided in this activity is the chance to help students experience the analysis and redesign aspects found in the *NGSS* domain of science and engineering practices.

This could be an extensive project, so again, it's as time permits and needs to be carefully scaled for the students who pursue it, but it may provide an excellent opportunity for students to deepen their understanding about their original findings and plans.

Our suggestion is for students to design another model to demonstrate the same principles and to provide a detailed written explanation for their design.

If time allows, the students could be provided the opportunity to run the same series of trials with their model, collect data, and provide an analysis of any variation or similarities to the data collected in the activity.

Depending on the time you have available, and any cross-curricular connections you might design into this activity, you could invest 2–4 class sessions in this extension.

Differentiation

1. **Broader Access Activity:** Limit the number of prey organisms of each type of prey coat color. By limiting the number of individuals of each variation, fewer generations will be required to get to the point of the activity. Students who

are easily distracted would have their attention focused only on the relevant items necessary for a particular stage of the activity, and have a reasonable expectation of completing the counting and sorting task around the same time that other teams are ready to record their data on the class data chart.

2. **Extension Activity:** Expand the options and have students explore other covariates, such as the size of the environment used and the density of prey species, as well as the number of predators, and so on. Also, students could investigate the role of genetics and environment on variability of organisms in more complicated models.
3. **Modified Assessment:** Modify the assessment to focus on the verbal, written, or diagrammatic elaboration of the principles in this lesson.
4. **Challenge Assessment:** Allow students to present a comparison of the effects of genetics and environment on variability among individuals in a species.

Note: These are examples as illustrations of possible differentiation options. The actual adaptations you create will depend on the results of your preassessment and ongoing formative assessments of individual students.

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Index

Doing Good Science in Middle School

A Practical STEM Guide

Expanded 2nd Edition

"We are among those who have come to enjoy the blossoming intellects, often comical behaviors, and insatiable curiosity of middle schoolers—and choose to work with them! With more than 130 years of combined experience in the profession, we've gathered a lot of ideas to share. We know from our interactions with educators around the country that precious few quality resources exist to assist science teachers 'in the middle,' and this was a central impetus for updating *Doing Good Science in Middle School*."

—From the preface

This lively book contains the kind of guidance that could only come from veterans of the middle school science trenches. The authors know you're crazy-busy, so they made the book easy to use, whether you want to read it cover to cover or pick out sections to help you with lesson planning and classroom management. They also know you face new challenges, so they thoroughly revised this second edition to meet the needs of today's students. The book contains

- big-picture concepts, such as how to understand middle school learners and explore the nature of science with them;
- a comprehensive overview of science and engineering practices, STEM, and inquiry-based middle school science instruction, aligned with *A Framework for K–12 Science Education* and the *Next Generation Science Standards*;
- 10 new and updated teacher-tested activities that integrate STEM with literacy skill-building;
- information on best instructional practices and professional-development resources; and
- connections to the *Common Core State Standards* in English language arts and mathematics.

If you're a new teacher, you'll gain a solid foundation in how to teach science and engineering practices while better understanding your often-enigmatic middle-grade students. If you're a veteran teacher, you'll benefit from a fresh view of what your colleagues are doing in new times. Either way, *Doing Good Science in Middle School* is a rich opportunity to reaffirm that what you do is "good science."

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Everyday Earth and Space Science Mysteries

Stories for Inquiry-Based Science Teaching

Richard Konicek-Moran

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EVERYDAY EARTH AND SPACE SCIENCE MYSTERIES

STORIES FOR INQUIRY-BASED SCIENCE TEACHING

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CONTENTS

The Stories and Background Materials for Teachers

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I would like to dedicate these stories and materials to the dedicated and talented teachers in the Springfield Public Schools in Springfield, Massachusetts. They have been my inspiration to produce materials that work with city as well as rural children.

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Louise Breton
Ruth Chappel
Theresa Williamson

Third-grade team at Burgess Elementary in Sturbridge, Massachusetts

Second-grade team Burgess Elementary in Sturbridge, Massachusetts

Fifth-grade team at Burgess Elementary in Sturbridge, Massachusetts

Teachers at Millbury, Massachusetts Elementary Schools

Teachers and children at Pottinger Elementary School, Springfield, Massachusetts

All the administrators and science specialists in the Springfield, Massachusetts public schools, who are too numerous to mention individually

My thanks also go out to all of the teachers and students in my graduate and undergraduate classes who wrote stories and tried them in their classes as well as using my stories in their classes.

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My sincere thanks goes to Claire Reinburg of NSTA who had the faith in my work to publish the original book and the second and third volumes and is now taking a chance on a fourth; and to Andrew Cooke, my editor, who helps me through the crucial steps. In addition I thank my lovely, brilliant, and talented wife, Kathleen for her support, criticisms, illustrations, and draft editing.

Finally I would like to dedicate these words to all of the children out there who love the world they live in and to the teachers and parents who help them to make sense of that world through the study of science.

Preface

Earth and Space Sciences (ESS) range from the entire Earth into all of space—the universe and its galaxies. I have often thought that ESS should be the culminating science course in high schools and colleges since it has roots in all of the other branches of science. One cannot study the history of the Earth without incorporating the life sciences that laid down fossils. One cannot study the planets without physics and biology. As the Mars rover lays fresh tracks across the red planet, it looks for evidence of water and other signs that might signify the existence at one time or another of life, or at least its prerequisites. Consider this quote from the *Frameworks* document (NRC 2012):

> As a result, the majority of research in ESS is interdisciplinary in nature and falls under the categories of astrophysics, geophysics, geochemistry, and geobiology. However, the underlying traditional discipline of geology, involving the identification, analysis, and mapping of rocks, remains a cornerstone of ESS. (p. 169)

In these everyday stories you will find climatology, weather, decomposition, and astronomy. You get to go along on a geology trip with students up Bare Mountain. You will study the concepts of time, evaporation, air and air pressure, and probability. All of these stories correspond with the *scientific principles*, the *crosscutting concepts*, and the *core ideas* suggested and explained in the National Research Council's *A Framework for K–12 Science Education* (2012).

These stories are packaged in separate subject matter volumes so that those teachers who teach only one of the three areas covered in these books can use them more economically. However, it bears repeating that the crosscutting concepts meld together the various principles of science across all disciplines. It is difficult, if not impossible, to teach about any scientific concept in isolation. Science is an equal opportunity field of endeavor, incorporating not only the frameworks and theories of its various specialties, but also its own structure and history.

We hope that you will find these stories without endings a stimulating and provocative opening into the use of inquiry in your classrooms. Be sure to become acquainted with the stories in the other disciplinary volumes and endeavor to integrate all the scientific practices, crosscutting concepts, and core ideas that inquiry demands.

Introduction

Case Studies on How to Use the Stories in the Classroom

I would like to introduce you to one of the stories from the first volume of *Everyday Science Mysteries* (Konicek-Moran 2008) and then show how the story was used by two teachers, Teresa, a second-grade teacher, and Lore, a fifth-grade teacher. Then in the following chapters I will explain the philosophy and organization of the book before going to the stories and background material. Here is the story, "Where Are the Acorns?"

Where Are the Acorns?

Cheeks looked out from her nest of leaves, high in the oak tree above the Anderson family's backyard. It was early morning and the fog lay like a cotton quilt on the valley. Cheeks stretched her beautiful gray, furry body and looked about the nest. She felt the warm August morning air, fluffed up her big gray bushy tail and shook it. Cheeks was named by the Andersons since she always seemed to have her cheeks full of acorns as she wandered and scurried about the yard.

"I have work to do today!" she thought and imagined the fat acorns to be gathered and stored for the coming of the cold times.

Now the tough part for Cheeks was not gathering the fruits of the oak trees. There were plenty of trees and more than enough acorns for all of the gray squirrels who lived in the yard. No, the problem was finding them later on when the air was cold and the white stuff might be covering the lawn. Cheeks had a very good smeller and could sometimes smell the acorns she had buried earlier. But not always. She needed a way to remember where she had dug the holes and buried the acorns. Cheeks also had a very small memory and the yard was very big. Remembering all of these holes she had dug was too much for her little brain.

The Sun had by now risen in the east and Cheeks scurried down the tree to begin gathering and eating. She also had to make herself fat so that she would be warm and not hungry on long cold days and nights when there might be little to eat.

"What to do ... what to do?" she thought as she wiggled and waved her tail. Then she saw it! A dark patch on the lawn. It was where the Sun did not shine. It had a shape and two ends. One end started where the tree trunk met the ground. The other end was lying on the ground a little ways from the trunk. "I know," she thought. "I'll bury my acorn out here in the yard, at the end of the dark shape and in the cold times, I'll just come back here and dig it up! Brilliant Cheeks," she thought to herself and began to gather and dig.

On the next day she tried another dark shape and did the same thing. Then she ran about for weeks and gathered acorns to put in the ground. She was set for the cold times for sure!

Months passed and the white stuff covered the ground and trees. Cheeks spent more time curled up in her home in the tree. Then one bright crisp morning, just as the Sun was lighting the sky, she looked down and saw the dark spots, brightly dark against the white ground. Suddenly she had a great appetite for a nice juicy acorn. "Oh yes," she thought. "It is time to get some of those acorns I buried at the tip of the dark shapes."

She scampered down the tree and raced across the yard to the tip of the dark shape. As she ran, she tossed little clumps of white stuff into the air, and they floated back onto the ground. "I'm so smart," she thought to herself. "I know just where the acorns are." She did seem to feel that she was a bit closer to the edge of the woods than she remembered, but her memory was small and she ignored the feelings. Then she reached the end of the dark shape and began to dig and dig and dig!

And she dug and she dug and she dug! Nothing! "Maybe I buried them a bit deeper," she thought, a bit out of breath. So she dug deeper and deeper and still, nothing. She tried digging at the tip of another of the dark shapes and again found nothing. "But I know I put them here," she cried. "Where could they be?" She was angry and confused. Did other squirrels dig them up? That was not fair. Did they just disappear? What about the dark shapes?

How Two Teachers Used "Where Are the Acorns?"

Teresa, a veteran second-grade teacher

Teresa usually begins the school year with a unit on fall and change. This year she looked at the National Science Education Standards (NSES) and decided that a unit on the sky and cyclic changes would be in order. Since shadows were something that the children often noticed and included in playground games (shadow tag), Teresa thought using the story of "Cheeks" the squirrel would be appropriate.

To begin, she felt that it was extremely important to know what the children already knew about the Sun and the shadows cast from objects. She wanted to know what kind of knowledge they shared with Cheeks and what kind of knowledge they had that the story's hero did not have. She arranged the children in a circle so that they could see one another and hear one another's comments. Teresa read the story to them, stopping along the way to see that they knew that Cheeks had made the decision on where to bury the acorns during the late summer and that the squirrel was looking for her buried food during the winter. She asked them to tell her what they thought they knew about the shadows that Cheeks had seen. She labeled a piece of chart paper, "Our best ideas so far." As they told her what they "knew," she recorded their statements in their own words:

"Shadows change every day."
"Shadows are longer in winter."
"Shadows are shorter in winter."
"Shadows get longer every day."
"Shadows get shorter every day."
"Shadows don't change at all."
"Shadows aren't out every day."
"Shadows move when you move."

She asked the students if it was okay to add a word or two to each of their statements so they could test them out. She turned their statements into questions and the list then looked like this:

"Do shadows change every day?"
"Are shadows longer in winter?"
"Are shadows shorter in winter?"
"Do shadows get longer every day?"
"Do shadows get shorter every day?"
"Do shadows change at all?"
"Are shadows out every day?"
"Do shadows move when you move?

Teresa focused the class on the questions that could help solve Cheeks's dilemma. The children picked "Are shadows longer or shorter in the winter?" and "Do shadows change at all?" The children were asked to make predictions based on their experiences. Some said that the shadows would get longer as we moved toward winter and some predicted the opposite. Even though there was a question as to whether they would change at all, they agreed unanimously that there would probably be some change over time. If they could get data to support that there was change, that question would be removed from the chart.

Now the class had to find a way to answer their questions and test predictions. Teresa helped them talk about fair tests and asked them how they might go about answering the questions. They agreed almost at once that they should measure the shadow of a tree each day and write it down and should use the same tree and measure the shadow every day at the same time. They weren't sure why time was important except that they said they wanted to make sure everything was fair. Even though data about all of the questions would be useful, Teresa thought that at this stage, looking for more than one type of data might be overwhelming for her children.

Teresa checked the terrain outside and realized that the shadows of most trees might get so long during the winter months that they would touch one of the buildings and become difficult to measure. That could be a learning experience but at the same time it would frustrate the children to have their investigation ruined after months of work. She decided to try to convince the children to use an artificial "tree" that was small enough to avoid our concern. To her surprise, there was no objection to substituting an artificial tree since, "If we measured that same tree every day, it would still be fair." She made a tree out of a dowel that was about 15 cm tall and the children insisted that they glue a triangle on the top to make it look more like a tree.

The class went outside as a group and chose a spot where the Sun shone without obstruction and took a measurement. Teresa was concerned that her students were not yet adept at using rulers and tape measures, so she had the children measure the length of the shadow from the base of the tree to its tip with a piece of yarn and then glued that yarn onto a wall chart above the date when the measurement was taken. The children were delighted with this.

For the first week, teams of three went out and took daily measurements. By the end of the week, Teresa noted that the day-to-day differences were so small that perhaps they should consider taking a measurement once a week. This worked much better, as the chart was less "busy" but still showed any important changes that might happen.

As the weeks progressed, it became evident that the shadow was indeed getting longer each week. Teresa talked with the students about what would make a shadow get longer and armed with flashlights, the children were able to make longer shadows of pencils by lowering the flashlight. The Sun must be getting lower too if this was the case, and this observation was added to the chart of questions. Later, Teresa wished that she had asked the children to keep individual science notebooks so that she could have been more aware of how each individual child was viewing the experiment.

The yarn chart showed the data clearly and the only question seemed to be, "How long will the shadow get?" Teresa revisited the Cheeks story and the children were able to point out that Cheeks's acorns were probably much closer to the tree than the winter shadows indicated. Teresa went on with another unit on fall changes and each week added another piece of yarn to the chart. She was relieved that she could carry on two science units at once and still capture the children's interest about the investigation each week after the measurement. After winter break, there was great excitement when the shadow began getting shorter. The shortening actually began at winter solstice around December 21 but the children were on break until after New Years Day. Now, the questions became "Will it keep getting shorter? For how long?" Winter passed and spring came and finally the end of the school year was approaching. Each week, the measurements were taken and each week a discussion was held on the meaning of the data. The chart was full of yarn strips and the pattern was obvious. The fall of last year had produced longer and longer shadow measurements until the New Year and then the shadows had begun to get shorter. "How short will they get?" and "Will they get down to nothing?" questions were added to the chart. During the last week of school, they talked about their conclusions and the children were convinced that the Sun was lower and cast longer shadows during the fall to winter time and that after the new year, the Sun got higher in the sky and made the shadows shorter. They were also aware that the seasons were changing and that the higher Sun seemed to mean warmer weather and trees producing leaves. The students were ready to think about seasonal changes in the sky and relating them to seasonal cycles. At least Teresa thought they were.

On the final meeting day in June, she asked her students what they thought the shadows would look like next September. After a great deal of thinking, they agreed that since the shadows were getting so short, that by next September, they would be gone or so short that they would be hard to measure. Oh my! The idea of a cycle had escaped them, and no wonder, since it hadn't really been discussed. The obvious extrapolation of the chart would indicate that the trend of shorter shadows would continue. Teresa knew that she would not have a chance to continue the investigation next September but she might talk to the third-grade team and see if they would at least carry it on for a few weeks so that the children could see the repeat of the previous September data. Then the students might be ready to think more about seasonal changes and certainly their experience would be useful in the upper grades where seasons and the reasons for seasons would become a curricular issue. Despite these shortcomings, it was a marvelous experience and the children were given a great opportunity to design an investigation and collect data to answer their questions about the squirrel story at a level appropriate to their development. Teresa felt that the children had an opportunity to carry out a long-term investigation, gather data, and come up with conclusions along the way about Cheek's dilemma. She felt also that the standard had been partially met or at least was in progress. She would talk with the third-grade team about that.

Lore (pronounced Laurie), a veteran fifth-grade teacher

In September while working in the school, I had gone to Lore's fifth-grade class for advice. I read students the Cheeks story and asked them at which grade they thought it would be most appropriate. They agreed that it would most likely fly best at second grade. It seemed, with their advice, that Teresa's decision to use it there was a good one.

However, about a week after Teresa began to use the story, I received a note from Lore, telling me that her students were asking her all sorts of questions about shadows, the Sun, and the seasons and asking if I could help. Despite their insistence that the story belonged in the second grade, the fifth graders were intrigued enough by the story to begin asking questions about shadows. We now had two classes interested in Cheeks's dilemma but at two different developmental levels. The fifth graders were asking questions about daily shadows, direction of shadows, and seasonal shadows, and they were asking, "Why is this happening?" Lore wanted to use an inquiry approach to help them find answers to their questions but needed help. Even though the Cheeks story had opened the door to their curiosity, we agreed that perhaps a story about a pirate burying treasure in the same way Cheeks had buried acorns might be better suited to the fifth-grade interests in the future.

Lore looked at the NSES for her grade level and saw that they called for observing and describing the Sun's location and movements and studying natural objects in the sky and their patterns of movement. But the students' questions, we felt, should lead the investigations. Lore was intrigued by the 5E approach to inquiry (*engage, elaborate, explore, explain, and evaluate*) and because the students were already "engaged," she added the "elaborate" phase to find out what her students already knew. (The five Es will be defined in context as this vignette evolves.) So, Lore started her next class asking the students what they "knew" about the shadows that Cheeks used and what caused them. The students stated:

"Shadows are long in the morning, short at midday, and longer again in the afternoon."

"There is no shadow at noon because the Sun is directly overhead."

"Shadows are in the same place every day so we can tell time by them."

"Shadows are shorter in the summer than in the winter."

"You can put a stick in the ground and tell time by its shadow."

Just as Teresa had done, Lore changed these statements to questions, and they entered the "exploration" phase of the 5E inquiry method.

Luckily, Lore's room opened out onto a grassy area that was always open to the Sun. The students made boards that were 30 cm^2 and drilled holes in the middle and put a toothpick in the hole. They attached paper to the boards and drew shadow lines every half hour on the paper. They brought them in each afternoon and discussed their results. There were many discussions about whether or not it made a difference where they placed their boards from day to day.

They were gathering so much data that it was becoming cumbersome. One student suggested that they use overhead transparencies to record shadow data and then overlay them to see what kind of changes occurred. Everyone agreed that it was a great idea.

Lore introduced the class to the *Old Farmer's Almanac* and the tables of sunsets, sunrises, and lengths of days. This led to an exciting activity one day that involved math. Lore asked them to look at the sunrise time and sunset time on one given day and to calculate the length of the daytime Sun hours. Calculations went on for a good 10 minutes and Lore asked each group to demonstrate how they had calculated the time to the class. There must have been at least six different methods used and most of them came up with a common answer. The students were amazed that so many different methods could produce the same answer. They also agreed that several of the methods were more efficient than others and finally agreed that using a 24-hour clock method was the easiest. Lore was ecstatic that they had created so many methods and was convinced that their understanding of time was enhanced by this revelation.

This also showed that children are capable of metacognition—thinking about their thinking. Research (Metz 1995) tells us that elementary students are not astute at thinking about the way they reason but that they can learn to do so through practice and encouragement. Metacognition is important if students are to engage in inquiry. They need to understand how they process information and how they learn. In this particular instance, Lore had the children explain how they came to their solution for the length-of-day problem so that they could be more aware of how they went about solving the challenge. Students can also learn about their thinking processes from peers who are more likely to be at the same developmental level. Discussions in small groups or as an entire class can provide opportunities for the teacher to probe for more depth in student explanations. The teacher can ask the students who explain their technique to be more specific about how they used their thought processes: dead ends as well as successes. Students can also learn more about their metacognitive processes by writing in their notebooks about how they thought through their problem and found a solution. Talking about their thinking or explaining their methods of problem solving in writing can lead to a better understanding of how they can use reasoning skills better in future situations.

I should mention here that Lore went on to teach other units in science while the students continued to gather their data. She would come back to the unit periodically for a day or two so the children could process their findings. After a few months, the students were ready to get some help in finding a model that explained their data. Lore gave them globes and clay so that they could place their observers at their latitude on the globe. They used flashlights to replicate their findings. Since all globes are automatically tilted at a 23.5-degree angle, it raised the question as to why globes were made that way. It was time for the "explanation" part of the lesson and Lore helped them to see how the tilt of the Earth could help them make sense of their experiences with the shadows and the Sun's apparent motion in the sky.

The students made posters explaining how the seasons could be explained by the tilt of the Earth and the Earth's revolution around the Sun each year. They had "evaluated" their understanding and "extended" it beyond their experience. It was, Lore agreed, a very successful "6E" experience. It had included the engage, elaborate, explore, explain, and evaluate phases, and the added extend phase.

References

Konicek-Moran, R. 2008. *Everyday science mysteries*. Arlington, VA: NSTA Press.

Chapter 15

Where Are the Acorns?

Cheeks looked out from her nest of leaves, high in the oak tree above the Anderson family's backyard. It was early morning and the fog lay like a cotton quilt on the valley. Cheeks stretched her beautiful grey, furry body and looked about the nest. She felt the warm August morning air, fluffed up her big grey bushy tail and shook it. Cheeks was named by the Andersons since she always seemed to have her cheeks full of acorns as she wandered and scurried about the yard.

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Now the tough part for Cheeks was not gathering the fruits of the Oak trees. There were plenty of trees and more than enough acorns for all of the grey squirrels who lived around the yard. No, the problem was finding them later on when the air was cold and the white stuff might be covering the lawn. Cheeks had a very good smeller and could sometimes smell the acorns she had buried earlier. But not always. She needed a way to remember where she had dug the holes and buried the acorns. Cheeks also had a very small memory and the yard was very big. Remembering all of these holes she had dug was too much for her little brain.

The Sun had by now risen in the east and Cheeks scurried down the tree to begin gathering and eating. She also had to make herself fat so that she would be warm and not hungry on long cold days and nights when there might be little to eat.

“What to do… what to do?” she thought as she wiggled and waved her tail. Then she saw it! A dark patch on the lawn. It was where the Sun did not shine. It had a shape and two ends. One end started where the tree trunk met the ground. The other end was lying on the ground a little ways from the trunk. “I know,” she thought. “I’ll bury my acorn out here in the yard, at the end of the dark shape and in the cold times, I’ll just come back here and dig it up! Brilliant Cheeks,” she thought to herself and began to gather and dig.

On the next day she tried another dark shape and did the same thing. Then she ran around for weeks and gathered acorns to put in the ground. She was set for the cold times for sure!

Months passed and the white stuff covered the ground and trees. Cheeks spent more time curled up in her home in the tree. Then one bright crisp morning, just as the Sun was lighting the sky, she looked down and saw the dark spots, brightly dark against the white ground. Suddenly she had a great appetite for a nice juicy acorn. “Oh yes,” she thought. “It is time to get some of the those acorns I buried at the tip of the dark shapes.”

She scampered down the tree and raced across the yard to the tip of the dark shape. As she ran, she tossed little clumps of white stuff into the air and they floated back onto the ground. “I’m so smart,” she thought to herself. “I know just where the acorns are.” She did seem to feel that she was a bit closer to the edge of the woods than she remembered, but her memory was small and she ignored the feelings. Then she reached the end of the dark shape and began to dig and dig and dig!

And she dug and she dug and she dug! Nothing! “Maybe I buried them a bit deeper,” she thought, a bit out of breath. So she dug deeper and deeper and still, nothing. She tried digging at the tip of another of the dark shapes and again found nothing. “But I know I put them here,” she cried. “Where could they be?” She was angry and confused. Did other squirrels dig them up? That was not fair. Did they just disappear? What about the dark shapes?

How can she find the acorns? Where in the world are they? Can you help her find the place where she buried them? Please help, because she is getting very hungry!

Purpose

The main purpose of the "Cheeks" story is to get the children to learn something about the behavior of shadows cast by objects in sunlight. Although the story takes liberties with the "thoughts and projections" of Cheeks, one can take it as merely a motivational story. Some may be concerned with anthropomorphism but children read stories every day about animals that talk and have emotions. To leave these aspects out of the story would remove the "hook" that connects the students to the story characters. We believe that the teacher can make sure that children do not use these liberties to further misconceptions about the animals involved.

Primarily, the story addresses the motion of the Sun in the sky throughout the seasons, or what is called *daytime astronomy*. It is unfortunate that both of these conceptual areas are often relegated to students merely reading about the Sun's path through the sky during the seasons. Books and diagrams without the benefit of observation have become the main entryway for students to learn about Earth-Sun relationships. This is not necessary since measurable data about these motions are readily available to all students who live in places where the Sun shines fairly consistently.

Related Concepts

- Rotation
- Revolution
- Earth-Sun relationships
- Measurement
- Periodic motion
- Axis
- Seasons
- Shadows
- Time
- Patterns

Don't Be Surprised

Your students may well feel that Cheeks is a victim of thievery if they have little experience with shadow lengths changing, either daily or seasonally. Others may have little understanding of shadows at all! It is not uncommon for students to believe that shadows bounce off objects rather than be caused by their blocking light. I have personally witnessed 7- to 10-year-olds who had never played with shadows in any way. At the same time other students will immediately suspect the reason for Cheeks' error in judgement. Playing games such as shadow tag or messing about with shadows may prove useful.

A common misconception held by children and adults alike is that summer is warmer in the northern hemisphere because Earth is closer to the Sun. Actually, due to Earth's slightly elliptical orbit and most surprising to most people, Earth is farther from the Sun during the time it is summer in the northern hemisphere. Another common belief is that the Sun is directly overhead at noon and there is no shadow cast at noon. Some students may also believe that shadows do not change in length at all, either daily or seasonally.

I cannot stress enough how important it is for you to collect some data by doing some shadow measurements yourself before trying this with your students. It will prepare you for the potential problems they may encounter and will give you some insight into what kinds of data they will bring into the classroom for analysis.

Content Background

The easiest way to begin is to find a place in your immediate area that is sunny most of the day. Place a dowel or pencil in the ground in the middle of a piece of paper that is attached to the ground by toothpicks so that the wind will not move it around. This stick is known as a Gnomon or shadow stick. (See Figure 15.1.) Make sure you put it in a level spot and then check the shadows cast by the gnomen every hour or so. You want to mark the shadow with a line that outlines the shadow. Mark the time as well as the outline of the shadow. After a few hours, you will notice that the shadows cast by the gnomon move clockwise around the paper and as the day approaches midday, the shadow becomes shorter. It will be at its shortest at midday, then begin to lengthen again. You will also notice that the Sun's apparent motion in the sky will correspond to the shadow cast in an opposite direction. In other words, the shadow will be pointing away from the Sun as it appears to move from east to west across the sky. This should give you a clue as to what to expect on a daily basis. You noticed that length and direction of the shadow change over the period of the day you observed. It should also have become apparent that as the Sun rose higher in the sky on its daily path, the shadow became shorter and that at the beginning of the day and after midday, the Sun moved lower in the sky and correspondently the shadow lengthened again (low Sun = long shadow, high Sun = short shadow). Your second observation should be that the shadow always pointed away from the Sun so that it moved from west to east as the Sun moved across the sky from east to west.

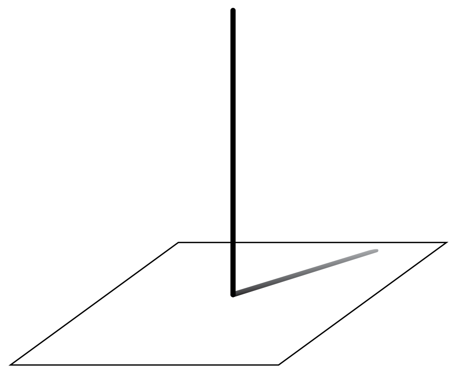
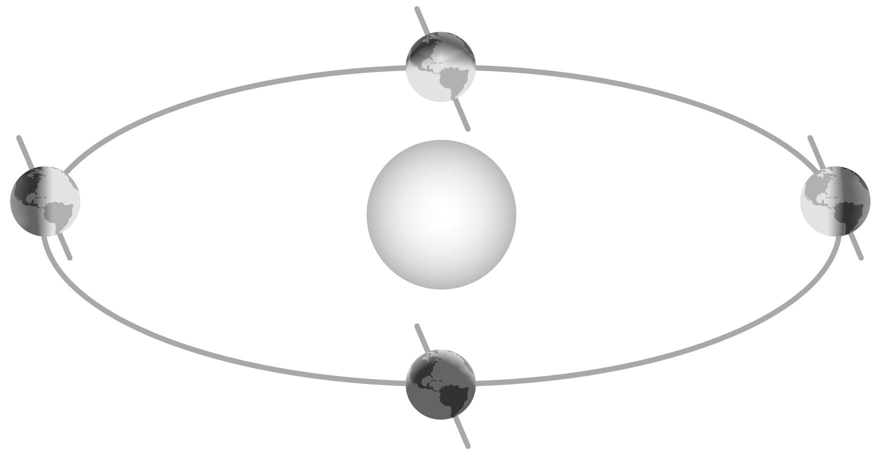


Figure 15.1. Gnomon

If you were able to do this for a whole school year, starting in the autumn (and the following observations are correct only if you start in autumn), you would notice that the shadows would not fall in the same place on the paper from one day to the next. They would fall a bit further counterclockwise to previous shadows. Using what you found out about the relationship between the Sun and the direction of the shadow, you would surmise that the Sun had shifted its position at any given time a little to the southeast. In the northern hemisphere this would mean that as autumn proceeded and winter approached, the Sun would rise later each day and would rise a bit more to the southeast than the day before. The Sun is spending less time in the daytime sky until December 21st (sometimes December 22nd) when winter officially arrives, also known as the "shortest day of the year." You should purchase a copy of the *Old Farmer's Almanac* at your local supermarket, bookstore, hardware store, or garden store. Specific tables give times for sunrises and sunsets for each day of the year. There are editions for each section of the country. If you do not have access to this book, the local newspapers also have an almanac that will provide you with astronomical times. You can also access the *Old Farmer's Almanac* online at *www.almanac.com*.

After December 21st, the "winter solstice," you will notice the opposite trend taking place. The Sun will be "rising" each day more toward the north and your shadows will correspondingly shift to this motion as you record them. The shadows will become shorter at any given time when compared to the shadows taken as winter approached. Your daily shadows will move even more to the south as summer approaches and the length of the day increases substantially. Unfortunately, school will probably end before the summer solstice on June 21st (sometimes June 20th), when your midday shadow would measure the shortest of the year. Perhaps, if you are fortunate, you students will become interested enough to continue gathering data through the summer so that they can witness the entire cycle. From June 21st on, your shadow measurements will begin to lengthen again and the cycle will repeat as the next autumn and winter approaches. You would have had to make a one-hour adjustment in your data collection for Daylight Saving Time in March. You would notice that on the day the clocks were changed to one hour ahead, the shadows you record would be an hour behind. You would therefore have to take your readings adjusted to Sun time rather than clock time. It is important to notice that Sun time is "real" time and that changing clocks does not alter the astronomical movement of the celestial bodies. I am reminded of the joke about the gardener who opposed daylight saving time because he thought that the extra hour of sunlight would be bad for his crops.

Your observations will eventually lead you to conclude, by means of your records of the motions of the Sun and the records of the corresponding shadows, that the Sun prescribes a predictable path in the sky and that each year this cycle continues. Further study may also lead you to the evidence that this motion is tied to the reasons for our northern and southern hemispheric seasons. This periodic motion is but one of many in the universe. In Chapter 4 ("Moon Tricks"), you were introduced to the periodic motion of the Moon and its phase cycles. Each year you witness the periodical motion of the Earth and Sun, which causes the seasons, and each day, the rotation of the Earth to cause day and night. In the story "Grandfather's Clock" (*Everyday Physical Science Mysteries* 2013) you witness the periodic motion of the pendulum, which has a cycle so dependable that you can use it to keep time. It is no wonder that the big idea of periodic motion is so important as a unifying concept in science. It is also evident that science seeks patterns that eventually lead to predictions, which lead to a better understanding of our universe.



Each year the Earth makes one revolution around the Sun. In the northern and southern hemisphere a tilt of 23½ degrees accounts for the seasons. Since the Earth's tilt always points in one direction, relative to the Earth's orbit there are times when the northern hemisphere is pointed more directly toward the Sun and therefore receives more heat from its direct rays.

This occurs at the summer solstice in June, the beginning of summer; days are long and nights are short. At the other extreme of its orbit, one half year later, the northern hemisphere is pointed away from the direct rays of the Sun at the winter solstice and days are short and nights are long. It is exactly the opposite in the southern hemisphere where the seasons come at opposite times of the year compared to the northern hemisphere. In between these two extremes, the Earth is in transition to either spring or fall and milder temperatures are common since the direct rays of the Sun fall more evenly above and below the equator. Days and nights are more equal in length. The tilt of the Earth is the main cause of seasons and of the differences in the Sun's position in the sky during the year and therefore the difference in shadow patterns. One helpful fact is that the farther north or south of the equator you are, the greater the differences there are in day-night hour lengths and seasonal shadow lengths.

Related Ideas From the National Science Education Standards (NRC 1996)

K–4: Objects in the Sky

- The Sun, Moon, stars, clouds, birds, and airplanes all have properties, locations, and movements that can be observed.

K–4: Changes in Earth and Sky

- Objects in the sky have patterns of movement. The Sun for example appears to move across the sky in the same way every day. But its path changes slowly over the seasons.

5–8: Earth in the Solar System

- Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.

Related Ideas From Benchmarks for Science Literacy (AAAS 1993)

K–2: The Universe

- The Sun can be seen only in the daytime but the moon can be seen sometimes at night and sometimes during the day. The Sun, Moon, and stars all appear to move slowly across the sky.

3–5: The Earth

- Like all planets and stars, the Earth is approximately spherical in shape. The rotation of the Earth on its axis every 24 hours produces the day/night cycle. To people on Earth, this turning of the planet makes it seem as though the Sun, Moon, planets, and stars are orbiting the Earth once a day.

6–8: The Earth

- Because the Earth turns daily on an axis that is tilted relative to the plane of Earth's yearly orbit around the Sun, sunlight falls more intensely on different parts of Earth during the year.

Using the Story With Grades K–4 and Grades 5–8

Please revisit the introduction to this book for the case studies about how two classroom teachers used this story. It will help you to see the overall picture of the process. Since the case study is available I will combine the grade level suggestions in one section. There are also a great many common elements for both levels, so to avoid repetition, please read ideas for both grade levels and choose the ideas most appropriate for your class.

Cheeks, of course, fell victim to the misconception that shadows caused by the blockage of sunlight do not move or change shape during the course of the day or over the seasons. We have discovered that most children, from first grade on, immediately suspect that the shadow's position in the story had changed. The students do not often realize that the Sun's apparent motion is the cause of the changes in the shadow, although one or more students may suggest that this is the case. Students' experience is such that when pressed to explain something like Cheeks' problem, they begin to recall their simple knowledge of shadows and apply it to explain why the acorns were "lost." Once the older children have agreed that shadows do indeed change from day to day, they usually wonder in what ways they change and by how much. As seen in the case study in the introduction, younger children may be satisfied with focusing on what happens to the length of shadows during the course of a school year.

The story might raise some other hypotheses in the minds of the children about what happened to Cheeks' acorns. A few children may carry on with Cheeks' initial suspicion and make up ideas about thieving squirrels or chipmunks. This is a productive entrance to the literacy possibilities open to the teacher. These ideas can be encouraged by suggesting they write some creative narratives about Cheeks, who might be imagined to star in a multitude of adventures in the backyard. These are great entries in the science notebooks. Encourage the children to back up their stories with some facts they can uncover about the behavior of squirrels. This is an excellent door into the secondhand inquiry using textual or internet information mentioned in Chapter 3. For example, when children learn something about what a squirrel's nest looks like and how it is built, stories can emerge from or around these bits of knowledge. I have had children suggest that the acorns sprouted after they were hidden. This could lead into another investigation in the biological area about seeds to see if all acorns germinate immediately when planted. If the teacher feels comfortable in having two or more investigations going on at once, it can lead to an exciting set of concurrent experiments. These can be sideline excursions for some children even though the main thrust is aimed at the discoveries they will be making about the Sun's movement and the shadows that mark it.

With both older and younger children the facilitator should help the children realize that they need to explore what happens to shadows out of doors during the day. Older students are usually more interested in what happens to shadows over the seasons. With both student groups, it might be a good idea to let them play with flashlights and objects to study shadows and their relationship to light sources. Productive questions to ask might include the following:

(1) Can you make the shadow change its length? How did you do that?
(2) Can you make a shadow that is longer or shorter than the object? How do you do that?
(3) Can you make the shadow move around the table (desk) in different directions? How do you do that?

These kinds of observations also belong in their science notebooks along with questions that arise from their explorations.

Once they have had practice with making shadows, the ideas for Cheeks' problem may become more obvious to them. Younger children may come up with knowledge statements recorded on the "Our best thinking" sheet, such as the following:

- Outdoor shadows get longer as the day goes on.
- Outdoor shadows get shorter as the day goes on.
- Outdoor shadows change all the time during the day.
- Outdoor shadows point in different directions during the day.

Older students may have other misconceptions that they will share. These might include:

- At noontime there will be no shadow because the Sun is directly overhead.
- Noontime and midday occur at the same time.

As suggested previously, these knowledge statements can be changed to questions so the knowledge statements become productive questions, e.g. "Do outdoor shadows get longer as the day does on?" "Will there be a shadow at noontime?" These are obviously testable questions and can be changed back to hypotheses and tested. This may seem like an unnecessary step to go from statement to question back to statement, but I believe it helps the children to see that hypotheses come from questions and that all knowledge should be open to question. It should also reveal that a hypothesis is a statement, not a question. Children should also be asked to give some reasons for their hypotheses. They need to learn that hypotheses are not merely wild guesses.

Once the children have given their opinion of why the acorns were missing, the adult can write these down on the "Our Best Thinking for Now" chart. I suggest that this list of theories or guesses about the motion of shadows be written on large pieces of paper and displayed in a public place. It should become a record of their "best thinking so far," and be modified as new ideas are incorporated into their thinking as a result of their activities. In this way they can revisit old ideas and see how they match with their new thinking. With new vocabulary, it is also a great help to ELL students. It helps them to remember where they have been as well as helping them see where they are going and that changing one's mind due to evidence is not a weakness. The hardest part of the adult role is helping the children learn how to look without telling them what to see.

The facilitator can help the children by asking some questions that can help the children focus on the problem and some solutions. Some of these questions for all students might be:

- What did Cheeks expect would happen to the shadows she used as markers?
- What do you think happens to the length and shape of shadows during one day?
- What can we do to find out what happens to the length and shape of shadows during one day?
- How can we make and keep records of what we find out?

For older students you might also ask:

- Do you think that the shadow Cheeks used changed in ways other than in length?

Once the children have agreed on how they will study the shadows during a day and several days recordings are on display, the next question might be:

- How will we find out what happens to shadows over a longer period of time, such as fall to winter or winter to spring?

The next section on methods will discuss the use of the gnomon to collect data to answer these questions.

This last question and discussion of the data collection methodology will bring up many design problems that you must be prepared to address. The children will probably want to use a tree as a marker since Cheeks' dilemma is based on tree shadows. However, during the winter months when the Sun is low in the sky, tall trees can cast very long shadows that can be interrupted by the school building or areas of the school site that cannot be entered because of brambles or fences, thereby frustrating measurements. Explain to the students that since we do not know if or how these shadows can change, they might choose a shorter tree or object in the center of a wide space, which will allow for all sorts of surprises without making data collecting difficult or impossible. One might be tempted to allow the students to find this out for themselves, but in the case of a study over a long period of time, this error can destroy not only the value of the data but the incentive to continue the study. Another way to prevent such disasters is to have several sites using teams of children at each site. If one site should run into problems, there are always data from the other sites. However, it is important that all teams agree on one method of collecting data so that any comparisons that might be required would be compatible. As a result of the discussion of the Cheeks story the children should be able to begin designing the data collection to answer their particular questions.

One of the time-honored methods for collecting shadow data is the gnomon. A gnomon is a stick that is placed in the ground or into a surface parallel to the ground with the stick perpendicular to the ground and which acts as an unchanging shadow producer. The stick blocks the Sun's rays and casts a shadow onto the ground in the shape of the stick. As the day progresses the shadow will change in two ways. It will become longer or shorter in length as the Sun gets higher or lower in the sky, and it will point in different directions as the Sun moves across the sky from east to west. Depending upon the position of the Sun, the shadow may be shorter, the same as, or longer than the stick. It is important that the surface upon which the shadows are cast is flat, not undulating or sloping. Of course, as long as shadows are measured at this exact spot each time, the shadows for each measurement will be comparable. If however, the placement of the gnomon is changed from time to time, as it probably will be, the level of the surface is very important. Paper can be placed on a board and the stick attached to the board at its center so that the shadows will be cast on the paper and can be recorded with pencil or felt-pen marker. You must only be careful that the place where the board is placed is level and not sloping.

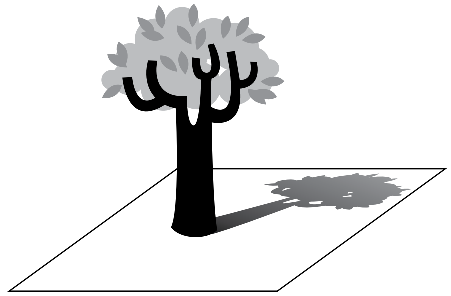
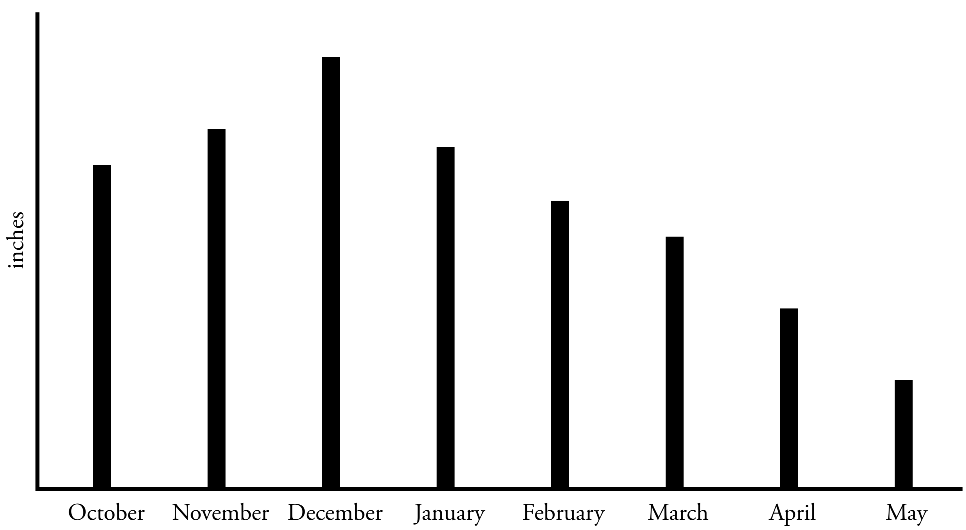


Figure 15.2. Tree Gnomon

If the gnomon is attached to a board, the board should be pointed in the same direction each time a recording is taken so the position changes can be noted. By this I mean that the sides of the board should be pointing in the same compass direction each time a reading is taken. If you want a really great class discussion, ask the students if it is important to align the board the same each day. The gnomon stick itself should be about the length of a toothpick so that the long winter shadows in higher latitudes do not go off the paper. You may want to add a triangle to the toothpick so that it looks like a pine tree and the story line is kept intact (see Figure 2).

Younger children can measure the shadow lengths with yarn or string and transfer the yarn to a paper to create a graph. Be sure to mark the dates and times carefully on the graph. You might want to have your children keep records of their measurements in their science notebooks. Children who are able to measure can transfer their measurements to a piece of centimeter graph paper and can compare lengths as well as directions of shadows. If these are placed on transparencies, shadow records from various dates and times can be superimposed on each other and compared for lengths and direction. It helps a great deal if each of the date's shadows are recorded in different colors so that comparisons can be made easier.

Graph of Shadow Lengths, October to May



The children will find that there are several changes in shadows over short and long time intervals. These main observations can be listed as follows when considering shadows created by the sunlight. These concepts are:

- Shadows change daily and from day to day.
- Shadows always point away from the source of light.
- Shadows are longest in the early mornings and late afternoons.

- Shadows are shortest during the midday hours.
- The shadows change from longer to shorter and back to longer during one day.

Older students may add the following as well:

- Shadows point to the west in the morning and to the east in the afternoon.
- Contrary to expectations, in latitudes higher than 23.5° north or south of the equator there is no time during the day when the Sun is so high that no shadow is cast.
- The shortest shadow is not always at noon. The shortest shadow is cast at midday, which is the midpoint between sunrise and sunset (often called local noon).
- Shadows at any given time change in length and direction as the year progresses.

All of these observations can help the students to understand the motion of the celestial bodies and ultimately the reasons for seasons. It is best to wait until middle school to expect any real understanding of the causes of the seasons. Their spatial relations will have developed by then and their ability to see the spatial relationships of the Sun and Earth will improve.

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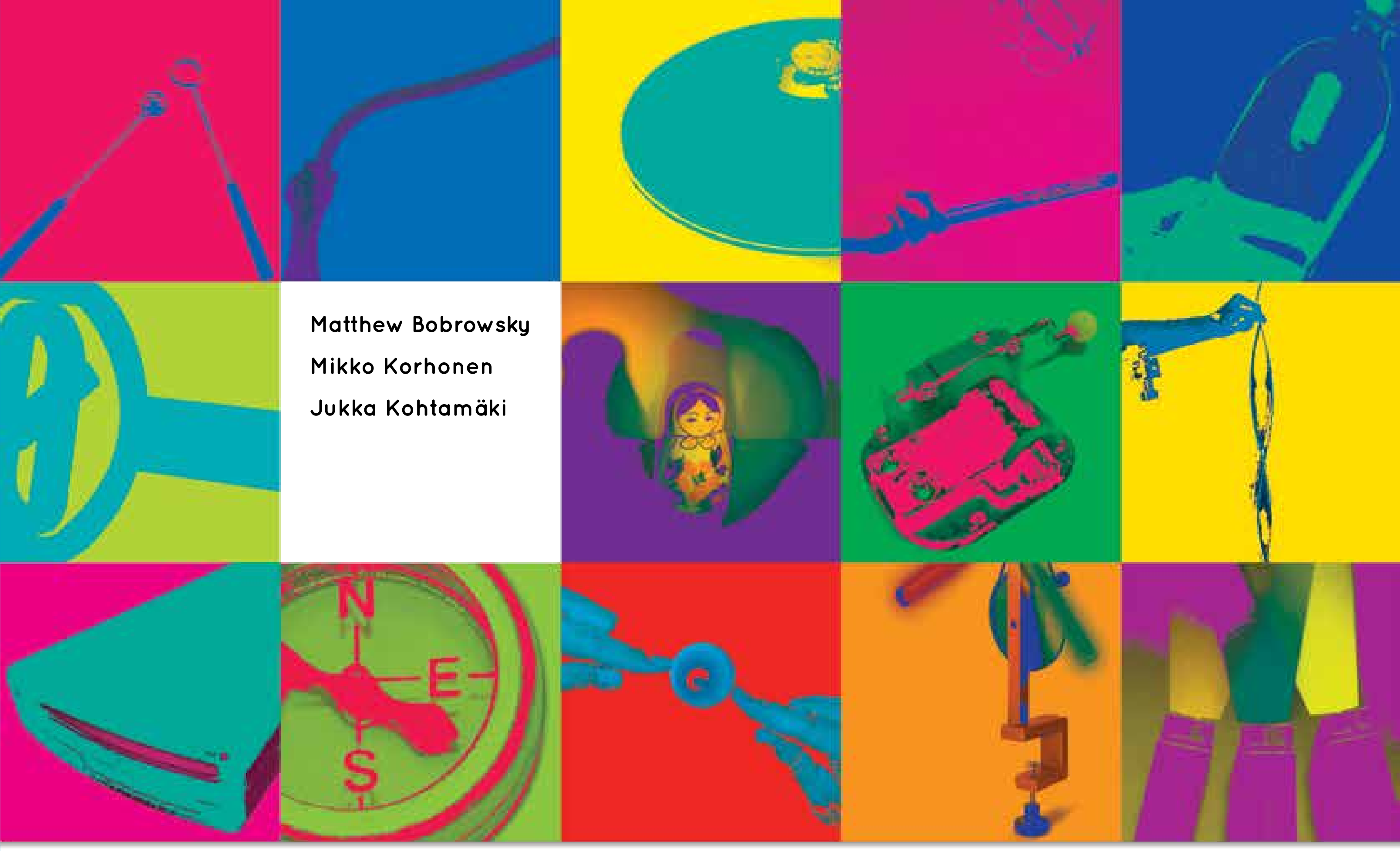

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Dr. Matt Bobrowsky has been involved in scientific research and science education for several decades. For four years, he served as Director of the Physics Demonstration Facility at the University of Maryland—a collection of over 1,600 science demonstrations. Also at the University of Maryland, Matt was selected as a Faculty Mentor for the Fulbright Distinguished International Teachers Program, where he met Mikko Korhonen.

Matt has taught physics, astronomy, and astrobiology both in the classroom and online. He has written K–12 science curricula and serves on the Science Advisory Committee for the Howard County Public School System in Maryland. Matt has conducted countless professional development workshops for science teachers and special presentations for students, speaking on a variety of topics beyond physics, such as the scale of the universe, life in the universe, misconceptions about science among students and the public, the process of science, and science versus pseudoscience. He is often asked to be an after-dinner speaker or keynote speaker at special events. Matt is a "Nifty Fifty" speaker for the USA Science & Engineering Festival and a Shapley Lecturer for the American Astronomical Society. Matt has received a number of awards for teaching excellence from the University of Maryland, including the Stanley J. Drazek Teaching Excellence Award (given to the top 2 instructors out of ~800) and the Board of Regents' Faculty Award for Excellence in Teaching (given to the top 3 instructors out of ~7,000). Matt's teaching is always innovative because he uses pedagogical techniques that are based on current science education research and known to be effective.

In his research, Matt has been involved in both theoretical and observational astronomy. He developed computer models of planetary nebulae—clouds of gas expanding outward from aging stars—and has observed them with telescopes on the ground as well as with the Hubble Space Telescope. One of the planetary nebulae that Matt investigated is the Stingray Nebula, which he discovered using Hubble.

MIKKO KORHONEN

Mikko Korhonen obtained a master's degree from Tampere Technical University in Finland, where he studied physics, mathematics, and pedagogics. Since then, he has been teaching physics, mathematics, and computer science at various schools in Finland. He has also developed a number of educational programs that brought some of his students to top scientific facilities in the world, including the Nordic Optical Telescope (NOT) observatory in La Palma, Spain, the CERN laboratory at the Franco-Swiss border, and the LATMOS laboratory in France. Most recently, some of his students have attended the Transatlantic Science School, which Mikko founded.

Mikko has written numerous other educational publications, including a book of physics experiments, manuals of physics problems with answers, an article on mathematics and logic for computer science, and two books with Jukka Kohtamäki on using toys to teach physics, one at the middle school and one at the high school level. (This book is an adaptation of the Finnish version of the middle school book.)

Mikko has obtained numerous grants and awards for his school and students, including awards from the NOT science school and the Viksu science competition prize, as well as individual grants from the Finnish National Board of Education and the Technology Industries of Finland Centennial Foundation, and grants for his "physics toys" project. His students are also award winners in the Finnish National Science Competition. Mikko received one of the Distinguished Fulbright Awards in Teaching, which brought him to the University of Maryland for a semester, where he worked with Matt Bobrowsky. Most recently, Mikko received the award of Distinguished Science Teacher in 2013 by the Technology Industries of Finland Centennial Foundation.

JUKKA KOHTAMÄKI

Jukka Kohtamäki obtained his master of science degree from Tampere University of Technology in Finland and since then has been teaching grades 5–9 at the Rantakylä Comprehensive School, one of the largest comprehensive schools in Finland. Jukka has participated in long-term professional development teaching projects and projects involving the use of technology in learning, as well as workshops that he and Mikko Korhonen conducted for Finnish science teachers. His writing includes teaching materials for physics and computer science, and he has written two books with Mikko on using toys to teach physics, one at the middle school and one at the high school level. (This book is an adaptation of the Finnish version of the middle school book.)

Jukka is a member of the group under the National Board of Education that is writing the next physics curriculum in Finland. He is also participating in writing curricula in chemistry and natural science (which is a combination of biology, geology, physics, chemistry, and health education). His goals are to get students engaged in lessons, to have them work hands on and minds-on, to encourage creativity in finding solutions, and to get students to discuss natural phenomena using the "language of physics." In 2013, Jukka received the Distinguished Science Teacher Award from the Technology Industries of Finland Centennial Foundation.

"The most beautiful thing we can experience is the mysterious. It is the source of all true art and science."

— Albert Einstein

AN INTRODUCTION TO PHENOMENON-BASED LEARNING

TO THE STUDENT

In 1931 Albert Einstein wrote, "The most beautiful thing we can experience is the mysterious. It is the source of all true art and science." Keep this in mind as we introduce you to phenomenon-based learning, a learning approach in which you start by observing a natural phenomenon—in some cases just a simple toy—and then build scientific models and theories based on your observations.

The goal is for you to first watch something happen and then become curious enough to find out why. You will experiment with some simple gizmos and think about them from different perspectives. Developing a complete understanding of a concept might take a number of steps, with each step providing a deeper understanding of the topic. In some cases, you will need to do further research on your own to understand certain terms and concepts. Like real scientists, you can also get help from (and provide help to) collaborators. This book's approach to learning is based on curiosity and creativity—a fun way to learn!

TO THE TEACHER

The pedagogical approach in this book is called phenomenon-based learning (PBL), meaning learning is built on observations of real-world phenomena—in this case of some fun toys or gadgets. The method also uses peer instruction, which research has shown results in more learning than traditional lectures (Crouch and Mazur 2001). In the PBL approach, students work and explore in groups: Exercises are done in groups, and students' conclusions are also drawn in groups. The teacher guides and encourages the groups and, at the end, verifies the conclusions. With the PBL strategy, the concepts and the phenomena are approached from different angles, each adding a piece to the puzzle with the goal of developing a picture correctly portraying the real situation.

The activities in this book can be used for various purposes. The introductions and the questions can be used as the basis for discussions with the groups before the students use the gizmos, that is, as a motivational tool. For example, you can ask where we see or observe the phenomenon in everyday life, what the students know about the matter prior to conducting the activities, and so on.

PBL is not so much a teaching method as it is a route to grasping the big picture. It contains some elements that you may have seen in inquiry-based, problem-based, or project-based learning, combined with hands-on activities. In traditional physics teaching, it's common to divide phenomena into small, separate parts and discuss them as though there is no connection among them (McNeil 2013). In our PBL approach, we don't artificially create boundaries within phenomena. Rather, we try to look at physical phenomena very broadly.

PBL encourages students to not just think about what they have learned but to also reflect on how they acquired that knowledge. What mental processes did they go through while exploring a phenomenon and figuring out what was happening? PBL very much lends itself to a K-W-L approach (what we **K**now, what we **W**ant to know, and what we have **L**earned). K-W-L can be enhanced by adding an H for "**H**ow we learned it" because once we understand that, we can apply those same learning techniques to other situations.

> *"Most of the time my students didn't need me; they were just excited about a connection or discovery they made and wanted to show me."*
>
> *—Jamie Cohen (2014)*

When you first look at this book, it might seem as if there is not very much textual material. That was intentional. The idea is to have more thinking by the students and less lecturing by the teacher. It is also important to note that the process of thinking and learning is not a race. To learn and really get the idea, students need to take time to think … and then think some more—so be sure to allow sufficient time for the cognitive processes to occur. For example, the very first experiment (using a tuning fork) can be viewed in two seconds, but in order for students to think about the phenomenon and really get the idea, they need to discuss the science with other group members, practice using the "language of science," and internalize the science involved—which might take 20 minutes. During this time, the students may also think of real-life situations in which the phenomenon plays a significant role, and these examples can be brought up later during discussions as an entire class.

LEARNING GOALS AND ASSESSMENT

The most important learning goal is for students to learn to think about problems and try a variety of approaches to solve them. Nowadays, most students just wait for the teacher to state the answer. The aim here is for students to enjoy figuring out what's going on and to be creative and innovative. Combining this with other objectives, a list of learning goals might look something like this:

By the end of these lessons, students will

- think about problems from various angles and try different strategies;
- demonstrate process skills, working logically and consistently;
- collaborate with others to solve problems;
- use the language of physical science (and science in general);
- reflect on the thinking processes that helped them to acquire new knowledge and skills in physical science; and
- view physical science as interesting and fun.

You will also notice that there are no formal quizzes or rubrics included. There are other ways to evaluate students during activities such as these. First, note that the emphasis is not on getting the "right" answer. Teachers should not simply provide the answer or an easy way out—that would not allow students to learn how science really works. When looking at student answers, consider the following: Are the students basing their conclusions on evidence? Are they sharing their ideas with others in their group? Even if a student has the wrong idea, if she or he has evidential reasons for that idea, then that student has the right approach. After all members of a group are in agreement and tell you, the teacher, what they think is happening, you can express doubt or question the group's explanation, making the students describe their evidence and perhaps having them discuss it further among themselves. Student participation as scientific investigators and their ability to give reasons for their explanations will be the key indicators that the students understand the process of science.

The PBL approach lends itself well to having students keep journals of their activities. Students should write about how they are conducting their experiment (which might differ from one group to another), ideas they have related to the phenomenon under investigation (including both correct and incorrect ideas), what experiments or observations showed the incorrect ideas to be wrong, answers to the questions supplied for each exploration, and what they learned as a result of the activity. The teacher can encourage students to form a mental model—perhaps expressed as a drawing—of how the phenomenon works and why. Then they can update this model in the course of their investigations. Students might also want to make a video of the experiment. This can be used for later reference as well as to show family and friends. Wouldn't it be great if we can get students talking about science outside the classroom?

A few of the questions asked of the students will be difficult to answer. Here again, students get a feel for what it's like to be a real scientist exploring uncharted territory. A student might suggest an incorrect explanation. Other students in the group might offer a correction, or if no one does, perhaps further experimentation, along with guidance from the teacher, will lead the students on the right course. Like scientists, the students can do a literature search (usually a web search now) to see what others know about the phenomenon. Thus there are many ways for a misconception to get dispelled in a way that will result in more long-term understanding than if the students were simply told the answer. Guidance from the teacher could include providing some ideas about what to observe when doing the experiment or giving some examples from other situations in which the same phenomenon takes place. Although many incorrect ideas will not last long in group discussions, the teacher should actively monitor the discussions, ensuring that students do not get too far off track and are on their way to achieving increased understanding. We've provided an analysis of the science behind each exploration to focus your instruction.

By exploring first and getting to a theoretical understanding later, students are working like real scientists. When scientists investigate a new phenomenon, they aren't presented with an explanation first—they have to figure it out. And that's what the students do in PBL. Real scientists extensively collaborate with one another; and that's exactly what the students do here as well—work in groups. Not all terms and concepts are extensively explained; that's not the purpose of this book. Again, like real scientists the students can look up information as needed in, for example, a traditional physics textbook. What we present here is the PBL approach, in which students explore first and are inspired to pursue creative approaches to answers—and have fun in the process!

PBL IN FINLAND

The Finnish educational system came into the spotlight after the Programme of International

Student Assessment (PISA) showed that Finnish students were among the top in science literacy proficiency levels. In 2009, Finland ranked second in science and third in reading out of 74 countries. (The United States ranked 23rd and 17th, respectively.) In 2012, Finland ranked 5th in science. (The U.S. was 28th.) Finland remains #1 in science among member nations of the Organization for Economic Co-operation and Development (OECD). Finland is now seen as a major international leader in education, and its performance has been especially notable for its significant consistency across schools. No other country has so little variation in outcomes among schools, and the gap within schools between the top- and bottom-achieving students is quite small as well. Finnish schools seem to serve all students well, regardless of family background or socioeconomic status. Recently, U.S. educators and political leaders have been traveling to Finland to learn the secret of their success.

The PBL approach is one that includes progressive inquiry, problem-based learning, project-based learning, and in Finland at least, other methods at the teachers' discretion. The idea is to teach bigger concepts and useful thinking skills rather than asking students to memorize everything in a textbook.

AUTHORS' USE OF GADGETS AND GIZMOS

One of the authors (M.B.) has been using gizmos as the basis of teaching for many years. He also uses them for illustrative purposes in public presentations and school programs. The other two authors (M.K. and J.K.) have been using PBL—and the materials in this book—to teach in Finland. Their approach is to present physics phenomena to students so that they can build ideas and an understanding of the topic by themselves, in small groups. Students progress from thinking to understanding to explaining. For each phenomenon there are several different viewpoints from which the student can develop a big-picture understanding as a result of step-by-step exploration. The teacher serves only as a guide who leads the student in the right direction. PBL is an approach that is not only effective for learning but is also much more fun and interesting for both the teacher and the students.

SAFETY NOTES

Doing science through hands-on, process, and inquiry-based activities or experiments helps to foster the learning and understanding of science. However, in order to make for a safer experience, certain safety procedures must be followed. Throughout this book, there are a series of safety notes that help make PBL a safer learning experience for students and teachers. In most cases, eye protection is required. Safety glasses or safety goggles noted must meet the ANSI Z87.1 safety standard. For additional safety information, check out NSTA's "Safety in the Science Classroom" at *www.nsta.org/pdfs/SafetyInTheScienceClassroom.pdf*. Additional information on safety can be found at the NSTA Safety Portal at *www.nsta.org/portals/safety.aspx*.

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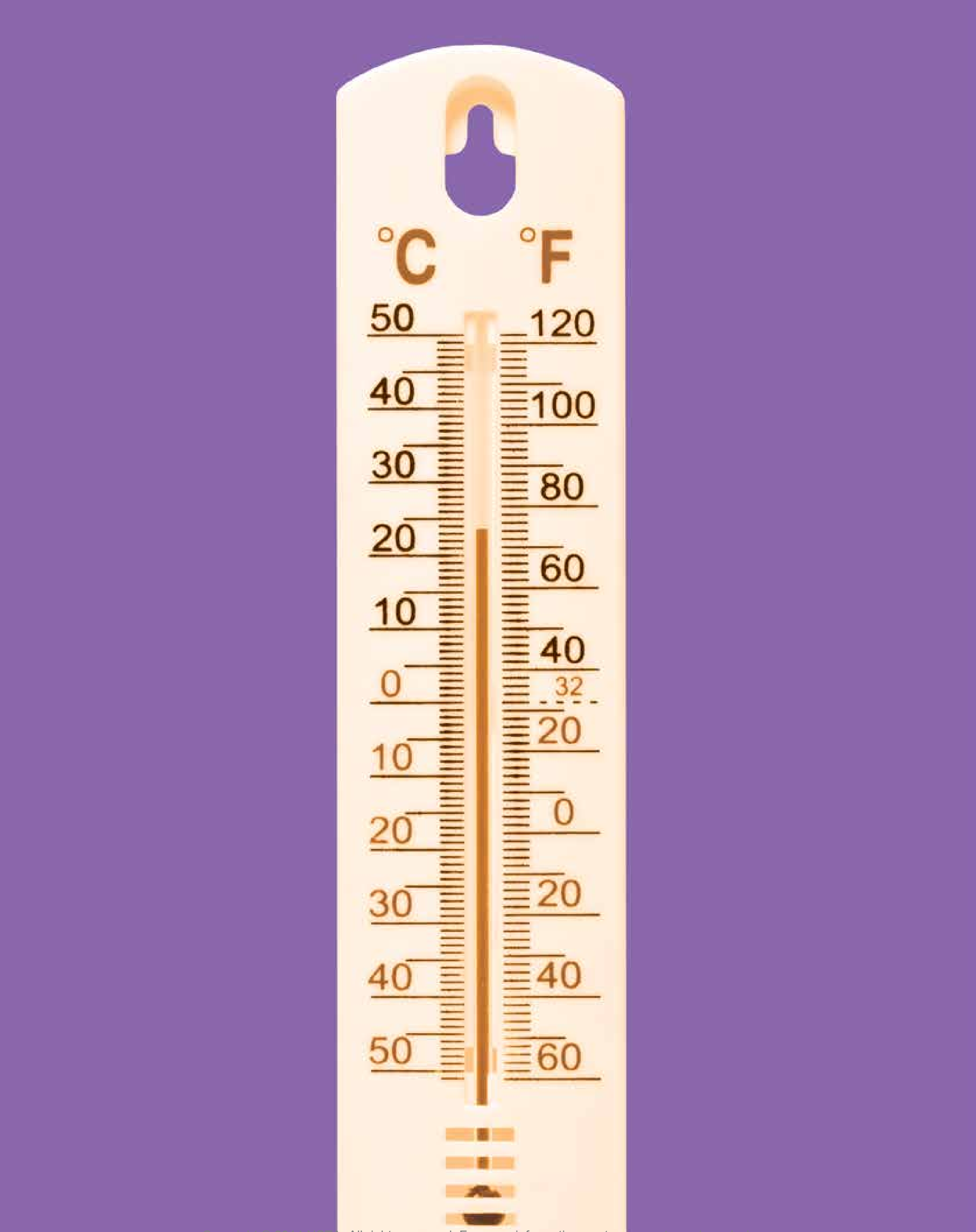
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3

THERMODYNAMICS

Thermodynamics is a very important part of physical science. When discussing thermodynamics, we can explore heat, thermal expansion, and insulation, as well as changes in state, thermal equilibrium, and thermal energy.

KEYWORDS

Knowing these terms will help you to enjoy the explorations.

thermometer

Celsius scale

Fahrenheit scale

energy

heat

Temperature tells us how hot or cold an object is. Temperature is also a measure of how quickly atoms and molecules vibrate. The faster the particles move, the warmer the object is. We can measure temperature with a thermometer. The number it reads tells us how warm or cold it is compared with certain reference points. In some temperature scales, the reference points are the freezing point of water and the boiling point of water. In the Celsius scale, the numbers are 0°C for freezing and 100°C for boiling. In the Fahrenheit scale the corresponding reference points are 32°F and 212°F, respectively. In the Kelvin scale, the lower reference point is absolute zero, which is approximately –273°C (or –460°F). In the Kelvin scale, there is no upper reference point, and one degree is the same amount of temperature difference as in the Celsius scale.

An understanding of heat and thermodynamics will help you understand why heat behaves the way it does and how you can use this understanding for your benefit. For example, why is a frying pan made of metal while its handle is made of plastic or wood? Why does the fan on the table make you feel more comfortable on hot summer days, even though the fan doesn't actually make the air any cooler?

The experiments in this chapter illustrate some of the key thermal physics phenomena from different perspectives.

3E Exploration

FIGURE 3.1: Radiation Cans

RADIATION CANS

In this experiment, you will study how the color of an object influences its temperature. You will need three bottles (white, silver, and black), such as the Radiation Cans (Figure 3.1), water, and a thermometer for each bottle.

Procedure

1. Pour exactly the same amount (e.g., 100 ml) of the same temperature water into each bottle.
2. Put a thermometer into each bottle.
3. Place the bottles in direct sunlight or near a hot, bright light.
4. Observe and record the temperatures in the bottles. Graph your data to see how the temperature changed in the different bottles.

Questions

- How did the color of the bottle affect how much the water warmed up?
- Which bottle changed temperature fastest?
- Show on your graph where you can see the differences in warming.
- How is the information you collected useful on hot sunny days or cold winter days?

SAFETY NOTES

- Wear safety glasses or goggles.
- Glass thermometers are fragile and can shatter. Handle with care.
- Do not use mercury thermometers.

FIGURE 3.2: Ice Melting Blocks

MELTDOWN

With the Ice Melting Blocks (Figure 3.2), you will explore some thermal properties of different materials.

Procedure 1

1. Briefly touch the surfaces of the two blocks.

Questions

- Which block feels colder?
- Predict on which block an ice cube will melt faster. Explain your reasoning.

Procedure 2

1. Put the O-rings on the blocks, and then set the ice cubes on the blocks.
2. Observe the melting of the ice. Take notes.
3. After a couple of minutes of melting, touch the blocks again (where there's no ice or water) and sense the temperatures.
4. Feel how warm or cold the table is under the blocks. Take notes.

SAFETY NOTES

- Wear safety glasses or goggles.
- Immediately wipe up any splashed water to prevent a slip or fall hazard.

Questions

- Why does one block feel much colder than the other one?
- How do you explain your observations of the temperature of the table under the blocks?
- Why did the ice cube on one block melt faster than on the other block?

SAFETY NOTES

- Wear safety glasses or goggles.
- Use caution when working with Bunsen burner or other heat source. They can burn skin.
- Never leave a heat source unattended when it is hot.
- Do not handle the metal part of the Ball and Ring equipment when it is heated. It can burn skin.

FIGURE 3.3: Ball and Ring

BALL AND RING

Here you will investigate some effects of changes in temperature. In addition to the Ball and Ring (Figure 3.3), you will need a Bunsen burner or some other kind of heater.

Procedure

1. Check that the ball fits through the ring.
2. Predict what will happen when the ball is heated. Explain your reasoning.
3. Heat the ball and try again.
4. Cool the ball down in water before the next experiment.
5. Predict whether the ball will fit through the ring if the ring is heated up. Explain your reasoning.
6. Heat up the ring and check your prediction.

Questions

- First the ball was heated, and then the ring. Describe your observations in each part of your exploration, and suggest an explanation for the physics that was involved in each part.
- Can you think of ways in which this phenomenon could be useful?
- How might engineers take this phenomenon into account when they, for example, design a bridge?

DRINKING BIRD

The Drinking Bird (Figure 3.4) demonstrates several phenomena related to thermodynamics. The demonstration is ambitious—the physics can be quite a challenge—but very interesting.

In addition to the bird, you will need a glass of water.

Procedure

1. Put some water in a glass and dunk the Drinking Bird's head in the water. Add more water so that the glass is completely full.
2. Set the drinking bird down so that when it tips over its beak goes in the water.

FIGURE 3.4: Drinking Bird

Questions

- What makes the bird's balance change?
- How does evaporation affect the bird's pecking?
- Does pressure play any role here? Why?
- Does anything different happen if you warm up the lower liquid container with your hand?
- What causes the pecking to begin?
- Is it a perpetual motion machine? Explain.

SAFETY NOTE

Wear safety glasses or goggles.

FIGURE 3.5:
Fire Syringe

FIRE SYRINGE

With the Fire Syringe (Figure 3.5) you can explore the connection between pressure and temperature. In addition to the Fire Syringe itself, you will need a tiny bit of cotton.

SAFETY NOTE

Wear safety glasses or goggles.

Procedure

1. Drop a tiny piece of cotton (about the size of a pencil point) into the cylinder. If it doesn't fall to the bottom, push it down with a thin rod.
2. Screw the piston into place with it all the way up.
3. Turn off the lights in the room.
4. Sharply—as fast as possible—press the piston down.

Questions

- What happened in the cylinder?
- Explain your observations from a physics point of view.
- Where could this phenomenon be useful?

Analysis

RADIATION CANS

FIGURE 3.6: Radiation Cans

Note on terminology: In physics, *heat* is energy moving from a hotter object to a cooler object. That is somewhat different from the popular use of the word *heat* to refer to the *thermal energy* contained in an object.

Thermal energy can be transferred from one object to another by *conduction* if the two objects are touching each other or by radiation, such as when infrared light energy from the wires in a toaster is absorbed by the bread to create toast. The Radiation Cans (Figure 3.6) explore the latter phenomenon.

If thermal energy is transferred to a fluid (liquid or gas), then the energy can be carried away with the flow of the fluid. Transporting of thermal energy by a fluid is called *convection*. An object gains thermal energy by conduction or by absorbing radiation. When thermal energy flows directly between two materials, it always flows from the hotter material to the colder material. That flowing energy is heat. When the temperatures of the objects in a system are equal, we say that the system is in *thermodynamic equilibrium*.

After cool water is poured in the bottles, the black bottle warms up the fastest. The black surface absorbs all wavelengths of visible light most efficiently. By absorbing that radiation, the bottle heats up. The white bottle and the silver bottle reflect some of the wavelengths of light that strike the bottles, so the change in temperature is less than in the case of the black bottle. This is why wearing dark clothes keeps you warmer on a cold sunny day. On a hot, sunny day, you might want to wear clothing of lighter colors to reflect more of the Sun's radiation and stay cooler.

FIGURE 3.7: Ice Melting Blocks

MELTDOWN

Thermal energy is the random movement or vibration of particles in an object. The faster the particles in an object vibrate, the hotter the object is. When a warmer object (like one of the Ice Melting Blocks [Figure 3.7]) touches a cooler object (like the ice cube), the faster moving particles in the warmer object hit the slower moving particles in the cooler object. This slows down the particles in the warmer object, making it cooler, and it speeds up the particles in the cooler object, making it warmer. In this way, thermal energy is transferred from the warmer object to the cooler object by a process called *thermal conduction*.

Some materials are better heat conductors than others. Materials that do not conduct heat well are called *thermal insulators*. Air is a thermal insulator. However, for air to work well as an insulator, it must be confined in small spaces so that it can't flow and transport heat away via convection. In a block of something like Styrofoam, the air is confined in very small spaces so that it can't flow. That makes a foam block—such as one of the two blocks in this experiment—a good insulator.

The second block is made of aluminum. In metals there are electrons that greatly increase the thermal conduction. These electrons move freely among the metal molecules. The aluminum block feels cold because it is a good thermal conductor, and thermal energy is rapidly transferred from your hand to the block. In the insulator there is not that kind of conduction present so your hand doesn't lose thermal energy very fast, and the block does not feel cold in your hand. In other words, even though both blocks start out at the same temperature (room temperature), the aluminum block *feels* colder because it conducts heat out of your hand more rapidly.

The ice cube put on the aluminum block melts faster because aluminum is a good conductor and transfers thermal energy into the ice cube quite effectively. The energy is transferred as long as there is a difference in temperature between the block and the ice cube. On the insulator, we cannot see the cube melting down as fast because there is not that much thermal energy being transferred from the block to the cube.

FIGURE 3.8:
Ball and Ring

If the air around the ice cube isn't moving much, there will be a cold, insulating layer of air that prevents a lot of thermal energy from flowing from the air to the ice cube. The cube would melt faster if air was blowing past it.

To melt ice requires energy from the surroundings, so the conductor (aluminum) block feels—and really is—cooler right after the experiment. The table surface under the conductor block feels colder too. As the aluminum block became cooler (having lost thermal energy to the ice), energy flowed from the table into the aluminum block, making the table cooler as well. Under the insulator block, the temperature of the table hasn't changed much.

Tip: If there are not enough blocks for each group to try the experiment, do this as a demonstration with a document camera. If you want a more precise measure than simply feeling the blocks can provide, you can attach thermal sensors to the blocks.

BALL AND RING

When the metal ball of the Ball and Ring (Figure 3.8) is heated up, the thermal motion (the vibration of atoms and molecules) increases, causing the particles to take up more space. After the ball expands, it will not fit through the ring.

When the ball has cooled down, you can see what happens when the ring is heated up. You may have thought that the ball would not fit through the ring because the thermal expansion acts in all directions, including pushing in the inner edge of the ring, making the hole smaller. However, the proportions of the ring remain the same when the ring is heated up. This situation can be compared with enlarging a photo. If you enlarge a photo of a ring, both the outer and inner edges of the ring increase in size. Likewise, the hole in the ring expands when the ring is heated up.

Another way to look at it is that when the expansion occurs, the distance between any two points on the ring will increase. This is true even if those two points are on opposite sides of the hole. Thus the diameter of the hole increases.

FIGURE 3.9: Thermometer

Thermal expansion is also the explanation for how many thermometers work. If it's the kind of thermometer with liquid in a tube (Figure 3.9), when it gets warmer the liquid in the tube (and in the bulb at the bottom) expands, and the liquid rises in the tube.

FIGURE 3.10: Bridge expansion joint

The rising liquid in the thermometer therefore provides a measure of the increasing thermal energy.

Thermal expansion is an everyday phenomenon that can not only be used to explain the function of a thermometer or the change in size of metallic materials at different temperatures, but that must also be taken in account when building houses or bridges. Bridges are made with expansion joints, which have extra room for the expansion that occurs at higher temperatures. Expansion joints like the one in the Auckland Harbour Bridge (see Figure 3.10) in New Zealand allow bridges to expand due to heat without buckling.

DRINKING BIRD

The Drinking Bird (Figure 3.11) consists of two glass bulbs connected by a thin tube. One bulb is the bird's head, and the other bulb is in the bird's lower body. At first the pressure and temperature are the same in both bulbs, all the liquid is at the bottom, and the bird remains in balance in an upright position. Although all the liquid starts out at the bottom, there is vapor from that liquid in the head.

After the head (or beak) is soaked, water starts to evaporate from the head. The evaporation cools down the head and the vapor inside it. When the

FIGURE 3.11: Drinking Bird

temperature goes down the pressure drops too, and some of the vapor condenses. Now the pressure is lower inside the head than in the lower bulb. Because of that pressure difference, the liquid in the lower bulb gets pushed up through the tube. The rising liquid changes the balance of the bird, and it begins to tip over. When the liquid reaches the head and starts to fill it, the bird is so top-heavy that it completely tips over, and the beak goes into the water again. When the bird tips over, the pressures in the two bulbs can equalize, the liquid flows back down, and the bird swings back to its starting position. Then the same process starts again.

You can also make the liquid flow up the tube by warming the lower bulb with your hand. The rise in temperature causes increased vaporization of the liquid and increased pressure of the gas in the lower container, causing the liquid to move up the tube.

This relation between temperature and pressure is described by Gay-Lussac's law, which expresses the fact that the ratio between pressure and temperature remains constant in a fixed volume. Thus, as the temperature rises, the pressure rises proportionately.

FIGURE 3.12: Fire Syringe

FIRE SYRINGE

When you push the piston of the Fire Syringe (Figure 3.12) down, the volume of the air inside the cylinder quickly decreases. Consequently, the speed and frequency of collisions of the air particles increases. In addition, the piston moving and colliding with the particles makes the particles speed up. Both the kinetic energy of the particles and the temperature increase in the cylinder. The temperature rises to the ignition temperature of cotton (350–400°C), and the cotton catches on fire. This process, in which the gas heats up so fast that it doesn't have time to lose much heat to the environment, is called an *adiabatic* process.

Adiabatic processes are used, for example, in diesel engines. The increase in pressure inside the cylinder heats up the diesel fuel, which then catches fire. In gasoline engines, the fuel is ignited by a spark plug.

Web Resources

Experiment with pressure, volume, and temperature changes with a piston.
www.mhhe.com/physsci/physical/giambattista/thermo/thermodynamics.html

Physics Applets on a variety of topics, including thermodynamics.
http://jersey.uoregon.edu/

Compare heat conduction through two materials of different thermal conductivities.
http://energy.concord.org/energy2d/thermal-conductivity.html

Explore how energy flows and changes through a system.
http://phet.colorado.edu/en/simulation/energy-forms-and-changes

Learn how the properties of gas (volume, heat, and so on) vary in relation to each other.
http://phet.colorado.edu/en/simulation/gas-properties

A Boyle's law experiment.
www.chm.davidson.edu/vce/gaslaws/boyleslaw.html

A Boyle's law animation.
www.grc.nasa.gov/WWW/k-12/airplane/aboyle.html

A Boyle's law worksheet.
www.grc.nasa.gov/WWW/k-12/BGP/Sheri_Z/boyleslaw_act.htm

A Charles's law experiment.
www.chm.davidson.edu/vce/gaslaws/charleslaw.html

Some animated activities and worksheets on gas laws.
www.nclark.net/GasLaws

A Charles and Gay-Lussac's law activity.
www.grc.nasa.gov/WWW/k-12/airplane/glussac.html

A Charles and Gay-Lussac's law animation.
www.grc.nasa.gov/WWW/k-12/airplane/aglussac.html

Relevant Standards

Note: The Next Generation Science Standards *can be viewed online at* www.nextgenscience.org/next-generation-science-standards.

PERFORMANCE EXPECTATIONS

MS-PS3-3

Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.* [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]

MS-PS3-4

Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]

MS-PS3-5

Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object. [Clarification Statement: Examples of empirical evidence used in arguments could include an inventory or other representation of the energy before and after the transfer in the form of temperature changes or motion of object.] [Assessment Boundary: Assessment does not include calculations of energy.]

SCIENCE AND ENGINEERING PRACTICES

Developing and Using Models

Modeling in 6–8 builds on K–5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to predict and/or describe phenomena. (MS-PS1-1),(MS-PS1-4)
- Develop a model to describe unobservable mechanisms. (MS-PS1-5)

Analyzing and Interpreting Data

Analyzing data in 6–8 builds on K–5 and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings. (MS-PS1-2)

Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 6–8 builds on K–5 and progresses to evaluating the merit and validity of ideas and methods.

- Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence. (MS-PS1-3)

CONNECTIONS TO NATURE OF SCIENCE

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Theories and laws provide explanations in science.
- Laws are statements or descriptions of the relationships among observable phenomena.

DISCIPLINARY CORE IDEAS

PS3.A: Definitions of Energy

- The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. (secondary to MS-PS1-4)

- The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material. (secondary to MS-PS1-4)

PS3.A: Definitions of Energy

- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. (MS-PS3-3) (MS-PS3-4)

PS3.B: Conservation of Energy and Energy Transfer

- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. (MS -PS3-4)
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones. (MS-PS3-3)

CROSSCUTTING CONCEPTS

Energy and Matter

- Energy may take different forms (e.g., energy in fields, thermal energy, energy of motion). (MS-PS3-5)
- The transfer of energy can be tracked as energy flows through a designed or natural system. (MS-PS1-6)

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
- Systems can be designed to cause a desired effect.

INDEX

*Page numbers in **boldface** type refer to tables or figures.*

USING PHYSICAL SCIENCE
GADGETS & GIZMOS
GRADES 6–8
PHENOMENON-BASED LEARNING

"The most beautiful thing we can experience is the mysterious. It is the source of all true art and science." — Albert Einstein

The authors say there are three good reasons to buy this book:

1. To improve your students' thinking skills and problem-solving abilities

2. To acquire easy-to-perform experiments that engage students in the topic

3. To make your physics lessons waaaaay more cool

What student—or teacher—can resist the chance to experiment with Rocket Launchers, Sound Pipes, Drinking Birds, Dropper Poppers, and more? The 35 experiments in *Using Physical Science Gadgets and Gizmos, Grades 6–8*, cover topics including pressure and force, thermodynamics, energy, light and color, resonance, and buoyancy.

The phenomenon-based learning (PBL) approach used by the authors is as educational as the experiments are attention-grabbing. Instead of putting the theory before the application, PBL encourages students to first experience *how* the gadgets work and then grow curious enough to find out *why*. Students engage in the activities not as a task to be completed but as exploration and discovery.

The idea is to help your students go beyond simply memorizing physical science facts. *Using Physical Science Gadgets and Gizmos* can help them learn broader concepts, useful thinking skills, and science and engineering practices (as defined by the *Next Generation Science Standards*). And—thanks to those Sound Pipes and Dropper Poppers—both your students and you will have some serious fun.

Grades 6–8

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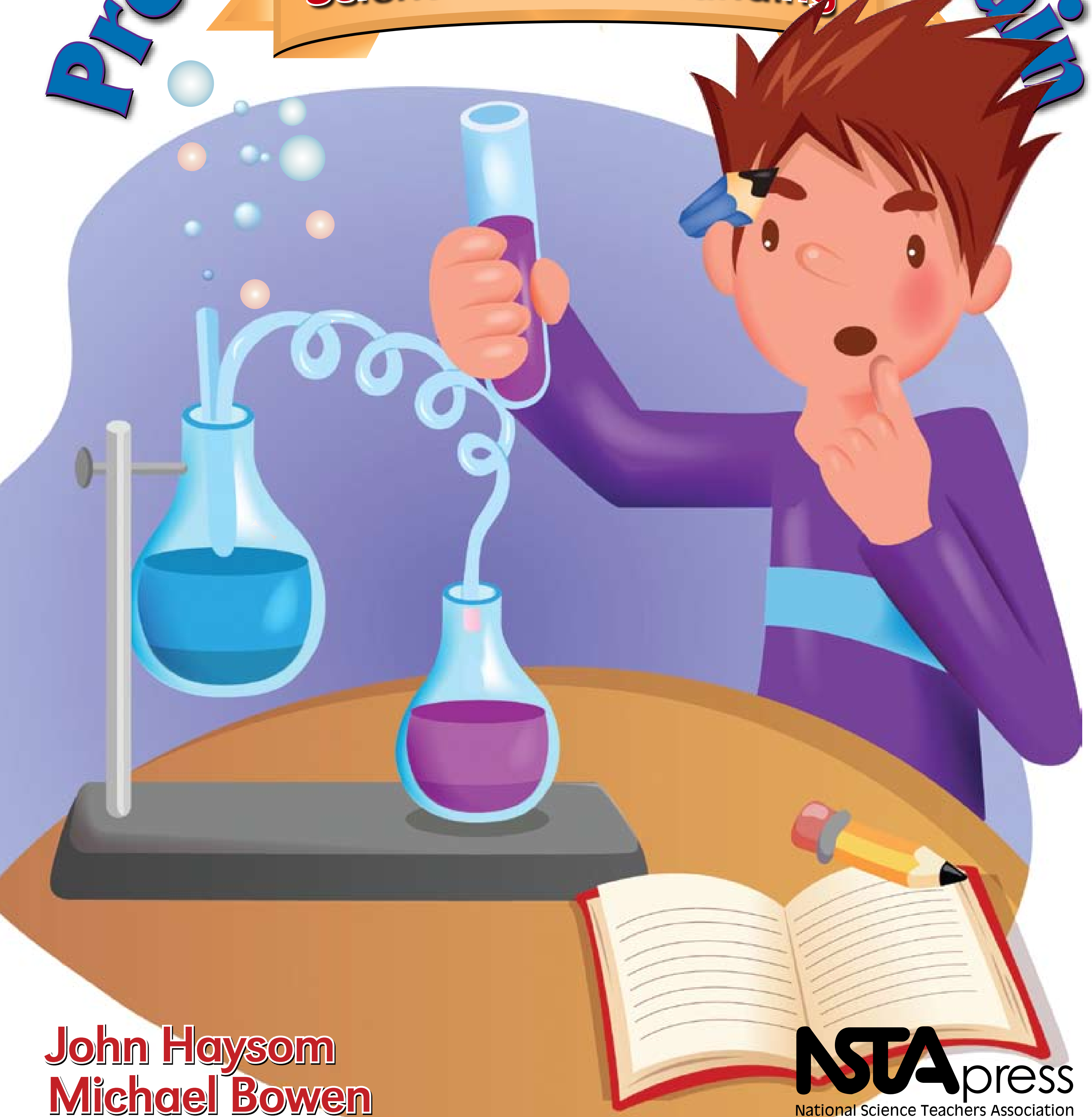
Predict, Observe, Explain

Activities Enhancing Scientific Understanding



John Haysom
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Acknowledgments

The Story of a Curriculum Development Project

This is a brief story of a curriculum project designed to produce learning materials that enhance students' understanding of important scientific concepts. It is not the story of a traditional curriculum project but, rather, of a project designed to involve practicing teachers in a meaningful way. Many teachers contributed in different ways, and this story is an expression of thanks for the efforts they made at different stages of the project. It also acknowledges the help received from science teacher educators in Canada, the United States, Australia, New Zealand, and the United Kingdom.

The story begins at a conference organized by Gaalen Erickson at the University of British Columbia (UBC). It was here that I learned about the power of Predict, Observe, Explain sequences (POEs) from two teacher-researchers, Jim Minstrell and Ian Mitchell. These people unknowingly planted the seed for this project.

Upon returning from my sabbatical at UBC, I made a request to Saint Mary's University for support. Over the course of the next three years, the university provided graduate assistantships to Clayton Coe, Judy Reynolds, Bob Dawson, Nevin Jackson, and Norma MacSween, all practicing teachers who were studying for their master's degrees. I also received invaluable help in the design and preparation of the trial materials from Sue Kent. On reflection, it is easy to recognize that this sort of support is crucial; without it, the project struggled to keep going.

The first task in Year 1 involved the design of sample learning sequences. This began with an extensive and comprehensive search of the research literature on children's scientific ideas. It was carried out by Clayton Coe with the assistance of librarian Doug Vaisey. In many instances, the research procedures used to elicit students' ideas stimulated the design of POE sequences. In addition, we scoured the products of other curriculum projects, especially SciencePlus by the Atlantic Science Curriculum Project, for ideas for activities that would lend themselves to being presented in the form of POEs. In subsequent years, many others contributed their ideas for learning sequences, notably Dick Gunstone and the Monash Children's Science Group.

Even though the learning sequences we had designed were far from perfect, we launched the field testing and evaluation of the materials at the end of the first year. We invited teachers to select a topic they would be teaching and return their evaluation of each sequence they used. The evaluation form was a simple one: We asked the teachers to rate the sequence on a five-point scale, provide their reasons for the rating, and note any problems they encountered when using the sequence, along with suggestions for making improvements. In addition, we had the hunch that the teachers themselves would benefit from using the POEs. Judy and Clayton examined their responses, and many reflected on the way in which they taught science. Here are some sample responses.

> ***POEs have given me more insight into the misconceptions students bring with them into a science class.***
>
> ***They have shown me that it is important for all students to reflect on their understanding of concepts and to verbalize it before and after the POE experience.***

Their findings were presented at a meeting of the Canadian Society for the Study of Education.

In the second year, Bob Dawson and Nevin Jackson focused on field testing and evaluation. Following a number of presentations at inservice meetings, which received enthusiastic responses, we invited the teachers to select a booklet of POEs on a topic they would be teaching. In return they undertook to send their evaluations of each POE they used, together with the students' scripts. However, by the end of the year, the return had been patchy, especially regarding the students' scripts. We attributed this to the demands we were making on the teachers' time, especially regarding the photocopying of the student worksheets.

As a consequence, in Year 3, we made contracts with a number of committed teachers and provided workbooks for all their students. Chuck McMillan, Bill Reid, and Frances Wallace undertook the bulk of the testing. This worked very well, even though we were unable to test all the POEs and we finished up with a pile of workbooks about two meters high. Norma MacSween began analyzing these. This project—coupled with revising the materials, checking the literature, and preparing for publication—proved to be an enormous task.

The writing of this book was brought to fruition when I renewed a long-standing professional relationship and brought my former student Michael Bowen on board to work with me in finalizing the POEs, organizing the writing, sourcing reference literature in the teaching guides, and honing the final text and images.

In addition to the people mentioned above, I would like to acknowledge the invaluable efforts of all of those who have assisted in this project. They have all helped bring together curriculum development, classroom teaching, and education research in a way that we hope will make an important contribution to science education.

—John Haysom

Using POE Sequences

POE sequences provide an important way to enhance your students' understanding of important scientific ideas. We believe that POE sequences are an important tool in every science teacher's repertoire. If you are teaching a traditional curriculum, one based on a textbook, the sequences can enliven the enrichment you provide. If you are teaching an activity-based curriculum, they can help provide a firm basis for understanding. POEs are based on a sound theoretical foundation that has been researched extensively.

Children live in a world of sense impressions. They see, hear, smell, touch, and taste. From infancy they spontaneously make sense of the world in which they live. They form concepts and try to link one concept with another to explain the world around them. For example, they might come to think that matter disappears when substances dissolve or burn, or that plants take in food through their roots, or that heavy objects such as stones or nails sink, or that heavy objects fall more quickly than lighter ones. They find such ideas useful in their lives. The idea that children—or all of us, for that matter—construct such understandings of the world is fundamental to the constructivist view of learning.

Scientists also try to make sense of the natural world of sense perceptions. This is their collective mission. They do this deliberately and carefully. They extend our sensory world by using instruments to measure mass, length, and time more accurately. They use instruments to measure the large and the small, the hot and the cold, the soft and the loud, and so on, to enhance our sensitivity. They expand the natural world by carrying out experiments, enabling them to observe phenomena that do not occur naturally. They formulate concepts such as density and gravitational force and arrive at powerful generalizations, such as that an object floats when its density is less than that of the liquid in which it is immersed, or the acceleration of all falling objects is the same in a vacuum.

There are thus two types of interpretations of the world in which we live: everyday, commonsense interpretations and those of the community of scientists. It is part of a science teacher's job to help each student build on everyday, commonsense interpretations so that the student can adopt and internalize scientists' interpretations. This can be a very challenging task, especially when the scientific interpretation is at odds with students' interpretations. For example, some students believe that electricity gets used up as it goes around a circuit, or that vacuums suck. These ideas have worked well for the students concerned. So why should they change their ideas now?

How can the science teacher respond to this challenge? A variety of teaching strategies have been developed to complement the constructivist view of learning. As you would expect, they have many features in common. The POE sequences we have developed embrace many of these features. They are included in the suggestions for using the POEs that follow. As you read about the steps in the sequence, you might find it useful to refer to one or two POEs to provide examples.

Step 1: Orientation and Motivation

The POE usually begins by drawing on the students' past experiences or previous understanding and raises a challenging question that can be addressed through the experiment that follows. A few minutes of full-class discussion will provide the students with the opportunity to reflect on their past experiences and understanding.

Step 2: Introducing the Experiment

Introduce the experiment. Linking it to the previous discussion will help make it meaningful.

Step 3: Prediction: The Elicitation of Students' Ideas

Before doing the experiment, ask the students to write down on the worksheet what they predict will happen, along with the reasons for their predictions. This exercise is valuable for both the students and the teacher. Making their reasons explicit helps the students become more aware of their own thinking. It also provides the teacher with useful insights and an opportunity to plan ahead. Hence, while students are writing, you might stroll around so as to prepare yourself for the discussion that will follow.

Step 4: Discussing Their Predictions

This is a two-stage process. First, ask your students to share their predictions in full-class discussion, using a chalkboard or SMART Board to highlight the range of predictions and reasons for them. This needs to be handled with sensitivity on account of some students' feeling anxious about seeming "wrong." Hence, you will need to be supportive and encourage as many students as possible to express their viewpoints. There are no poor ideas! All ideas are valued because they represent our best efforts to make sense of the world. You might explain that making our predictions explicit helps us learn.

After this has been done, you might invite the class to discuss which predictions and reasons they now think are best. When students reconsider their reasons, some may begin to change their minds and reconstruct their thinking. Immediately prior to the experiment, it's often fun and illuminating to have a straw vote about the outcome.

Step 5: Observation

Most of the experiments in this book are designed to be done as demonstrations, although some make good student explorations. If you demonstrate the experiment, invite the students to help out whenever appropriate. Ask them to write down their observations.

Step 6: Explanation

Students often reshape their ideas through talking and writing. We have frequently found that it's useful for students to discuss their explanations of what they observed with a neighbor or in a small group before formulating a written explanation. They seem to find this action reassuring. After they have done this, collect a sample and invite a full-class discussion of these as appropriate.

Step 7: Providing the Scientific Explanation

Introduce the scientific explanation by saying, "This is what scientists currently think," rather than, "This is the right explanation." Many teachers choose to ask their students to write the explanation in their notebooks or on the back of their activity record sheets. The students might then be invited to compare their explanations with those of scientists, looking for similarities and differences (another opportunity for them to reconstruct their ideas).

Step 8: Follow-Up

Researchers have found that students' ideas often are resistant to change and there is no guarantee that a POE will do the trick, even though it might provide a valuable beginning. This also was evident in the field testing, when student explanations before and after the experiment were compared. Hence, in some POEs, we have included a follow-up at the end. This often is designed to help the students reconsider or apply the scientific ideas they have just encountered and begin to appreciate how useful they are for explaining natural phenomena.

So many steps may seem to make POEs complex and unmanageable, but this isn't the case in practice. The underlying pedagogy resonates with the beliefs held by most teachers, and after a little experience you will probably find the procedure becomes routine for both you and your students. This is liberating and will enable you to focus your attention on facilitating learning by responding to your students. Incidentally, many teachers have found that they can complete Steps 1 through 7 in a 40-minute period. Sometimes they take a break after Step 5: Observation, and set the next step for homework.

A major strength of POEs is that they can continuously provide you with insights into your students' thinking: Steps 1 through 4 probe your students' initial conceptions, Steps 6 and 7 enable you to monitor your students' efforts to reconstruct their thinking, and Step 8 provides you with feedback on your students' progress. POEs thus can offer you "authentic responses" from your students, provided that judgment and assessment do not come into play. It's important, therefore, to encourage your students to share their thinking, which for the time being may or may not be scientifically acceptable, and to value their responses. In this way, it becomes possible for you to adjust the pace of your teaching and to plan for subsequent instruction, thus optimizing your effectiveness.

The Teacher's Notes

Alongside each POE, you will find the scientific explanation; students' explanations: field experience; students' explanations: research findings; and apparatus and materials.

Scientific Explanations

We have tried to express these in a student-friendly form, one you might choose to use in Step 7.

Students' Explanations: Field Experience

These might well be worth reading before you use the POE because they can help you anticipate what your students might say. Even though your class of students will be unique, it could well be that they will have similar ideas to those we have found. On account of the way in which the field testing was conducted, it was not possible to provide these students' explanations for all of the POEs. In these cases, we hope you might make time to analyze some of your own students' scripts.

Students' Explanations: Research Findings

The research findings similarly provide you with an idea about the responses that your students might give, and you might find it interesting to check these out not only before but also after using a POE. When you do this, you will be locating your personal experience alongside the body of knowledge about teaching, and this can be professionally enriching.

In most cases, we expect that you will find it sufficient to simply refer to these summaries. However, some teachers, perhaps those engaged in further study, might find it worthwhile to go into greater depth. As was mentioned before, this area has been extensively researched, and literally hundreds of papers have focused on children's ideas. *Making Sense of Secondary Science* (Driver et al. 1994) is a wonderful resource that summarizes the findings through the date of publication. These days, the research literature is much more accessible, and fortunately this has removed much of its esoteric nature. Accessibility of the literature has been made possible by the arrival of Google Scholar. If you have a reference, you may view a summary or abstract of the article simply by filling in a few key words on the Advanced Scholar Search page. Sometimes the whole article is available, but if it is not and the article looks promising, many libraries, especially university libraries, will be able to help you access it. (A comprehensive bibliography of students' and teachers' conceptions and science education up to 2009 by Reinders Duit is available online: *www.ipn.uni-kiel.de/aktuell/stcse/stcse.html*.)

During the field testing, we were intrigued to find many similarities between our experience and these research findings, and it was illuminating to compare the two. Because many of our POEs and elicitation procedures are original, we have incidentally added to these findings. Moreover, we hope that in the future some teachers will take time to analyze their students' scripts, especially where we weren't able to do so, and thus add to this body of work by becoming researchers themselves.

Apparatus and Materials

Teachers often have difficulty acquiring and storing the necessary apparatus. With this in mind, we have tried to keep the requirements simple and have recommended the use of everyday items wherever possible. We would like to offer these two ideas, which may help teachers overcome the problem:

1. You might organize a curriculum night for parents featuring POEs. We are confident they would enjoy participating in a simulation of one or two sequences themselves. At the end, you could solicit their help in acquiring the materials you need, dividing up the apparatus and materials lists between them.
2. We have found that shoe boxes, fish trays, and other similar containers are useful for storing the items needed for most POEs. They can be labeled and kept on a shelf, ready to use at a moment's notice.

Finally, a few comments about your use of the student activity sheets. It is our intention that teachers who own this book should be free to copy the activity sheets for their own students' classroom use. To facilitate this, the publishers selected a binding that makes it possible to easily open the book and keep it flat. However, we gather that in some schools and districts there are strict policies about making limited photocopies. In such cases, many teachers have reported that they copy the student POE pages onto overhead transparencies or PowerPoint slides and have students answer the questions in their notebooks. To us, this would not be as effective for learning; we carefully considered the layout and space allotted for writing to enhance student engagement and provide students with a record of the activity. Nevertheless, it certainly helps overcome the problem.

Reference

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science*. London and New York: Routledge.

Safety in the Classroom Practices

Although most of the experiments are designed to be done as demonstrations, some make very good student explorations. It is important to set a good example and to remind students of the pertinent safety practices when they do perform an experiment.

1. Always review Material Safety Data Sheets (MSDS) with students relative to safety precautions in working with hazardous materials.
2. Remind students to only view or observe animals and not to touch them unless instructed to do so by the teacher.
3. Use caution when working with sharp objects such as scissors, razor blades, electrical wire ends, knives, or glass slides. These items may cut or puncture skin.
4. Wear protective gloves and aprons (vinyl) when handling animals or working with hazardous chemicals.
5. Wear indirectly vented chemical splash goggles when working with liquids such as hazardous chemicals. When working with solids such as soil, metersticks, glassware, and so on, safety glasses or goggles can be worn.
6. Always wear closed-toe shoes or sneakers in lieu of sandals or flip-flops.
7. Do not eat or drink anything when working in the classroom or laboratory.
8. Wash hands with soap and water after doing the activities dealing with hazardous chemicals, soil, biologicals (animals, plants, etc.), or other materials.
9. Use caution when working with clay. Dry or powdered clay contains a hazardous substance called silica. Only work with and clean up clay when wet.
10. When twirling objects around the body on a cord or string, make sure fragile materials and other occupants are out of the object's path.
11. Use only non-mercury-type thermometers or electronic temperature sensors.
12. When heating or burning materials or creating flammable vapors, make sure the ventilation system can accommodate the hazard. Otherwise, use a fume hood.
13. Select only pesticide-free soil—commercially available for plant labs and activities.
14. Many seeds have been exposed to pesticides and fungicides. Wear gloves and wash hands with soap and water after an activity involving seeds.
15. Never use spirit or alcohol burners or propane torches as heat sources. They are too dangerous.
16. Use caution when working with insects. Some students are allergic to certain insects. Some insects carry harmful bacteria, viruses, and so on. Use only biological supply house insects and wear personal protective equipment, including gloves.
17. Immediately wipe up any liquid spills on the floor—they are slip-and-fall hazards.

About the Authors

After completing his doctorate in chemistry at Cambridge University, **John Haysom** taught science in various schools before becoming a member of the faculties of education at five universities: Oxford University, Reading University (United Kingdom), University of the West Indies, Saint Mary's University (Canada), and Mount Saint Vincent University (Canada).

John has gained an international reputation as a teacher educator and curriculum developer. In the United Kingdom, he was coordinator of the groundbreaking Science Teacher Education Project, funded by the Nuffield Foundation. This was probably the first teacher education curriculum project in the world and was adapted for use in Australia, Canada, Israel, and other countries. At the University of the West Indies, he was responsible for the design and implementation of an innovative, theme-based inservice B.Ed. curriculum. As a professor of education at Saint Mary's University, he initiated and helped lead the Atlantic Science Curriculum Project's SciencePlus textbook series. This curriculum was highly rated and became widely adopted in the United States. He has acted as a science curriculum consultant to the government of Trinidad and Tobago and to a number of projects in the United States.

He is the author of many books for teacher educators, teachers, and schoolchildren, as well as academic papers in curriculum design, evaluation and implementation, and teacher education.

Michael Bowen completed his doctorate at the University of Victoria. After studying the research practices of field biologists, he developed a curriculum for middle school students. This was tested with grade 6 and 7 students in the classroom. Following a postdoctoral fellowship in the sociology department at Trent University, he became a member of the faculties of education at three universities: Lakehead University, the University of New Brunswick, and Mount Saint Vincent University (where he is now an associate professor).

Michael's ongoing research has many facets, including studying student learning from participation in science fairs, the development of competency with science inquiry practices in student teachers, and the creation of online communities of learners where participants conduct and share research projects in a science-project-specific social networking site. His research has been presented at national and international conferences in Canada, the United States, and Europe and has been published in journals in jurisdictions throughout the world. The work he is most proud of is that which has been published in professional teachers magazines. His science teacher preparation classes are known for using innovative approaches to teacher preparation.

Understanding Solutions
Chapter 11

Contents

Scientific Explanation

Dissolve means to mix perfectly. When a solid dissolves into a liquid, the particles of the solid intermingle perfectly with the particles of the liquid. The solution is the same all the way through.

When a reaction takes place, a chemical change occurs and new substances (new particles) are formed.

When a substance melts, it changes from a solid state to a liquid. It is still made up of the same particles. You can often get the solid back by cooling the liquid.

	Water	Vinegar	Alcohol
Chalk	nothing (insoluble)	reacts (bubbles)	nothing
Ice	melts	melts and dissolves	melts and dissolves
Sugar	dissolves	dissolves	nothing
Baking soda	dissolves	reacts (bubbles)	nothing

Students' Explanations: Field Experience

This POE was used with a class of 22 grade 7 students at the beginning of their study of solutions.

At the outset, the majority of students (70%) used the word *disappear* in their definitions. Some of the students (20%) included the idea that the solid was still there, even though you couldn't see it.

> ***To disappear but not gone.***

Some students (20%) included the idea of particles in their definitions:

> ***It means that solids like sugar or salt break up into little pieces, not big enough to be seen by the naked eye.***

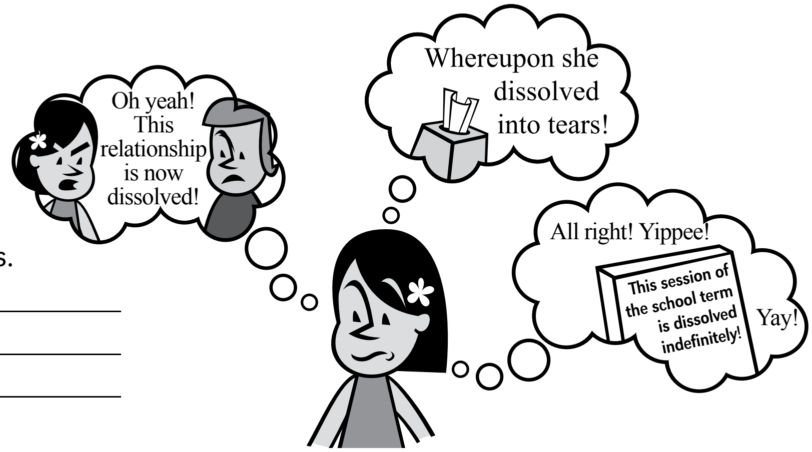
With regard to their predictions, all the students knew that sugar would dissolve in water; most thought it would dissolve in vinegar and alcohol, too. A considerable proportion (more than 25%) thought chalk would dissolve in water and alcohol, ice would dissolve in alcohol, and baking soda would dissolve in water.

During the field testing, the teachers noted that the students really enjoyed doing this as a lab.

Apparatus and Materials

- Test tubes
- Water
- Vinegar
- Ethyl alcohol and/or methyl alcohol (beware poison)
- Sugar
- Baking soda
- Chalk
- Ice

Solution Words



Not a Riddle

Do you know what the word *dissolve* means?

Seriously! Try to put it in your own words.

Predict

Do you know what happens when different solids (on the left-hand side of the table) are mixed with the different liquids (along the top of the table). Put a *D* in the box if you think we should use the word *dissolves* to describe what happens.

	Water	Vinegar	Alcohol
Chalk			
Ice			
Sugar			
Baking soda			

Observe

Let's try some out! What do you see? Keep your eyes open for any differences in the way the solid changes.

(a) baking soda and water ______

(b) baking soda and vinegar ______

(c) baking soda and alcohol ______

(d) ice and water ______

(e) your choice ______

Explain

People in everyday life often mix up the words *dissolve, disappear, disintegrate, react, melt,* and *destroy*. Scientists are particular. When they use the words *dissolve, react,* and *melt,* they mean different things. Which words do you think they would use to describe the following reactions:

(a) baking soda and water ______

(b) baking soda and vinegar ______

(c) baking soda and alcohol ______

(d) ice and water ______

(e) your choice ______

Can you explain the differences between dissolving, reacting, and melting?

So …

What is special about the word *dissolve*?

Scientific Explanation

When the sugar dissolves, it breaks up into very, very small particles, too small to be seen. The same number of sugar particles that were in the solid cube end up being dissolved in the water. Even though some people think of the particles as being "suspended" in the water, they still have weight. Because the weight of the sugar has not changed, the two sides will remain balanced.

Students' Explanations: Field Experience

This POE was used with 50 grade 7 students.

Thirty-two percent (32%) correctly predicted that there would be no change in weight. Fifty-four percent (54%) predicted that the sugar solution would be lighter. Not surprisingly, some thought the sugar would disappear. Others thought the cube would lose trapped air when it dissolved:

> ***... because in the sugar cube there is air causing it to weigh more but once the air is crushed out it will weigh less.***

Others reasoned in terms of the sugar being spread out:

> ***... because the sugar will dissolve and spread out making it lighter.***

Many students gave reasons that were difficult to interpret:

> ***... the sugar molecules are smaller and so they weigh less than the larger ones.***

Fourteen percent (14%) predicted that the sugar solution would be heavier. Some associated this with the solution being more concentrated:

> ***... the sugar particles will get between the water particles and make it heavier.***

The students who predicted incorrectly seemed to have little difficulty constructing the scientific explanation after they had seen the experiment.

Students' Explanations: Research Experience

Driver (1985) has summarized the findings of a number of studies. In one study, two-thirds of English students ages 9- to 14-years-old predicted that the mass of the solution would be less. In another study, more than half of a sample of English and Swedish 15-year-olds similarly predicted that the mass would be less. Some of these students thought the sugar disappeared, others confused mass and volume, and others believed the sugar was still present, but lighter.

Holding, cited by Driver et al. (1995), found that most students at age 12 were able to appreciate that a dissolved substance was still there, but some did not consider the particles to have weight (that the weight of the sugar was now "up in the water," that it was in a "suspended state," and that it was not "pressing down" on the bottom of the container).

Apparatus and Materials

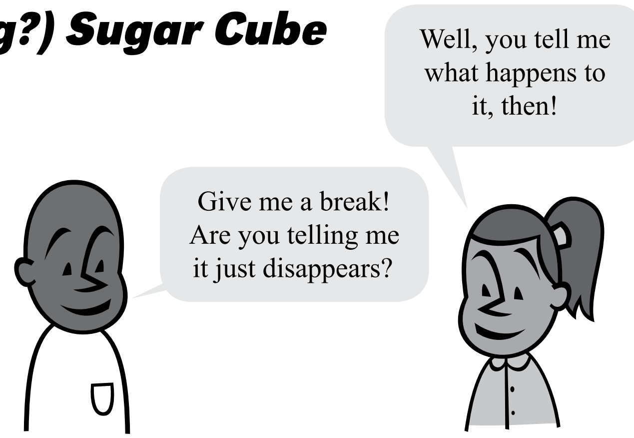
- Sugar cubes
- 2 glasses or beakers
- 2-pan balance
- Watch glass or glass slide
- Source of heat

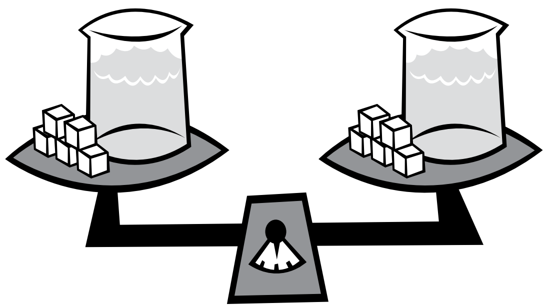
The Dissolving (Disappearing?) Sugar Cube

Magic or Not?
When a sugar cube dissolves in water, is it still there or has it just vanished?

If you can't see it, how do you know it's still there?

Does it still have mass?





An Experiment
Balance a scale with a beaker of water and 5 lumps of sugar on each side.

What do you think would happen to the balance if the sugar on one side is dissolved in the water?

Predict

Please explain your answer.

Observe
Let's give it a try! Take one of the beakers off the balance. Stir in the sugar until it dissolves. Put the beaker back on the balance. What do you see?

Explain
Try to explain what you observed in the experiment.

Try This!
Can you get the sugar back? Gently heat a drop of the solution on a watch glass or a microscope slide. Boil off the water or let it evaporate overnight. What happens?

Scientific Explanation

Filter paper is like a very fine sieve. It consists of wood fibers, lying across one another. The gaps between the fibers are very small indeed.

Chalk dust is far too large to pass through the filter paper and is left behind. Milk particles are smaller and are able to pass through. The particles of copper sulphate, which are blue, are so small (less than one-millionth of a millimeter across) that a solution in water appears to be clear—they pass through the filter paper easily. If the filter paper appears blue after you have filtered the copper sulphate solution, you can wash the remaining solution through the filter with water.

When you make coffee from ground beans, the brown flavored part that we drink dissolves and leaves behind the insoluble dregs or grounds. The clear brown coffee solution can pass through the paper.

Students' Explanations: Research Findings

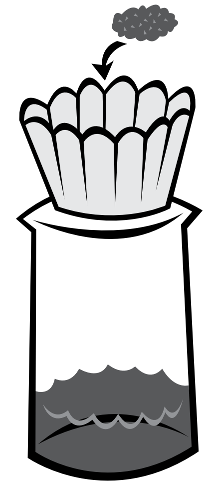
Biro and Zwolanski-Morovic (1992) report that some students predict that the blue color of copper sulphate will be trapped in the filter paper.

Apparatus and Materials

- 3 beakers
- Teaspoon
- Filter funnel
- Filter paper
- Flask
- Copper sulphate
- Milk
- Powdered calcium carbonate (chalk)
- Instant coffee

Note: In addition, you might have a range of other substances available, such as soil and rust (iron oxide), with which you can experiment.

Will It Go Through Filter Paper?



Making Coffee

Have you ever watched filter coffee being made?

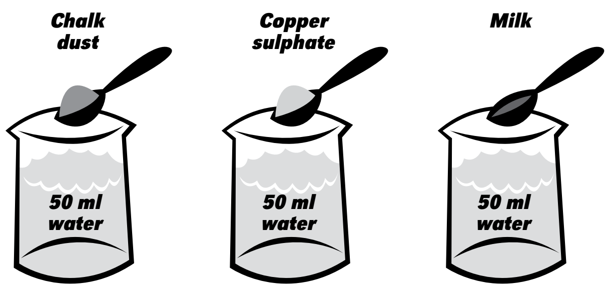
What goes through the filter?

What do you see if you hold it up to the light?

Can you see through it?

What gets left behind in the filter?

How does a filter work?



An Experiment

Put a teaspoon of the following substances into 50 ml water and stir them well: chalk dust, copper sulphate, and milk. Now filter them.

Predict

What do you think will be left behind when each is filtered?

(a) Chalk dust and water mixture ______________________________

(b) Copper sulphate and water mixture______________________________

(c) Milk and water mixture ______________________________

Please give your reasons. ______________________________

____

Observe

Let's do it! What gets left behind? (a) ____________________

(b) ____________________ (c) ____________________

Explain

Why do you think some parts of a mixture can pass through a filter but others can't?

____

____

So?

What happens when you make filter coffee? ______________________________

How about replacing the coffee grounds with a spoonful of instant coffee? We could try it!

____

Scientific Explanation

Milk does not dissolve in water even when you dilute it 1,000 times. However, it is still there—the milk particles are very tiny, too small for the eye to pick up.

You can see them at very low dilutions if you pass a beam of light through the solution. The tiny milk particles scatter some of the light. You might have seen this effect before when a beam of light is scattered by smoke, fog, or dust.

Shining a beam of light through a clear liquid can help you determine if it is truly a solution. If the particles are large enough to reflect light, then it is not a solution.

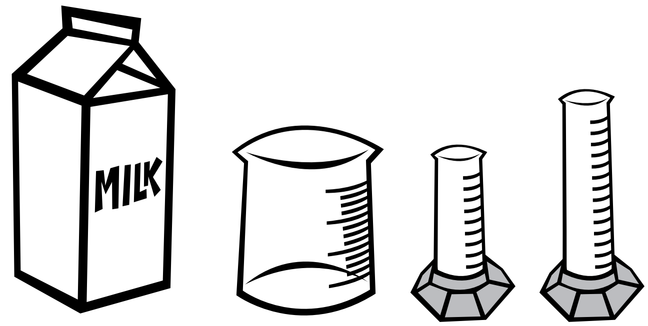
Apparatus and Materials

- 100 ml and 10 ml graduated cylinders
- 2 beakers
- Milk
- Flashlight
- Cardboard with a hole

Note: The Tyndall effect is more readily observed in a darkened room.

Seeing Is Believing? The Milk Mystery

How much can you dilute milk and still see it?



Predict

What's your best guess? Check one[√].

(a) 10 times [ ]

(b) 100 times [ ]

(c) 1,000 times [ ]

(d) More! [ ]

Let's try it! Take 10 ml of milk and tip it into a beaker containing 90 ml of water. This dilutes 10 ml to 100 ml (10 times). Repeat using 10 ml of the already diluted milk. Repeat ... repeat ...

Observe

What did you see?

(a) Diluting 10 times: ____________________

(b) Diluting 100 times: ____________________

(c) Diluting 1,000 times: ____________________

(d) Your choice: ____________________

Explain

Do you think any milk is left after you have diluted it 1,000 times? ____________________

Do you think any milk is left when you can't see it anymore? ____________________

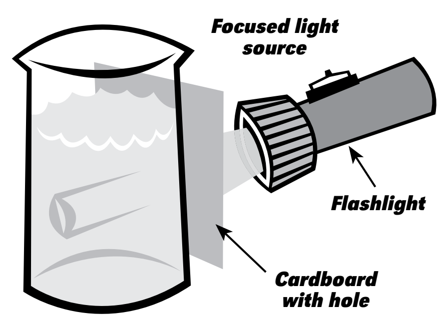
What do you think would happen to a carton of milk if you emptied it into a lake?

____

____

Interesting!

Try shining a flashlight through the most diluted milk you made.



What do you see? ____________________

____

Try to explain what you see. ____________________

____

Now shine the flashlight through tap water and see if there is a difference!

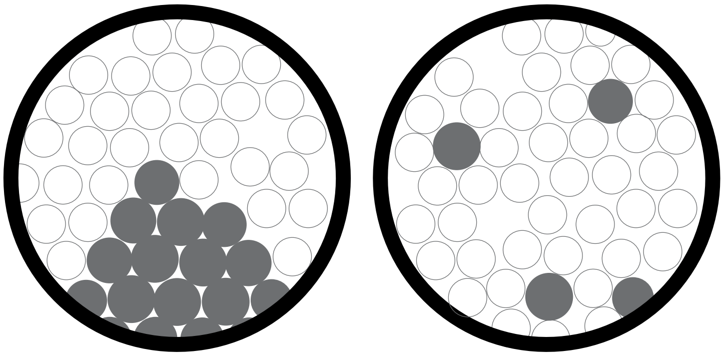
____

Scientific Explanation

Before dissolving: Notice how the solid particles are regularly spaced, with no gaps between them. Solids are like this. In contrast, there are holes between the particles of liquids. It is the presence of these holes that gives a liquid its runny quality.

After dissolving, the solute particles are now fairly evenly (randomly) scattered throughout the solution. This explains why it appears to be evenly colored all the way through.

Note: In this simplified explanation, copper sulphate is considered to consist of one type of particle.



Students' Explanations: Field Experience

An earlier version of this POE was used with 30 grade 7 students. Seventy-five percent (75%) predicted that Dr. Y would see a homogeneous mixture under the "mega microscope":

> ***The particles all moved around and mixed up.***
>
> ***Dr. Y saw that the particles were mixed with the Jolly Rancher (candy) particles.***
>
> ***I think Dr. Y saw tiny dots floating around in the water.***
>
> ***The water broke up the particles and spread them around.***

Students' Explanations: Research Findings

Prieto, Blanco, and Rodriguez (1989) asked students to portray in drawings their images of what a substance in solution would look like. More than two-thirds of grade 7 students perceived solutions as being homogeneous. However, more than half reflected a continuous vision of the dissolved substance.

Stepans and Veath (1994) asked grade 7 students what they would see if they viewed a salt solution through a "giant microscope" that showed the smallest particles. Hardly any students were able to apply particle theory in a scientifically acceptable way.

Apparatus and Materials

- 2 beakers
- Copper sulphate (or any other colored water-soluble substance, such as candy)

Solutions Under the Mega Microscope

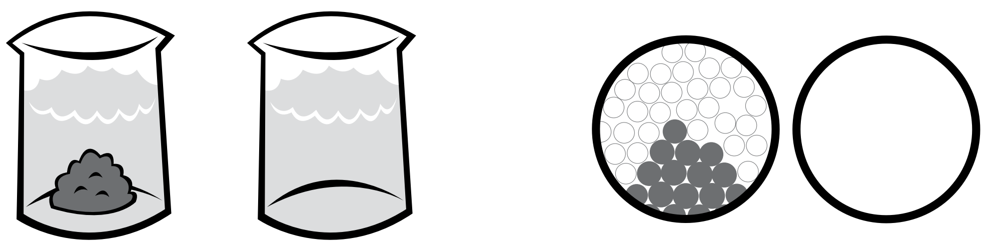
Scientists think all substances consist of very tiny particles. This idea helps them explain many of the things they see happening in this world: water boiling, ice melting, crystals forming, and substances dissolving.

Scientists think these particles are very small indeed. You can't see them—not even with a very powerful microscope. Microscopes can only magnify about 1,000 times. You would need to magnify a million times to be able to see them.

A Future Imaginary Experiment!

In the year 2030, Dr. Y invented the new mega microscope. It magnified a million times! He decided to check up on the way scientists thought substances dissolved.

He took some copper sulphate and put it in some water. He focused the microscope on the edge of the solid. Wow! Check below to see what he saw. Then he stirred the mixture. The copper sulphate dissolved. He looked down the mega microscope again. ...



Predict

What do you think Dr. Y sees under the mega microscope when he looks at the copper sulphate solution? Very carefully, complete his view down the mega microscope (far right).

____

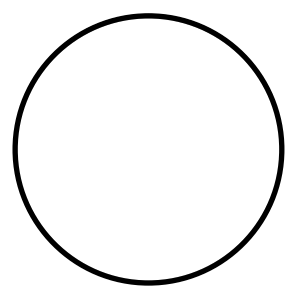
Observe

Describe what happened when we stirred the mixture to dissolve the copper sulphate.

____

____

Complete the diagram after your teacher tells you what Dr. Y saw.



Explain

Use the idea of particles to explain what happens when something dissolves.

____

____

Topic: Solutions **Concept:** Change of volume on dissolving provides evidence for the particulate theory of matter.

Scientific Explanation

When a solute such as salt dissolves, the particles from which it is made are able to move. The particles of solvent and solute are now able to pack together more closely than before. This results in a reduction of volume.

Apparatus and Materials

- Flask (500 ml)
- Stopper
- Pickling salt
- Jar with a top
- Marbles of 2 different sizes (Some teachers prefer to use marbles and sand.)

Dissolving: Is There a Volume Change?

Maybe they are discussing whether there is a change of volume when something dissolves.

Does the volume of sugar plus the volume of water equal the volume of sugar solution?

What do you think?

An Experiment

Cover the bottom of a flask with crystals of pickling salt.

(These crystals are solid—they contain no air.)

Slowly fill the flask with water. Only a little salt will dissolve.

Push in a rubber stopper so the extra water overflows.

Shake it until no more salt dissolves.

Will the volume change?

Does the volume of the salt plus the volume of the water equal the volume of the salty water?

Predict

What do you think will happen? Will the volume change or stay the same?

____

Please give your reasons. ____

____

Observe

Let's do it! What do you observe? ____

____

Explain

Put some marbles in a jar. Fill up the jar with marbles of a different size. Put on the lid and gently shake the jar. Does this help explain what happened in our experiment?

____

____

____

Scientific Explanation

Liquids do not shrink. The particles that they are made from do not shrink. When you mix two liquids, the particles of each intermingle and pack together more closely than before. This is why there is a reduction in volume.

A similar reduction of volume can be seen if you shake a jar containing marbles of two different sizes. If ethyl alcohol or acetone is substituted for methyl alcohol, the reduction of volume is different. You would expect this because the ethyl alcohol and acetone particles are larger than the methyl alcohol particles.

A similar effect can be seen if you change the size of the marbles.

Students' Explanations: Field Experience

During field testing of this POE with grade 7 students, students' predictions appeared to be guesswork, rather than reasoned examples. For example,

> ***... there are just two liquids mixing. (Level stays the same.)***
>
> ***... because the air goes out of the water. (Level drops.)***
>
> ***... because there is a lot of acid in the alcohol and I think it will bubble and overflow.***
>
> ***... because when you shake up pop it overflows. (Test tube overflows.)***

If they are to draw on pertinent understanding, then it would seem to be important for this POE to be put in the context of instruction that is related to the particulate theory of matter. For example, this POE could well follow the previous one, "Dissolving: Is There a Volume Change?"

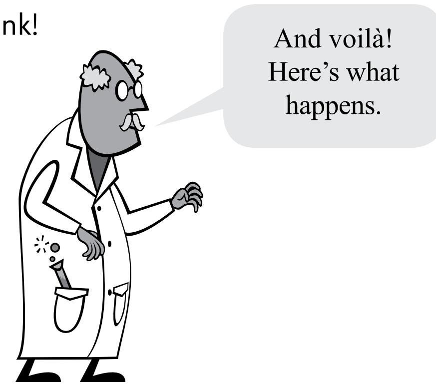
Apparatus and Materials

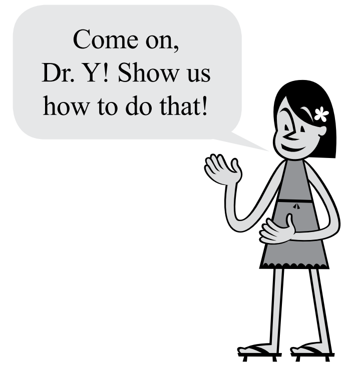
- Test tube
- Ethyl alcohol or methyl alcohol (methyl hydrate) or isopropyl alcohol (rubbing alcohol). You might dye it with food coloring.
- Jar with lid
- Marbles

Note: Some teachers prefer to use sand and marbles instead of two different sizes of marbles.

Mixing Liquids: Is There a Volume Change?

Dr. Y is trying to make liquids shrink!





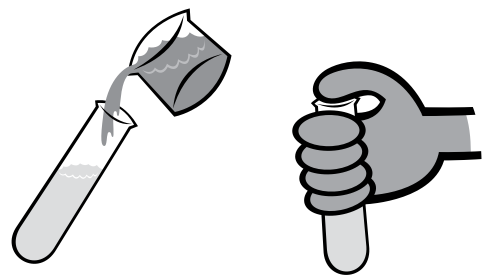
An Experiment

Fill a test tube halfway with water.

Pour some alcohol very carefully down the side of the test tube until it reaches the top.

Try not to mix the liquids.

What do you think will happen to the level of the liquid when it is mixed?



Predict

Check one [√]:

Level stays the same. **[ ]** Level drops. **[ ]** Test tube overflows. **[ ]**

Try to explain your thinking.

____

____

Observe

Let's shake it! What happens?

____

____

Explain

Can you explain Dr. Y's trick? Hint: Think of the water and alcohol as being made up of different-size particles.

____

____

____

Hmm …

What do you think would happen if you shook a jar that contained different sizes of marbles?

____

____

____

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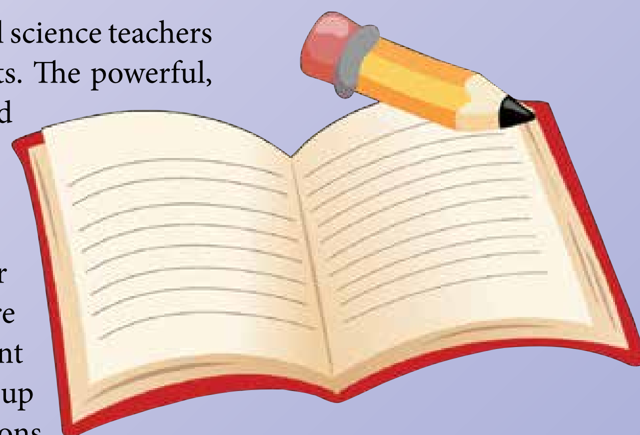
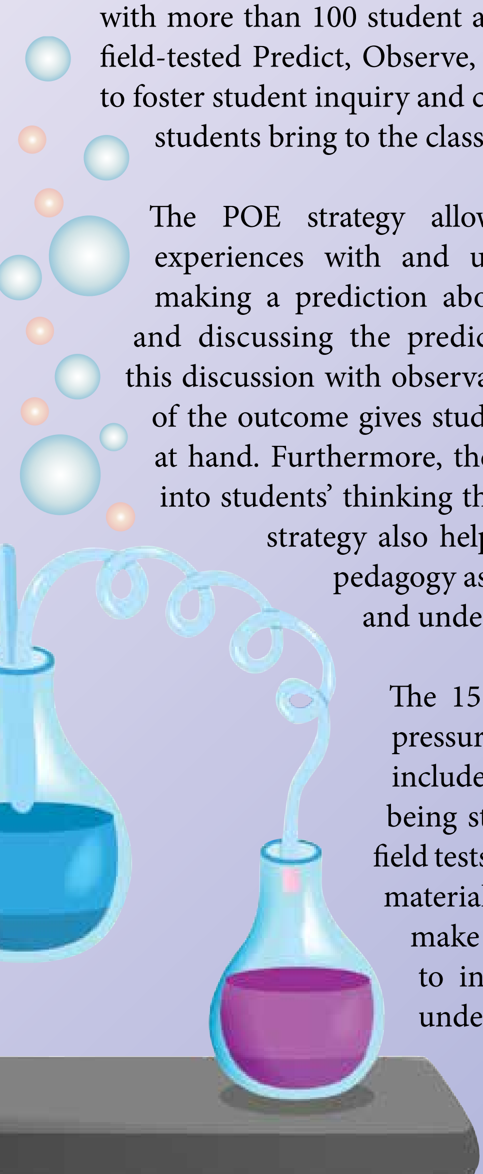
Predict, Observe, Explain

Activities Enhancing Scientific Understanding



John Haysom and Michael Bowen provide middle and high school science teachers with more than 100 student activities to prove scientific concepts. The powerful, field-tested Predict, Observe, Explain (POE) strategy is designed to foster student inquiry and challenge existing conceptions that students bring to the classroom.

The POE strategy allows students to reflect on their experiences with and understanding of a subject before making a prediction about the outcome of an experiment and discussing the prediction with classmates. Following up this discussion with observations and then scientific explanations of the outcome gives students a more in-depth understanding of the subject at hand. Furthermore, the authors' POE strategy helps teachers gain insight into students' thinking throughout the learning process. Practicing the POE strategy also helps preservice teachers who need to develop strong pedagogy as they attempt to engage students in science learning and understanding.



The 15 chapters cover topics such as force and motion, pressure, light, floating and sinking, and solutions. Lessons include worksheets, scientific explanations of the concepts being studied, summaries of student responses during the field tests, synopses of research findings, and lists of necessary materials. In *Predict, Observe, Explain*, Haysom and Bowen make it easy for novice and experienced teachers alike to incorporate a teaching method that helps students understand—and even enjoy—science and learning.

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