High School Sampler

1. Hard-to-Teach Biology Concepts
   Revised 2nd Edition
   Designing Instruction Aligned to the NGSS
   By Susan Koka and Anne L. Tweed

2. Argument-Driven Inquiry in Biology
   Lab Investigations for Grades 9-12
   By Victor Sampaio, Patrick Eshleman, Lessons Glim, Jonathan Graetz, Melanie Hata, Charm Sutherland, and Kristin Wilson

3. It's Debatable!
   Using Socio-scientific Issues to Develop Scientific Literacy
   By Daniel Zoller and Sara Kahn

4. Using Physics Gadgets & Gizmos
   Grades 9-12
   Phenomenon-Based Learning
Included in this collection are:

*Hard-to-Teach Biology Concepts, Revised 2nd Edition*

*It’s Debatable*

*Using Physics Gadgets & Gizmos,*
  *Grades 9–12*

*Argument-Driven Inquiry in Biology*
Hard-to-Teach Biology Concepts
Revised 2nd Edition

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About the Authors

Susan Koba, a science education consultant, works primarily with the National Science Teachers Association (NSTA) on its professional development website, The NSTA Learning Center. She retired from the Omaha Public Schools (OPS) after 30 years, having taught on the middle and high school levels for more than 20 years and then having served as a curriculum specialist and district mentor. Koba ended her service to OPS as project director and professional development coordinator for the OPS Urban Systemic Program serving 60 schools.

Koba has been named an Alice Buffett Outstanding Teacher, Outstanding Biology Teacher for Nebraska, Tandy Technology Scholar, and Access Excellence Fellow. She is also a recipient of a Christa McAuliffe Fellowship and a Presidential Award for Excellence in Mathematics and Science Teaching. She received her BS degree in biology from Doane College, an MA in biology from the University of Nebraska–Omaha, and a PhD in science education from the University of Nebraska–Lincoln.

Koba has published and presented on many topics, including school and teacher change, effective science instruction, equity in science, inquiry, and action research. She has developed curriculum at the local, state, and national levels and served as curriculum specialist for a U.S. Department of Energy Technology Innovation Challenge Grant. A past director of coordination and supervision on the NSTA Board and a past president of her state NSTA chapter, she currently serves NSTA on the Budget and Finance Committee. Other past NSTA work includes serving as the chairperson of the Professional Development Task Force, scope author for the NGSS SciPack currently in development, and the conference chairperson for the 2006 Area Conference in Omaha. She is also a past president of the National Science Education Leadership Association (NSELA) and served as NSELA's Interim Executive Director.

Anne Tweed is the Director of STEM Learning with McREL International in Denver. Her work at McREL is research-based and includes ongoing professional development workshops in the areas of science and standards, assessment systems, effective science and math instruction, and formative assessment. Additionally, she is a co-principal investigator on an IES Formative Assessment project that supports implementation in middle level classrooms and was the co-principal investigator for the recently completed NanoTeach NSF-funded project that supported teachers as they learned about nanoscience and technology content and effective science instructional strategies to help them design and implement lessons focused on this emerging area of content.
Tweed earned an MS in botany from the University of Minnesota and a BA in biology from Colorado College. A 28-year veteran classroom biology and environmental science teacher and department coordinator, Tweed also taught AP Biology and AP Environmental Science in addition to Marine Science and off-campus programs. Tweed is a past president of the National Science Teachers Association (2004–2005). She also served at a District Director and a High School Division Director for NSTA and chaired the 1993 and 1997 NSTA Regional Conferences in Denver. Additionally, Tweed chaired the life science program planning team revising the 2009 NAEP (National Assessment of Educational Progress) Framework for Science. Tweed has been recognized for her work in education and has received the Distinguished Service Award and the Distinguished High School Science Teaching Award from NSTA, and the Outstanding Biology Teacher Award for Colorado; she is also a state Presidential Award honoree.

Anne Tweed has published many articles, authored and co-authored several books (Designing Effective Science Instruction, 2009, NSTA Press), and given more than 250 presentations and workshops at state, national, and international conferences. Tweed has provided numerous webinars and conference presentations on the instructional shifts and changes in lesson design resulting from the Next Generation Science Standards.

Chapter Contributors

Ravit Golan Duncan
Associate Professor of Science Education
Rutgers University
New Brunswick, NJ

Nancy Kellogg
Science Education Consultant
Boulder, CO

Cynthia Long
COO & Director of Education
Ocean Classrooms
Boulder, CO

Brian J. Reiser
Professor, Learning Sciences
Northwestern University
Evanston, IL

Sue Whitsett
eCYBERMISSION Outreach Manager
with NSTA
Biology Teacher (1979–2012)
Oshkosh, WI
Introduction

“Biology has become the most active, the most relevant, and the most personal science, one characterized by extraordinary rigor and predictive power.”
—John A. Moore, 1993

“A pessimist sees the difficulty in every opportunity; an optimist sees the opportunity in every difficulty.”
—Winston Churchill (1874–1965)

Biology is a science in which the curriculum continuously changes. New knowledge and emerging content have an enormous impact on our lives. With each new discovery, biologists develop new questions, which lead to more new knowledge. As biology teachers, we constantly learn new content and develop not only our own understanding of biological concepts but also ways to best teach that content to our students.

In addition, we now have new standards in the Next Generation Science Standards (NGSS; NGSS Lead States 2013) and A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (Framework; NRC 2012) to inform the teaching and learning in classrooms. The NGSS, based on the Framework, bring significant conceptual shifts that must be reflected in our curriculum, instruction, and assessment. These changes, along with continually increasing content, bring new challenges to biology teachers—but these challenges bring opportunity to improve teaching and learning in our classrooms.

This book does not contain a recipe to follow as you plan and deliver lessons. Nor is it a set of predesigned lessons for use in biology classrooms. Instead, it features both an instructional framework you can use as you plan—our Instructional Planning Framework (for a visual representation of the framework, see Figure 1.1, p. 7)—and sets of strategies and resources you can select from to help your students learn. We believe that both new and veteran teachers can use the framework to develop students’ conceptual understanding of hard-to-teach biology topics.

The Next Generation Science Standards were written to emphasize a teaching approach that blends science and engineering practices with disciplinary core ideas and crosscutting concepts. This represents a significant change with implications for teacher knowledge and practices. We recognize that you, as a biology teacher, will need to reflect on your beliefs, attitudes, and instructional approaches to address the shifts
represented in the new documents. This second edition will expand on the previous edition to include the revised thinking and reflection that will be needed for you to make adjustments to your planning and teaching. We recognize that all states are in different places with their review of the Next Generation Science Standards but we hope this second edition will provide a perspective that supports your teaching of important biology ideas. Chapters 5–8 are chapters where the teaching and learning shifts are described from the perspective of contributing authors (who are educators like you). We will take this journey with you as you review your current practices and make adjustments needed to realize the vision for teaching the hard-to-teach biology concepts. One concept from the first edition is repeated to model how an existing unit can be modified to align with NGSS. The four concepts addressed by contributing authors are new to this edition.

We will begin this book by looking at what is known biologically and what is expected in the NGSS. From there we must determine what and how we should teach to develop our students’ biological literacy (essential biology concepts) and appreciation of the living world. Obviously we all want students to understand ideas such as genetic engineering, stem cell research, and evolutionary biology. But for students to learn about genetic engineering, they also must understand how molecules in the cell work and how they provide the genetic information in all living things. To understand stem cells, students have to understand the process of cell division and differentiation. To understand evolutionary biology, they have to understand the processes that produced the diversity of life on Earth. And to understand the new standards, we need to appreciate and implement the intimate relationship among the disciplinary core ideas, the crosscutting concepts, and the science and engineering practices in the NGSS. Making sure that students understand the fundamentals of biology is not a simple process, and therein lies the dilemma we all face.

Learning biology is clearly a struggle for many of our students, as evidenced by biology achievement scores across the country. In other words, if you have trouble teaching your students the basic principles of biology, you’re not alone! What might be the reasons for these difficulties? With the advent of state standards, adoption of NGSS, and high-stakes assessments, biology teachers are finding it difficult to teach in ways that worked for them in the past. A common complaint of both students and teachers is that there is so much content to cover that there is not enough time to do the investigations and activities that engage students with the ideas. Biology teachers know that laboratory experiences help students learn complex concepts (Singer, Hilton, and Schweingruber 2007), yet we get caught up in the attempt to cover so many topics and lists of vocabulary that, on average, students are only provided one laboratory investigation each week. “Science educators have decried the common practice of reading textbooks instead of doing investigations: the former is still alive and well” (Stage et al. 2013). In the classroom, we often focus on the names and labels for living organisms or steps in processes, and our students get lost in details without learning the important, essential biological principles and the scientific practices used to make sense of them.
With this book, we seek to help all biology teachers teach the hard-to-teach biology concepts that are found in the broader high school level, life science, and disciplinary core ideas. Although this book is not about providing teachers with scripted lessons, it does include much that we have learned from our own experiences and from recent research findings, as well as outlined in the NGSS. Science research that focuses on how students learn recommends certain strategies that teachers can use to help develop and implement effective instructional methods. In this book, we do not tackle all the issues in high school biology. Rather we focus on selected research that informs our Instructional Planning Framework.

We realize that teachers’ implementation of selected instructional strategies impacts the effectiveness of a strategy in the classroom. Even with research-based strategies and tools, we need to figure out ways to use them in the best way possible. For example, we know that classroom discourse helps students think about their ideas and supports sense making. But if we just ask students to discuss a question or problem without setting a time limit, establishing the groups they will work with, and determining how they will report-out to the class, then classroom discourse won’t help students make sense of the hard-to-teach biology concepts. And when planning with a focus on NGSS, teaching biological argumentation procedures that incorporate effective discourse strategies makes this a critical practice that also connects to literacy skills.

We love teaching biology, and we want to provide opportunities for you to meet the challenges posed when teaching hard-to-teach biology concepts. We were prompted to write the first edition of this book because guidance for teachers is located in so many different places; our hope was to put all of the findings together into a model that made sense to us and would support your work. Our hope in this second edition is that you are provided one way in which to interpret and implement the NGSS, while still using the best thinking from the first edition. This book presents a framework for planning, shares appropriate approaches to develop student understanding, and provides opportunities to reflect on and apply those approaches to specific concepts and topics. It is more about helping you learn how to improve your practice than it is about providing sample lessons that recommend a “best” way to provide instruction. Clearly, you must decide what works best for you and your students.

Science Education Reform and Conceptual Understanding

At that same time that our students struggle to master biology concepts, many states require students to pass high-stakes tests in order to graduate. Science reform efforts stress science understanding by all citizens; unfortunately, little impact is made on persistent achievement gaps (Chubb and Loveless 2002). However, the current cycle of science education reform that resulted in the Next Generation Science Standards (NGSS Lead States 2013) expects, among other things, meaningful science learning for all students at all
grade levels—that is, students are able to build connections among ideas, moving past recall and into more sophisticated understandings of science. To meet the standards, it is critical that all of us work to implement strategies shown as effective to build these types of student understandings.

We know that serious change takes time, often 7–10 years to move from establishing goals to changing teacher practice and curriculum materials that meet the needs of our students (Bybee 1997). One major obstacle to change is the lack of support for teachers to fully understand ways to teach hard-to-teach concepts (Flick 1997). School structures in the United States do not adequately provide professional support for us to engage in new learning to improve our teaching. We are rarely provided the time to work individually or collaboratively to inquire into our own teaching and our students’ learning (Fisher, Wandersee, and Moody 2000). So what makes current reform efforts any different from those in the past? Perhaps the standards, political influences, and the growing body of research provide an answer.

Hope for change begins with the NGSS because we now have standards that integrate a few core disciplinary ideas with crosscutting concepts and science and engineering practices. Integration of the practices, in particular, aligns with research about conceptual change since it calls for building understanding through models and explanations and requires discourse to argue, criticize, and analyze. With the review and revision process associated with the framework and NGSS documents, the teaching shifts needed to support conceptual change by students have been clearly identified. Brian Reiser identifies the following shifts as important and we will address them in the revised components of Instructional Planning Framework and the invited chapters.

- The goal of instruction needs to shift from facts to explaining phenomena.
- Inquiry is not a separate activity—all science learning should involve engaging in practices to build and use knowledge.
- Teaching involves building a coherent storyline across time.
- Students should see that they are working on answering explanatory questions and not just moving to the next topic.
- Extensive class focus needs to be devoted to argumentation and reaching consensus about science ideas.
- A positive classroom culture is necessary to support teaching and learning where students are intellectually motivated, where they actively share responsibility for learning and where they work cooperatively with their peers. (Reiser 2013)
The next ray of hope is that the political focus on science education has grown even more since the first edition of this book, as evidenced by the federal government’s growing focus on the needs in mathematics and science, which has resulted in increased funding for science education efforts in support of science, technology, engineering and mathematics (STEM) education.

What should directly impact us, as educators, is a growing body of research on teaching and learning in general (Bransford, Brown, and Cocking 1999) and science teaching and learning in particular (NRC 2005; Banilower, Cohen, Pasley, and Weiss 2010; Banilower et al. 2013; Windschitl, Thompson, Braaten, and Strope 2012). Also, we now have access to a considerable body of research on the understandings and skills required for meaningful learning in biology (Fisher, Wandersee, and Moody 2000; Hershey 2004), inquiry (Anderson 2007; Windschitl, Thompson, and Braaten 2008), and the nature of science (Lederman 2007). Finally, there is an increasing understanding of conceptual change (Driver 1983; Hewson 1992; Lemke 1990; Minstrell 1989; Mortimer 1995; Scott, Asoko, and Driver 1992; Strike and Posner 1985; Darling-Hammond et al. 2008), as well as research on common misconceptions and strategies to address them (Coley and Tanner 2012; Committee on Undergraduate Science Education 1997; Driver, Squires, Rushworth, and Wood-Robinson 1994, Mortimer and Scott 2003; NAS 1998; Tanner and Allen 2005).

But hope, by itself, is not a method. Because biology is the most common entry course for science in secondary schools, it is essential that changes in science teaching and learning begin with us, the biology teachers. It is the goal of this book to support your walk down the path to more effective teaching and learning in biology as aligned with the Next Generation Science Standards. Even if your state has not adopted the NGSS, we believe that you will find the suggestions for instructional planning and the strategies recommended helpful.

**Hard-to-Teach Biology Concepts—Why Are They Hard?**

Traditionally students struggle to learn some of the basic ideas taught in high school biology classes. To understand why, we must analyze not only the content itself but also the classroom conditions and learning environment. One concern cited by biology teachers is the “overstuffed” biology curriculum. Because of the sheer amount of information that is taught related to each topic, even good students find it difficult to retain what they learn (NRC 2011b). Because of an emphasis on a fact-based biology curriculum, instruction often relies on direct instruction to cover all of the material. As a result, students have limited experiences with the ideas and rarely retain what they learned past the quiz or unit test.

Certain biology topics are hard for students to learn because students aren’t given the time they need to think and process learning. We must give students multiple
opportunities to engage with biology ideas. Research suggests that students need at least four to six experiences in different contexts with a concept before they can integrate the concept and make sense of what they are learning (Marzano, Pickering, and Pollock 2001; Dean, Hubbell, Pitler, and Stone 2012).

Another reason that there are hard-to-teach (and learn) topics relates to the prior knowledge of our students. High school students are far from being blank slates; they come to us with their own ideas and explanations about biology principles. After all, everyone knows something about biology and our students have had a variety of experiences both as they have grown up outside the school setting and in previous science classrooms. Student preconceptions can be incomplete and students often hold onto them tenaciously. One classic research study was captured in the video A Private Universe: Minds of Our Own (Harvard-Smithsonian Center for Astrophysics 1995). In one segment, researchers asked Harvard graduates where the mass of a log came from. The response was water and nutrients from the soil. Students and even college graduates hadn’t learned the fundamental concept that photosynthesis requires carbon dioxide from the air to manufacture carbohydrates, which are the basis for the vast majority of a tree’s mass.

This example relates to two additional reasons why some biology topics are hard to teach: (1) many biology lessons are highly conceptual and students can’t visualize what is taking place on a microscopic level. And (2) some biology teachers are not aware of strategies that engage students with a scientific way of knowing (Banilower, Cohen, Pasley, and Weiss 2010; Lederman 2007). Such strategies include asking questions, building and using models to explain and argue, inferring from data, challenging each other’s ideas, communicating results, and synthesizing student explanations with scientific explanations.

When we consider these various impeding factors, it is no wonder that students struggle in our biology classes.

Why Aren’t Students Learning?
Science research helps us answer this question.

- Students may not learn because of their learning environments. The meta-analyses of the research in How People Learn: Brain, Mind, Experience, and School (Bransford, Brown, and Cocking 1999) and How Students Learn: Science in the Classroom (NRC 2005) report that the instructional environment must be learner-, not teacher-, centered. Students come to school with conceptions of biological phenomena from their everyday experiences and teachers need to take into account such preconceptions. Furthermore, what we teach is often too hard for students because they lack the necessary backgrounds on which the hard-to-teach topics are based.
Several studies have shown that high school students perceive science knowledge as either right or wrong (NRC 2005). Unfortunately, biology concepts are rarely this clear-cut and the body of knowledge in biology is ever-changing. Biological systems are dynamic, and long-term observations are often needed to understand and make sense of the evidence. The norm in many classrooms, however, is to come up with a correct answer, which is not reasonable or possible in biology classrooms, where we look at probabilities, changes over time, and trends. Quantitative and qualitative data can be ambiguous. This can be very uncomfortable for students who ask us, “Why don’t you just tell me the answer?” While biologists, like other scientists, give priority to evidence to justify explanations, students think that we should have the answer to biology questions and problems. Students may believe that biology is really a collection of facts because we often use direct instruction to cover the biology facts and vocabulary that may be addressed in state assessments.

Students learn best when they are able to work collaboratively with other students. With only one investigation per week in the average biology classroom, students may not receive sufficient opportunities to engage in interactive work, where, as explained in the NGSS documents, learning should be driven by questions about the phenomena and ideas.

Organization of the Book

Hard-to-Teach Biology Concepts: Designing Instruction Aligned to the NGSS is designed to support biology teachers as they plan and implement NGSS-aligned lessons that will intellectually engage students with the biology concepts that most students find challenging. To develop successful learners, teachers must identify prior student conceptions and research-identified misconceptions related to the concept being taught and then select instructional approaches to dispel those misconceptions and promote students’ conceptual understanding.

The book is made up of two parts: Part I, The Toolbox: A Framework, Strategies and Connections (Chapters 1–4), and Part II, Toolbox Implementation: The Framework and Strategies in Practice (Chapters 5–8). In Part I, we share our instructional planning framework and tools and outline the connection between our framework and the NGSS. In addition, we share a process to implement our framework and describe other connections that enhance learning by all students. Chapter 1 introduces our research-based framework to address conceptual change—the Instructional Planning Framework—and gives an overview of (1) the identification of conceptual targets and preconceptions, (2) the importance of confronting preconceptions, (3) sense-making strategies to address preconceptions, and (4) best ways in which students can demonstrate understanding. Chapter 2 outlines some of the major instructional shifts in the
Introduction

NGSS and the connections of the standards to the instructional framework. It also introduces a process to use during development of instruction. Chapter 3 uses the topic Proteins and Genes to model the process outlined in Chapter 2 and discusses specific instructional approaches that teachers might use to dispel preconceptions: metacognitive approaches, standards-based approaches, and specific strategies for sense making. Chapter 4 introduces research related to formative assessment, the Common Core State Standards, STEM, and Universal Design for Learning (UDL) and then builds connections for each to the unit of study developed in Chapter 3. Though our framework can be followed in a linear manner, it is not really intended as a stepwise process. Instead, it is important for you to reflect on the framework presented in Chapter 1, adapt it for your use, and select strategies from Chapter 3 most appropriate for your own classroom.

Part II is organized to model use of our framework through its application in the analysis of four additional hard-to-teach topics not covered in the first edition of this book. The topics were carefully chosen to include those related to each of the NGSS disciplinary core ideas. Each chapter is developed based on Part I, but through the interpretation of a contributing author. Recommended resources, including technology applications and websites, will be found at the end of each chapter in Part II. The Part II chapters focus respectively on the following disciplinary core ideas:

- Chapter 5: From Molecules to Organisms: Structures and Processes
- Chapter 6: Ecosystems: Interactions, Energy, and Dynamics
- Chapter 7: Heredity: Inheritance and Variation of Traits
- Chapter 8: Biological Evolution: Unity and Diversity

The appendixes found in the NGSS enhance our understanding of our framework and its application. We will discuss several of this book's appendixes in Chapter 4 when we address connections to NGSS.
Chapter 7

Variations of Traits

By Ravit Golan Duncan and Brian J. Reiser
“Genetics is to biology what atomic theory is to physics. Its principle is clear: that inheritance is based on particles and not on fluids. Instead of the essence of each parent mixing, with each child the blend of those who made him, information is passed on as a series of units. The bodies of successive generations transport them through time, so that a long-lost character may emerge in a distant descendant. The genes themselves may be older than the species that bear them.”

—John Stephen Jones 1999, p. 115

About the Authors

By way of introduction, we would like to provide the reader with a sense of who we are and what expertise and relevant experiences we bring to the writing of this chapter. We are educational researchers who focus our research on the teaching and learning of science. Both of us have extensive expertise in developing inquiry-based curriculum materials in biology for the middle and high school grades. An integral part of our research involves working closely with teachers and students, to implement innovative instruction in the science classroom. Teachers nationwide from grades 4–12 have used the curriculum materials we have developed over the years.

In addition to expertise in curriculum design, Ravit Duncan also brings content expertise. She has a graduate degree in molecular biology and has studied the learning and teaching of genetics in grades 6–16 over the past decade. In collaboration with colleagues she has developed a learning progression in genetics that lays out a roadmap describing how students’ knowledge of genetics should develop across grades 5–10.

Brian J. Reiser’s research over the past two decades has involved the interweaving of scientific practices such as modeling, argumentation, and explanation with core content ideas in biology. Reiser was a member of the National Research Council committees authoring the reports Taking Science to School (2007) which provided research-based recommendations for improving K–8 science education; A Framework for K–12 Science Education (2012), which guided the design of the Next Generation Science Standards; and Developing Assessments for the Next Generation Science Standards (2014). Reiser co-led the development of IQWST (Investigating and Questioning our World through Science and Technology), a three-year middle school curriculum that supports students in science practices to develop disciplinary core ideas.

We believe that the Next Generation Science Standards hold the promise of a much brighter future for science education and a science-literate public in the United States.
Therefore, we are dedicated to helping teachers understand these standards and be able to employ effective teaching strategies to support their students in achieving them. We hope this chapter provides you with useful insights and tools for teaching genetics.

**Overview**

The disciplinary core ideas (DCIs) for heredity (LS3) focus on two fundamental aspects of genetics that are important to understand both from the perspective of scientific literacy for civic and personal engagement, and in preparation for STEM careers. The first aspect relates to the cellular and molecular mechanisms by which genes bring about our physical traits, in essence the gene to protein connection discussed in Chapter 3. This aspect deals with genetic mechanisms within an individual and explains how the genes we have (once we inherit them) result in our traits. The second aspect relates to the passing of genetic information across generations and the mechanisms involved in generating variations of genes and traits. In this chapter we will focus primarily on this second aspect, as described in the NRC Framework and NGSS-LS3B: Variation of Traits. Using the Instructional Planning Framework we will establish developmentally appropriate learning targets, figure out what performances can be expected of students who achieve these targets, and develop a coherent storyline and corresponding instructional sequence to support student engagement with the learning targets. There are many possible ways to develop instruction about the heredity DCI. We provide but one example of our own thinking process with the aim of making explicit the kinds of decisions and trade-offs involved in operationalizing the 10 stages of the framework in relation to this core idea.

**Why This Topic?**

The authors of the NRC Framework had good reasons for selecting heredity as a DCI. Scientific achievements, both theoretical and technical, in the field of genetics over the past few decades have been tremendous. These accomplishments have made headlines, spurred public debate, and resulted in many practical applications that citizens may encounter in their everyday lives. As a few examples: screening tests for a variety of genetic disorders are a fairly routine feature of obstetrics care; gene therapy methods have also been gaining some success with a few types of inherited cancers, retinal disease, and severe combined immunodeficiency; and sequencing of one’s genetic material is now commercially available in many countries. What seemed like substance of science fiction 30 years ago is now within reach of ordinary citizens. We are wielding considerable power in our ability to manipulate genetic material, and with great power comes great responsibility.

The public needs to be educated about the meaning of these tremendous discoveries and technologies, as well as their shortcomings and the ethical issues that surround them (e.g., Billings et al. 1992; Feldman 2012). For example, research has shown that
most high school graduates do not possess sufficiently sophisticated understandings in genetics to provide truly informed consent to the use of genetic technologies (Condit 2010; Miller 2004, Mills Shaw, Van Horne, Zhang, and Boughman 2008). As science educators, we must take part in the effort to help the next generation of citizens develop understandings in genetics that will be powerful and generative such that they can use them to reason about genetic phenomena and technologies that they may encounter in their lives now and in the future.

Phase I: Identifying Essential Content

Stage I: Identify DCI, Practices, and Crosscutting Concepts

We began our process of identifying the DCI, practices, and crosscutting concepts, with a close examination of the DCI as described in the NRC Framework and the relevant high school-level NGSS performance expectations (shown below).

By the end of grade 12. The information passed from parents to offspring is coded in the DNA molecules that form the chromosomes. In sexual reproduction, chromosomes can sometimes swap sections during the process of meiosis (cell division), thereby creating new genetic combinations and thus more genetic variation. Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. Environmental factors also affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus the variation and distribution of traits observed depend on both genetic and environmental factors. (NRC 2012, p. 160)

The first point to note is that there are some important differences between the specifications in the NRC Framework and the PEs of the NGSS (see Figure 7.1). While the Framework’s expectations for grade 12 are directly relevant to our topic of variation of traits, the PEs include some ideas that are not. Specifically, the PE HS-LS3-1 is a combination of several ideas, not all of which are relevant to the concept of genetic variation. This PE includes ideas from LS3-A, which deals with the connection between genes and proteins (see Chapter 3) as well as LS1-A, which includes two ideas: (a) all organisms contain genetic information in the form of DNA molecules, and (b) genes are regions in the DNA that code for the formation of proteins. The latter idea here (b) is also about the gene-protein connection. For our topic we will not tackle the gene-protein connection and the parts of the PE HS-LS3-1 that deal with this connection. Rather we will assume that content relevant to the proteins and genes topic will be a separate unit as described in Chapter 3. We assume that students will have studied that unit.
prior to this one, and will have figured out how genes determine the characteristics of organisms through proteins.

**Figure 7.1**

**NGSS Performance Expectations for Heredity**

<table>
<thead>
<tr>
<th>HS-LS3</th>
<th>Heredity: Inheritance and Variation of Traits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students who demonstrate understanding can:</td>
<td></td>
</tr>
<tr>
<td><strong>HS-LS3-1.</strong> Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring. (Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanisms of specific steps in the process.)</td>
<td></td>
</tr>
<tr>
<td><strong>HS-LS3-2.</strong> Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors. (Clarification Statement: Emphasis is on using data to support arguments for the way variation occurs.) (Assessment Boundary: Assessment does not include the phases of meiosis or the biochemical mechanisms of specific steps in the process.)</td>
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<tr>
<td><strong>HS-LS3-3.</strong> Apply concepts of statistics and probability to explain the variation and distribution of expressed traits in a population. (Clarification Statement: Emphasis is on the use of mathematics to describe the probability of traits as it relates to genetic and environmental factors in the expression of traits.) (Assessment Boundary: Assessment does not include Hardy-Weinberg calculations.)</td>
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Examination of the DCI and PEs suggests that in terms of our topic (how variation in traits occurs) the focus is on four important sources of genetic variation that can arise between individuals even from the same parents: (a) independent assortment in sexual reproduction (HS-LS3-1); (b) chromosomal recombination (HS-LS3-2); (c) mutations due to random errors in DNA replication (HS-LS3-2); and (d) environmental sources of variation, namely mutation and influence on gene expression (HS-LS3-2). It is important to note here that the idea of independent assortment (captured in the first bullet) was part of the expectations for the end of middle school:

Sexual reproduction provides for transmission of genetic information to offspring through egg and sperm cells. These cells, which contain only one chromosome of each parent’s chromosome pair, unite to form a new individual (offspring). Thus offspring possess one instance of each parent’s chromosome pair (forming a new chromosome pair). Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited or (more rarely) from mutations. (NRC 2012, p. 159)

Thus, at the end of middle school, students should be able to explain how having two alleles (one from each parent) can explain how parents can have an allele for a trait that is not expressed in their own phenotype, but can pass that trait on to progeny.

At the high school level supplementary mechanisms for generating variation in traits are added to students’ developing understanding of this idea. However, at both the middle and high school level the goal is to understand meiosis, the cellular process for generating sex cells, at the input-output level. That is, the focus is on understanding
how meiosis helps explain how variation between siblings can arise, and how sexually reproducing species combine genetic material without doubling the amount of genetic material in subsequent generations. The NRC Framework and the NGSS do not call for a focus on the steps of the process. This is a really important point that we wish to emphasize. Much of current instruction, often driven by textbooks, includes an extensive focus on the steps of the process (Kurth and Roseman 2001). This focus on detail and the specific steps in meiosis does not result in a deeper understanding of what the process accomplishes; students still struggle to reason about the implications of this process for inheritance (Freidenreich, Duncan, and Shea 2011).

Another interesting point to note is the way the role of the environment is discussed. There are actually two ways in which the environment impacts traits. The first is by mutating the DNA. This is similar to the random errors generated in DNA replication, but in this case the errors are due to the involvement of mutagens—substances that can alter DNA and thus enhance the rate of mutation. The specific mechanisms by which mutagens act (for example, the generation of thymidine dimers by UV light) are not part of the expected understandings. Rather the idea here is that there are two types of mutations, spontaneous errors in replication and errors due to harmful mutagens in the environment.

The second way in which the environment influences our physical appearance is by impacting the expression of traits. Here too the story can get very complicated and there are many different ways in which trait expression can be altered, these fall into the growing field of epigenetics. A simple example is the phenomenon of tanning. While almost all individuals can tan to some extent, the resulting skin color is a factor of both our genes and the extent to which we expose our skin to UV rays. Tanning is mediated by the activation of genes that ultimately enhance the production of melanin—the pigment that gives skin its brownish color. Similarly to the mutagen story, the NRC Framework expects students to be able to explain how, at the phenomena level, the environment can influence an organism’s characteristics that are partially determined by genes. The actual mechanisms are not part of the story for even high school students. However, the focus on the role of the environment in genetics is emphasized to a greater extent in the NRC Framework and NGSS compared to prior standards (NRC 1996; AAAS 1993). This is a welcome and important shift given students’ tendency towards genetic determinism (Dougherty 2009); more on this in the section on students’ alternative conceptions and conceptual challenges.

The last PE stated in the NGSS for this core idea is about explaining the distribution of traits in a population. This PE does not directly relate to how variation in traits is generated, the focus of our topic. We have therefore chosen not to address it as part of our topic. Ideas about population genetics may be a better fit as part of a unit on evolution or as its own unit.

Now that we have a sense of the content for heredity, let’s turn our attention to the practices and crosscutting concepts. The NGSS provide some suggestions for relevant
practices: asking questions, defending claims with evidence, and developing explanations. These three practices are fairly complementary and dovetail nicely with each other. In addition, we plan to bring in the practice of developing and using models, since our ultimate goal is for students to develop a model for how variation occurs and use it to explain phenomena. We can develop our instructional activities (in the next phase) by engaging students with phenomena that will raise questions and require the development of an explanation. To support the development of the explanation, we will provide evidence. (More on this later in the chapter.)

In terms of crosscutting concepts there are two that seem most conducive to our topic: Patterns, and Cause and Effect. Since we are trying to explain relationships between genes and phenotypes, in particular patterns of association between these, the “patterns” concept is pertinent. While we noted there is a limited emphasis on the biochemical and molecular mechanisms involved in the generation of variation, there is still a sufficient role for mechanisms at the cellular level to merit attending to the mechanism and explanation concept. Structure and Function is another crosscutting concept that we considered. However, this concept seemed to fit better with the first part of LS3 detailing how genes bring about their effects in the organism. If our focus is on sources of variation, then structure and function relationships are less crucial, although they are still relevant and may gain some attention in the instructional sequence. Energy, Systems, Scale, and Change were also less clearly relevant to our topic.

We now have our relevant ideas, practices, and crosscutting concepts identified and we are ready to move on to the next stage: unpacking the DCIs into specific learning targets that include the practices and crosscutting concepts and developing the storyline for instruction.

**Stage II: Deconstruct DCIs, Create a Storyline, and Align With Practices and Crosscutting Concepts**

In some ways we have already started the unpacking process in the prior section in terms of identifying critical boundaries, namely, what is not included in the expectations for learning. We feel that it is just as crucial to identify the limits of what we should be teaching as the core, or essential understandings. Thus our topic is defined by both what is at the center and what is out of bounds.

We unpacked the sources of variation into the following learning targets:

1. DNA is the information-encoding molecule in our body that makes up chromosomes. The molecular structure of DNA enables it to encode instructions for making proteins in the sequence of nucleotides that make up the DNA molecule. Changes to this sequence can alter the instructions and result in substantive changes to traits (mostly detrimental but occasionally beneficial). The molecular structure also affords accurate replication so that the information can be passed on to future generations.
a. DNA is made up of two strands, each composed of smaller building blocks called nucleotides of which there are four types (ATGC).

b. The A-T nucleotides can bind to each other, as can G and C, thus the two strands are connected by bonds between A-T and G-C on opposite strands.

c. DNA is packed into structures called chromosomes. It is these chromosomes that are segregated into sex cells in the process of meiosis.

2. During the process of meiosis, chromosomes can swap parts. This results in additional shuffling of alleles and more variation (unlinking of allele variants of genes that were on the same chromosome).

3. Mutations due to random errors in DNA replication also generate genetic variation that leads to variation in traits.
   a. DNA is replicated by splitting the double strand and building complementary strands to each of the existing strands. This process thus makes use of the DNA strand as a template, increasing the accuracy of the process.
   b. However, errors do still occur and these can result in substantial changes to the information encoded (recipes for proteins).
   c. There are proofreading mechanisms in the cells that catch some of the errors of replication, but not all of them.

4. The environment can also impact genetic variation:
   a. Either by mutating the DNA (chemical mutagens found in the environment),
   b. or by influencing which genes are activated in the cell.

The first learning target builds on what students learned about genes in middle school, specifically, the idea that individuals have pairs of chromosomes each with many genes and particular alleles of those genes, and that these influence traits by determining which proteins are made.

At the high school level students delve further into the molecular level to understand how genes influence traits, and we want them to understand that DNA is the information-carrying molecule that makes up the chromosomes they learned about before, and to be able to reason about how the structure of that molecule enables it to encode information. In terms of boundaries the NGSS and NRC Framework do not expect students to know the detailed structure of the DNA molecule. The focus is on how that structure of DNA affords encoding of information that influences the organism’s traits. This presents a significant departure from current teaching in most high schools. It seemed unrealistic to us that teachers would be willing to forgo teaching about the structure of DNA entirely, we therefore surmised that some compromise
is needed. In the *Framework* and NGSS, the key ideas about DNA structure are those needed for understanding how the genetic code is “read,” and how DNA is replicated in ways that minimize errors; namely, the complementary base pairing of the double stranded molecule. We do not think that additional details about DNA structure, such as the phosphate backbone, the 3 and 5 prime ends, or the chemical structure of the nucleotides, are necessary. This instructional design decision involved a critical trade-off—balancing the addition of ideas beyond what is specified in the NGSS while not derailing the intent of the NGSS to focus on a few core ideas. We strongly agree with the NRC *Framework’s* position regarding the need to substantially prune existing instruction; however, it is important to remember that the DCIs and PEs state the minimum requirements and that there is an acknowledgement that teachers may choose to go beyond those specifications. The key here is to ensure that the big ideas do not get buried and lost in a minutia of details. We have chosen to add some detail to the core idea and PEs that elaborate what the core ideas can explain, but only after we justified to ourselves the need for the addition.

The second learning target also clearly builds on what students learn at the middle school level: Chromosomes come in pairs and children inherit one member of the pair from each of their two parents, and this can be used to explain variation in traits between siblings. At the high school level we provide a mechanism for the laws of segregation and independent assortment—meiosis. Here we are also in complete agreement with the NRC *Framework’s* boundaries and do not believe there is a need to teach the details (i.e., stages) of the process. For one thing, meiosis is a rather confusing process, with its two cellular divisions. Students do not see a need for two divisions given that the “goal,” so to speak, of the process is to halve the genetic content in the cell. From that standpoint it would be more logical to simply divide the material and generate two sex cells rather than first duplicating all of it and then halving it twice to generate four sex cells. Even understanding recombination does not really require an understanding of the steps of meiosis, merely the existence of homologous pairs of chromosomes that swap parts before segregating. Note that the argument is not that these ideas are too complicated for students to learn; rather it is that these extra details about the process, while making a more complete story, do not add to the utility of what meiosis can explain. Learning the stages can easily become an exercise in learning the process as an outcome by itself, rather than using the understanding of the process to reason about and explain phenomena, such as how sexually reproducing species combine genetic information from two parents to produce offspring.

The third learning target builds on the first, in that we added the idea of complementary base pairing to our expectations of what students should know about DNA structure. In our unpacking here we have specified what is meant in the DCI by the statement “DNA replication is tightly regulated and remarkably accurate.” This refers to the idea that DNA replication is semi-conservative, i.e., each strand serves as a template for the construction of a new strand. Thus after cell division the parent and
daughter cells each end up with a DNA molecule that is made up of one “old” strand and one “new” strand. The use of a template increases the accuracy of the process. It is this latter idea that is at the core of why understanding that DNA replication is semi-conservative (terminology is far less important that the idea itself) as it allows one to explain the how accuracy in replication is achieved. Had the process been less accurate we would probably not have multicellular organisms because the rate of mutation would not sustain the delicate complexity involved. However, errors do occur and while they are often fixed by the proofreading process, some errors are still missed. We do not expect students to learn about the details of the proofreading machinery, these are highly involved molecular complexes, just the idea that there are some “black-boxed” ways in which the cell can proofread and catch errors in the process.

We have already discussed the ideas captured by the fourth learning target (the role of environment in generating variation) in the previous section. We will therefore simply reiterate that this learning target captures the two ways by which the environment impacts trait variation—modifying the DNA and modifying gene expression. The mechanisms of gene expression remain black-boxed in the Framework and NGSS. We do not advocate that teachers delve into the complex, albeit interesting, signal transduction pathways by which cells alter the profile of genes they express (for example, the famous lac-operon). Rather, students can simply learn that genes can be turned on or off and that environmental factors (chemical and physical) can trigger activating or inactivation of genes (i.e., they can influence which genes are translated into proteins by the cell).

The key to helping students develop understandings of sources of trait variation is pushing them to develop causal mechanistic models of these sources. Often this will entail problematizing incomplete or nonmechanistic explanations. Problematizing involves leading students to see how their current ideas cannot explain a new case. For example, at the middle school level, the need for two alleles per trait is not readily obvious. Left to their own devices, students are likely to develop models of inheritance that link single alleles to phenotype. One kind of phenomenon that can call that model into question consists of cases in which a trait appears to “skip” a generation. That is, a trait apparent in a parent is not apparent in its progeny, but appears again in the third generation. This leads to the idea that it is possible to have genetic information that does not affect the traits of the individual but can be passed on to progeny. This need can motivate investigation of the process of sexual reproduction to trace how genetic information is physically transmitted from parent to offspring, and ultimately to the construction of the idea that there are two copies of genetic information for each trait. In this way, the skipped generation case uncovers a problem in the single allele to trait model, motivating learners to revise and extend the model to encompass these more complex phenomena (Stewart, Cartier, and Passmore 2005).

Now that we have unpacked the DCIs and PEs into a set of four learning targets, the question becomes: What is the storyline that will allow students to develop these
understandings in a coherent manner? Our overall approach here is one of problematizing students’ existing models of genetic phenomena. These existing models were likely developed in middle school (some of which we alluded to above) and while they work well for the phenomena students are expected to explain at that level, they may break down in trying to explain more complicated phenomena. These shortfalls of the models serve as the motivation for revising and refining the models such that they provide explanations of a wider array of genetic phenomena.

Let’s take for example the model that NGSS targets students to construct in middle school, in which each parent contributes half the genetic information by contributing half the chromosomes. This model works well until one starts tracking which information is encoded on which chromosome, and encounters phenomena that reveal a lack of expected linkage (correlation) between alleles of genes on the same chromosome. If sex cells simply contain either one chromosome or the other from each pair, at random, how can specific alleles stored on the same chromosome fail to travel together? Pushing to explain this problematizes the simple model of random segregation and introduces the need for recombination. From a pedagogical stance the “game” is to problematize students’ initial models such that they continue to develop more sophisticated and complex models that account for more aspects of the phenomenon at hand (variation).

Using this general approach of problematizing will be helpful in thinking about the phenomena we will want to engage students with as we develop the unit (in the second phase of the instructional framework). However, this approach does not dictate a particular order of which models or aspects of students’ cognitive models we should problematize first. We identified at least two viable starting points: investigating unexpected patterns of inheritance (i.e., problematizing for recombination), or investigating sources of mutations. If we begin with the former, we will be problematizing students’ conceptions about how genes are passed on from one generation to the next and what they would expect to see in terms of patterns of correlation between traits on the same chromosome. We would then have to “switch gears” to problematize changes to traits due to mutations (caused by either replication errors or mutagens).

In contrast, if we begin with sources of mutations, we can problematize students’ notions of the permanency of alleles, for example, how is it possible that a child would have a recessive trait if both parents are homozygote dominant? Or how can we get a completely new variant of a trait? We can begin with replication errors, which happen very infrequently, and then move to mutagens, which can significantly increase mutation rate (and the appearance of new trait variants). We would then switch gears again and tackle genetic recombination. In either case, regardless of the starting point, the second aspect of environmental influences on gene expression is not tightly related to either starting points and would have to be addressed as a third separate piece.

Since the mechanisms involved are rather distinct, we would have to “switch gears” more than once no matter where we start. We ended up selecting the first option with
the following rationale: If we start with this option, we are not introducing entirely new variants right off the bat. Rather we are introducing a mechanism for reshuffling existing variants, that is, introducing variation by creating new combinations of traits rather than new traits. We can then problematize students’ revised model (that now included recombination) further with phenomena in which new variations of the traits appear. This will entail revising the model of meiosis by examining changes to the actual genes (the instructions) rather than how genes are shuffled and sorted into sex cells. To us this revision of the model seemed less of a “jump” or switch in gears than the alternative sequence in which students first revise a model of mutations and then see phenomena that require recombination to explain. We will develop this instructional sequence in somewhat more detail in the second phase. Now we want to revisit the issue of practices and crosscutting concepts and their alignment with our current storyline.

Recall we selected the practices of: Asking Questions, Defending Claims With Evidence, Developing and Using Models, and Developing Explanations. The problematizing existing models approach is certainly well aligned with these practices. Problematizing involves introducing phenomena carefully selected to reveal the limitations of students’ current models, leading them to construct questions that motivate further investigation. This driving question leads to additional questions that are more specific to the phenomenon itself that students can generate (e.g., can alleles change from dominant to recessive or vise versa?). The entire basis of this approach is in revising existing models and explanations; we can support students in their revision attempts by proving them with evidence that can help them pinpoint the troublesome aspects of their models and can give them clues about the genetic mechanisms at play.

We selected patterns and mechanism as our two crosscutting concepts. These also fit nicely with our general approach. Students are trying to explain anomalies in patterns of inheritance and traits by developing their existing mechanistic accounts of these. The idea of patterns suggests consistency and predictability; we capitalize on these properties in our problematizing approach. We deliberately introduce a phenomenon that “breaks” these patterns in unforeseen ways, thus problematizing the existing cognitive models that can explain the regular pattern but not the new counter-example. The way to solve this conundrum for students is by examining the mechanisms underlying their existing models and modifying or elaborating them.

Stage III: Determine Performance Expectations and Identify Criteria to Determine Student Understanding

NGSS specifies learning targets as the integration of content (disciplinary core ideas and crosscutting concepts) and practices. The NGSS performance expectations establish performances that students should be able to accomplish if they understand the content and can engage with the practice. We anticipate the students who have mastered the learning targets will be able to develop model-based explanations of the key processes involved that lead to the sources of variation in the evidence. These explanations should include
a causal mechanism and be accurate. Below we provide an example of an assessment task and the criteria one can use to evaluate student performance on this task.

For our assessment task we use the context of a common phenomenon of bacteria developing resistance to drugs. The question posed to students is how is it possible that population of bacteria that were once susceptible to particular antibiotics can now tolerate them? As evidence students can be shown the proportion of resistant bacteria developing in a two populations: one that is irradiated with UV light (more resistant cells), and one that is not disturbed in this way (less resistant cells). Although natural selection can explain why preexisting variation would increase over time, it cannot provide an explanation for the difference between the two conditions. For that, students need to make a claim about the source of the new trait of resistance and defend it using the evidence provided. We would expect students’ responses to include reference to environmental mutagens as the cause, in this case UV, and to explain how mutations, when not corrected, can result in new traits. Students should be able to explain why the non-irradiated bacteria population still have some resistant cells, but fewer by invoking the idea that some random errors occur during replication and that these can also generate the new trait. Thus this task can address two of our four learning targets. Students should be able to provide both mechanisms (mutagens and replication errors), they should be able to link the evidence to both mechanisms thus defending their claim about the source of variation in this interesting phenomenon.

Stage IV: Determine Nature of Science (NOS) Connections

There are three nature of science ideas that are most relevant to the modeling and explanation students need to engage in to develop these disciplinary core ideas:

- Scientific Knowledge Is Based on Empirical Evidence
- Scientific Knowledge Is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

The strategy of problematizing models to motivate investigations relies, of course, on the understanding that knowledge building in science needs to be guided by empirical evidence. Understanding that models need to explain natural phenomenon is also relevant, and realizing that the process of building models is incremental. That is, models provide the best explanation of phenomena we have figured out so far, but new evidence may push us to revise existing models so they can handle new findings. Thus students need to see scientific knowledge as open to revision as we obtain new evidence, and see the role of investigation as uncovering evidence that may help us decide between competing models or may call an existing model into question. Thus, the problematizing of the model from middle school and its extension to handle new cases of variation are a great example of how science knowledge can be refined over
Models are partial explanations that leave some open questions. With new investigations of phenomena, we can revise models so that they explain everything they explained earlier, but also address new phenomena or unpack steps that had been black-boxed earlier.

We envision incorporating these nature of science ideas as they are relevant to the model-building work we would do with students, rather than attempting to “front-load” the unit with discussion of these issues. For example, we might start with phenomenon that can be explained by the simple two-allele model, and then bring in phenomenon that cannot be explained by that model. In discussion about how to proceed, the importance of revising models in light of new evidence could then become an explicit focus, as students strategized about how to respond to the problematic evidence.

Stage V: Identify Metacognitive Goals and Strategies
The key metacognitive goal we have identified is self-regulated thinking. This goal is key given the incremental model building and model revision we are targeting for this unit. Students will continually need to be monitoring what we can explain and what evidence poses problems for the current model, and what are our current questions that will help us resolve these problems. There are several specific strategies we see as important to draw on in supporting this type of self-regulated thinking.

The strategy “identify what you know and what you don’t know” will be important for helping students keep track of the model they are building incrementally. We envision that we will want to keep track of progress and open questions in an ongoing chart as we progress through the unit. At each point, we will need to discuss the current assumptions in the model (there are two alleles, genes determine traits, genes are located on chromosomes, independent assortment, and so on), the evidence we have collected that led us to these parts of the model, and the open questions (why don’t traits that are on the same chromosome “travel together” as we would expect from independent assortment?). We will have students periodically revisit the chart to record new evidence and the questions it motivates, and revisions to the model as we figure out other ways that variation can arise.

The strategy “talking about thinking” will also be a part of students’ work in this area. It will be important to push students to talk through their reasoning as they make arguments about how the current model can account for the patterns in data or fails to do so. Self-evaluation strategies will also be a key part of the work. We will need students to review the progress in explaining the variation data, and to identify what questions they have about these patterns. Our goal is for students to take responsibility for figuring out which parts of the phenomena cannot be explained with the current model and articulating research questions to guide the next steps in the investigation, and which parts of the model are problematic and need to be revised.
Phase II: Planning for Responsive Action

Stage VI: Research Student Misconceptions Common to This Topic That Are Documented in the Research Literature

Having identified the core ideas, practices, and crosscutting concepts as well as the beginning of a coherent storyline for teaching them, we next turn to the research to identify the cognitive challenges students may encounter when learning these ideas, practices, and concepts. We review the research as it relates to our four learning targets.

The domain of genetics is rife with terminology and scientific representations. A quick search of Google images related to chromosomes can give you a sense of the many ways in which we represent these structures in science as well as in instructional texts and tools (see Figure 7.2, p. 244). The abundance of terms and representations do not help students disentangle these structures and their role in genetics (Bahar, Johnstone, and Hansell 1999; Lewis and Wood-Robinson 2000). We know that students do not always see a connection between DNA, genes, and chromosomes (Lewis and Wood-Robinson 2000; Venville, Gribble and Donovan 2005). Students tend to think of DNA as a unique personal identifier found in the blood, determining our traits and found in cells (Venville et al. 2005). As can be seen in Figure 7.2 (p. 244), some of these representations make the connection between DNA and chromosomes relatively clear, while the others do not. Thus helping students integrate their conceptions of DNA and chromosomes into a coherent explanatory model is a non-trivial task we will need to undertake as we design instruction to address our first learning target.

The ideas captured in our second learning target involving the process of meiosis are fairly well researched in genetics education. We have known for decades now that students can develop algorithmic understandings of meiosis and even accurately use tools like Punnett squares without truly understanding what this process accomplishes. For example, students may be able to recount the phases of meiosis or calculate Punnett squares correctly, but they cannot use the process of meiosis to explain how the system of two copies of information for each trait can lead to passing on information for a trait that the parent doesn’t exhibit (Stewart and Dale 1989). For example, we have shown that while students can correctly determine the genotype of a homozygote recessive parent with a genetic disorder, when asked what proportion of the parent’s sex cells will carry the allele for the disorder, they do not always realize that all the sex cells will have this allele. Thus the correlation between a parent’s genotype and the makeup of their sex cells is not obvious even after instruction about meiosis (Freidenreich et al. 2011). The process itself is also confusing for students. Research suggests that students struggle to distinguish between mitosis and meiosis (i.e., students state that these are the same cell division processes), and often are not be able to accurately describe how meiosis leads to the generation of genetic diversity among offspring (Lewis and Wood-Robinson 2000; Williams et al. 2012). Again, we feel the
key here is to focus on the input and output of the process with the aim of explaining genetic variation.

In regard to our third learning target, mutations during DNA replication, there is not much research about this specific idea. However, we know that students tend to hold a view of mutations as being harmful (Mills Shaw et al. 2008) and an unwanted consequence. However, mutations form the basis of genetic variation and the fodder of natural selection. While most are probably harmful, some low rate of mutation is critical for the survival of populations and species. We therefore need to help students recognize the important role of mutations in generating genetic diversity and provide them with some examples of both neutral and beneficial mutations.

As noted earlier, the NRC Framework and NGSS have placed much greater emphasis on the role of the environment in influencing trait expression, our fourth learn-
ing target. This is not an idea that has been extensively researched. However, we do know that students have little understanding of the ways in which the environment can influence our genes and traits (Mills Shaw et al. 2008). Overall students tend to hold a rather deterministic view of genetics (Dougherty 2009) as exemplified by ideas like each trait is controlled by a single gene, genes determine all traits, and there is a lack of environmental influence. This view is highly problematic given that most traits are under the heavy influence of the environment and complex genetic interactions. For example, students tend to think that if a parent has cancer the child is very likely to have cancer as an adult (de Vries, Mesters, van de Staag and Honing 2005). However, most cases of cancer are not due to inherited mutations related to that cancer (like mutations BRCA 1 and 2 genes). Moreover, while students likely understand that exposure to some environmental factors like UV rays can cause cancer, it is less clear that they understand the underlying mechanism as involving mutations in our DNA. Thus students’ prior conceptions here seem to miss the mark on both causal mechanisms by which the environment influences our traits.

In this section we highlighted only those alternative conceptions and conceptual challenges that we deem are most directly relevant to the topic at hand. However, instruction may surface alternative ideas that we did not discuss. For example, we know that students do not always presume a two-allele model, and may not even assume equal contribution of genetic material by both parents. For the purposes of this chapter we assumed that students have developed relatively sophisticated and accurate understandings of the content expected for the middle school level, and thus do not continue to hold such alternative ideas.

Stage VII: Determine Strategies to Elicit and Confront Your Students’ Preconceptions

Now that we have identified key alternative ideas that students may bring with them to learn our focus topic, we need to find ways of identifying which of these are held by students in a particular context. The most obvious way is to use a written or interview-based preassessment. We would argue for a two-tiered approach, giving all students a written survey and then interviewing a handful of them regarding ideas that are unclear on the written survey. Russ and Sherin (2013) present helpful guidance for using interviews to tap students’ prior conceptions. The survey and interviews should be done relatively close to the beginning of instruction and after other relevant concepts have been taught. That is, we would recommend teaching the topic of genes and proteins first and then surveying students. This is because the former topic may change students’ ideas in ways that are relevant to the current topic. An alternative to surveying individual students is to conduct a brainstorming discussion in which students are asked to speculate about how to explain challenging cases drawing on the target ideas.
The written preassessment, or survey, need not be long and time-consuming; however, it should focus on the four learning targets and be designed to elicit potential alternative ideas that students may have. One could do this by using a combination of forced choice items and short open-ended items. The forced choice items can be designed to pinpoint specific alternative that we suspect exist (as described in the prior section), whereas the open-ended items leave room for identifying other alternative conceptions that we did not anticipate. An example of such items is shown in Figure 7.3.

**Figure 7.3**

**Preassessment Item Formats**

<table>
<thead>
<tr>
<th>Alternative Items for Learning Target 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced choice: T/F format</td>
</tr>
<tr>
<td>Determine whether each of the following statements is True or False</td>
</tr>
<tr>
<td>1. Genes are in our cells and DNA is in our blood.</td>
</tr>
<tr>
<td>2. Genes determine our traits but DNA does not.</td>
</tr>
<tr>
<td>3. Genes are part of the DNA they are what hold the two strands of DNA together.</td>
</tr>
<tr>
<td>4. Genes are segments of DNA that code for proteins.</td>
</tr>
<tr>
<td>5. Everyone's DNA is unique, we do not share DNA with other family members.</td>
</tr>
</tbody>
</table>

An alternative approach to identifying student conceptions we considered was to merge this stage with the next and to periodically engage students with an activity designed to elicit their naïve ideas prior to instruction about those concepts. For example, before beginning the instructional sequence for Learning Target #1 and #2, having a class discussion about how the egg and sperm are formed in the parent and what is the nature of the genetic material in these specialized cells. Then once that sequence is completed engaging in another group or whole-class activity to elicit students’ understandings about mutations or the role of the environment in determining our traits. The drawback to this piecemeal approach is that students’ alternative ideas about one concept may be related or influenced by their ideas about another (e.g., ideas about DNA, and ideas about mutations). Having a sense of the broader gamut of ideas students have about the different aspects of the topic, that is seeing the whole landscape, may impact design decisions about specific instructional strategies and activities that a more piecemeal view would not afford.
Stages VIII and IX: Strategies for Eliciting and Addressing Preconceptions: Sense-Making Strategies

As we discussed earlier, the general approach we have chosen is to problematize exiting models. We have combined stages VIII and IX from the instructional framework, weaving our strategies for eliciting and addressing prior conceptions into an instructional sequence to support students’ development of the target models. In this section we discuss some potential instructional strategies and activities for doing so, with the aim of helping students see the gaps in their understanding and motivating the need to revise their existing conceptual models. We also describe the sense-making strategies we use to help students develop these revised models. The overall sequence is summarized in Table 7.1.

**Table 7.1**

**Instructional Sequence and Strategies**

<table>
<thead>
<tr>
<th>Part 1: How can variation happen?</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Elicit current ideas about genes and traits (Concept Mapping)</td>
</tr>
<tr>
<td>• Reconstruct middle school model of simple dominance to explain variation</td>
</tr>
<tr>
<td>• Draw out predictions of original model</td>
</tr>
<tr>
<td>• Present problematizing cases that violate predictions</td>
</tr>
<tr>
<td>• Help students revise the independent assortment model to include recombination in meiosis</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part 2: How does new variation occur?</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Elicit current ideas about the outcomes of mutations (Concept Cartoon)</td>
</tr>
<tr>
<td>• Provide evidence to help students understand that whether a mutation is beneficial or disadvantageous depends on context</td>
</tr>
<tr>
<td>• Provide competing models for source of mutations</td>
</tr>
<tr>
<td>• Provide evidence to reason about models</td>
</tr>
<tr>
<td>• Develop combined model that includes both sources of mutations</td>
</tr>
</tbody>
</table>

We suggest an instructional approach such as project-based science in which there is an overarching question, sometimes called a driving question (Krajcik and Czerniak 2014) that teachers develop with students, anchored in phenomena from the classroom and their daily lives. This driving question provides the coherence for the unit, and motivates specific subquestions to explore and develop pieces of the story leading to the four learning targets. The driving question for student inquiry should focus on the general issue of how variation between individuals in a species can occur; what makes us look different from each other? It is probably wise to focus the exploration on humans and then expand and generalize to other organisms. This is because students
have more experiences, and prior knowledge to draw on, with regard to humans. Their understandings of genetics are more robust for mammals than for other organisms.

**Part I: How Can Variation Happen?**

We have chosen concept mapping as a general strategy for getting students to think about and discuss their ideas in ways that would help them see differences and potential gaps in their understanding. While vocabulary is not the learning focus of the unit, there are many terms and concepts that students bring into the classroom. We felt that it would be helpful to get students to articulate their initial ideas and definitions, and identify problematic vocabulary and open questions right at the start. Concept maps are akin to brainstorming webs (Tool 3.7) except that students are provided with a set of concepts they need to think about and connect. For this activity students can work in small groups or pairs and receive a large piece of paper and cards with the following words on them (one per card): genes, traits, DNA, chromosomes, nucleotides, cells, parents, blood (and others can be added). Students are asked to place these cards on the large paper and draw labeled arrows to connect the terms.

Students can share their concept maps in various ways. We like the idea of a gallery walk as a means of sharing ideas because it can help students understand the importance of explaining their thinking and it allows students to provide constructive feedback to peers. In a gallery walk students walk around and review other students’ concept maps and provide comments and questions (on sticky notes). Students do not have to view all the maps, commenting on three or four is sufficient. A whole-class discussion can follow, in which the teacher can attempt to develop a class concept map that captures students’ ideas as well as their questions and uncertainties. In essence this class discussion can combine a concept mapping and KWL (Know, Want to know, and Learn) thus engaging students in the practices of defending their claims and questioning. Overall, the goal of this activity would be to have students share their ideas, note differences in what they believe to be true, and highlight aspects of their understandings that are incomplete.

Following the concept mapping would be a sense-making activity in which students use evidence to figure out hierarchical organization of the genetic information (such as genes as segments of DNA on a chromosome). The evidence in this case can include historically important experiments that contributed to our understanding of the genetic material and its structure. For example, students can explore patterns of diffraction made by shining a laser pointer at by various structures (like a rod, a circle, a spring) and then they can compare the patterns they have with photo 51, the famous x-ray diffraction image made by Rosalind Franklin. The pattern in the picture can be replicated by shining a laser pointer through a spring from a ballpoint pen. A more detailed description of this activity and how it can be used with students can be found in an article in *The Physics Teacher* by Braun, Tierney, and Schmitzer (2011). Additional evidence can be provided to help students understand the relationship between DNA
and chromosomes (for example, simplified descriptions of the experiments of Boveri and Sutton). Using these kinds of evidence pieces, students can construct a more complete and accurate model of DNA structure and organization (from nucleotide to chromosomes), which addresses the first learning target. This model can be used as the basis for activities that address the second learning target.

The next step is to help students articulate their current models about how traits are inherited, as developed at the middle school level. It is key to have all students on the same page, being able to use the model to reason about how genetic information is passed on, how variation can occur between siblings due to having two alleles that are segregated and randomly assorted, and how the information in the two alleles are used to determine the trait. To do this, we would present students with phenomena that need to be explained (e.g., a specific genetic trait or disorder), and have them use their current model to develop an explanation for the pattern of inheritance as evidenced in pedigrees of families with the specific trait. The pedigrees would show multiple siblings across three generations, and would include cases of inheritance where the recessive trait skips a generation. Students would have to explain how it is possible for a child to have a trait that neither of her parents have. In framing this as a task in which students are asked to explain using a model, students need to do more than simply say, “traits can skip generations when they are recessive alleles.” They will need to provide an explanatory account that connects the observation above with the underlying mechanism of meiosis and Mendel’s Laws. Such an account would have to show what alleles must have been passed to each of the parents in order for them to have produced a child that has two recessive alleles, which is what the child would have to possess in order to show the recessive phenotype. The account would also have to explain how each combination of alleles for each individual determined the individual’s trait.

Once we have helped students reconstruct this model from middle school, we introduce new phenomena that will problematize their current conceptual models. The second learning target requires some setup first. It is unlikely that students have thought about all the consequences that are derived from their model of genes as segments on chromosomes. One would have to walk students through some predictions that can be made based on their current model, namely, that genes located on the same chromosome would show a pattern of association for their alleles. The prior problems students have solved (in middle school and the activities described above) only dealt with one gene at a time, and so are completely handled by students’ model from middle school. To push that model, we present problems tracing two genes at once, and ask students to analyze possible genotypes for the phenotypes in a pedigree. In doing this, we ask students to identify which chromosomes the alleles must have come from. We establish the process first with traits on different chromosomes, which present no challenge to the existing model. Then we provide a case in which the genes (and therefore their alleles) are on the same chromosome, and a resulting child has what appears...
to be an impossible combination of traits (drawn from two different chromosomes). We do not tell the students the difference in the case, the goal is for them to try and figure out how to explain this unexpected result.

The case of two genes on the same chromosome can more easily be observed with X-linked traits like color blindness and hemophilia since only one chromosome is involved and the allele on that chromosome is always the one expressed in males (i.e., recessive phenotype is always shown). One would expect that in families with color blindness and hemophilia these traits would go together. Indeed, according to students’ current model it is not possible for a male to have one trait and not the other. Once students come to understand this prediction they can be presented with a discrepant event, the existence of males who only have one trait and not the other (a real phenomenon). We will then use these cases to pose a problem for the model, first getting students to realize why the current model cannot explain these cases. This establishes the need to revise the model in a way that it can handle how a sex cell could end up with traits drawn from two different chromosomes of the same pair.

As a class, we discuss and summarize (a) the problem for our model (b) our current investigation goal, namely how can a sex cell end up with one allele from one chromosome and another allele from the other chromosome of the same pair. We then ask students to brainstorm different types of modifications to the meiosis model that could potentially explain the anomalous data. We do not expect students to solve the problem without additional evidence and support. However, the experience of trying to solve it and failing is still highly productive for learning as it allows students to notice important features of a potential solution (Kapur and Bielaczyc 2012). The approach of letting students struggle with a problem they are likely unable to solve is called productive failure, and it has been shown to be very effective when coupled with direct instruction following the problem-solving activity (Kapur 2008).

As noted above we can provide students with some relevant evidence to support students in their sense making around this phenomenon and their attempts to come up with a mechanism to explain it. The evidence, again, can be drawn from historical experiments conducted by Barbara McClintock, and her student Harriet Creighton, on traits in maize and their relationships to specific alleles on chromosomes. McClintock and Creighton mapped crossing over events they observed under a microscope to resultant traits in maize plants to show that homologous chromosomes were swapping sections. Once the class has established what the evidence shows us must be happening, we can then present a mechanism that can explain it—the recombination as a part of meiosis. Recall, there is no need to delve into much detail here, it is sufficient that students understand that chromosomes can swap sections. Given their attempt to account for the anomalous data it is very likely that the idea of swapping parts will be seen as way to resolve the conundrum as soon as it is introduced. Students’ struggles earlier will prepare them to see the fruitfulness of this solution more readily. Moreover, the understanding of meiosis and recombination will satisfy a need-to-know (Edelson
2001) that the prior activity established; students are likely to be motivated to learn the solution given their attempts to come up with one.

**Part II: How Does New Variation Occur?**

We expect the concept of mutations to arise in part 1 of this unit as a possible explanation for how unexpected outcomes could occur. If the idea of mutations arises, it provides a natural transition to the second half of the unit. If it does not arise from the students, the teacher can bring in this idea as something that we know can influence inheritance in particular ways. We will then focus students’ attention on trying to figure out what actually happens in mutations and why it matters.

To elicit students’ alternative conceptions about mutations, we chose the strategy of concept cartoons (Tool 3.8, p. 134). Concept cartoons essentially pit two or more competing ideas/perspectives about a phenomenon and the idea is to have students choose the position they agree with and argue with students who have chosen one of the alternative positions. The claims or alternative positions presented in the concept cartoon often reflect known alternative conceptions that students have (for examples and explanation about concept cartoons go to www.conceptcartoons.com). One can construct a concept cartoon for practically any topic for which students may harbor alternative conceptions that are nonaligned with canonical understandings.

In Figure 7.4 we present an example of a potential concept cartoon that addresses our third learning target. Students select which of the three perspectives they agree with the most and then engage in a whole-class argumentation discussion about these ideas. Much like the concept mapping activity, the goal of this activity is to help students see gaps in their understanding by highlighting alternative viewpoints that may “shake the foundations” of their existing conceptual models, thus problematizing them. It is also likely that such a class discussion would raise questions for students, such as, what are mutations, and how are they caused? Following this activity one could, again, provide students with evidence to help them revise their existing model.

One approach to doing this is to present some evidence about actual cases of known mutations and their consequences. A good example for this purpose is sickle-cell anemia, because the mutation itself is simple to explain and its consequences vary depending on whether the individual inherits one or two mutated copies. The mutation in
sickle cell is a change to the hemoglobin proteins that makes it “sticky” and causes hemoglobin proteins to clump together, altering the shape of the cell and preventing proper transportation of oxygen. Overall, this change is a bad thing and the resulting phenotype is a painful and dangerous anemia. However, in heterozygous (individuals with only one mutated copy) there is some advantage because sickle cells are not as susceptible to malaria. In a complex mechanism the sickled hemoglobin makes the host tolerant to the parasite that causes malaria. This type of evidence can help students understand that “beneficial” and “harmful” are rather context dependent and what might be harmful in one context can be beneficial in another. There are many other examples that can be used to bolster this understanding: (a) a mutation in the CCR5 protein that confers resistance to HIV, (b) a mutation in MC1R that results in fair skin was advantageous when our ancestors moved to colder northern climates because fair skin allows more vitamin D production, and (c) a mutation in the lactase gene that stays turned “on” and expressed throughout an individual’s life allows us to drink milk (earlier humans were lactose intolerant from the age of 4 or 5). For all of these examples, students can compare the mutated and normal genes to identify the change. The exact nature of the mutation is less important that having students see that errors can arise in the genetic sequence, and how that could then affect the role of the gene in determining the phenotype.

After students understand what a mutation is, we will raise the central question of how mutations arise. Again our goal is to help students work out two different mechanisms for mutation—spontaneous errors in replication and changes to the DNA due to harmful mutagens in the environment. The question of where novel variation comes from could also be introduced using a concept cartoon. There could be just two alternative perspectives provided in this cartoon: (a) mistakes made when copying DNA, and (b) changes to the DNA due to toxin in the environment. We chose to juxtapose two correct options in the cartoon this time (and a third incorrect option) in order to help students later understand that often there are multiple causes for a particular outcome. Students are likely to initially pick one side of the cartoon; however, with appropriate evidence we hope they will come to see that both claims are true and can account for the new phenomenon. The kinds of evidence that can be used here include studies about the rate of changes to DNA when single-celled organisms are exposed to mutagens in the environment; the disorder xeroderma pigmentosum, in which there is a mutation in a DNA repair protein causing patients to have higher incidence of mutations and cancer; and studies of the effects of UV rays on DNA structure. Through analysis of such evidence and engagement in sense making regarding what they suggest about potential causes of mutations, students can develop models that include the two mechanisms for mutations—random replication errors and the effects of mutagens. These activities would conclude the unit and address all four learning targets.

We next discuss some useful assessment strategies that can help tailor the instruction to students’ developing understandings.
Stage X: Determine Responsive Actions Based on Formative Assessment Evidence

As we have described earlier, the science practice that frames most of the students’ activity will be constructing an explanatory model and using their models to construct explanations of the particular phenomena. In the sequences in stages VIII and IX, we have already mentioned some of the strategies we will use to respond to formative assessments in order to support sense making and revealing understanding. The models we ask students to construct and use can be seen as visual models involving diagrams and verbal models of metaphors (Instructional Tool 3.6, p. 119). We envision diagrams would be key in the first learning target, explaining how two genes on the same chromosome could become swapped during meiosis. The model would have to track the location of the genes on each allele in each of the two parents, then the resulting sex cells, and finally the alleles in the offspring that exhibit the recombination. We will also ask students for written explanations using the model (Instructional Tool 3.3, p. 93), in which they walk through the cause-and-effect sequence and tie observed data (e.g., what we know about the location of the two genes on the chromosomes, and the observed combination of phenotypes in the parents and the offspring). By combining the diagrammatic models with written explanations that draw on the models, we will ensure that students are pushed to make their reasoning explicit, tracing the genetic information from parent to child, and using the information to determine traits.

We envision that large- and small-group discussions (Instructional Tool 3.5, p. 110) will play a key role. To engage in scientific modeling, students need to talk through their ideas, use their models to try to account for evidence in test cases, and attempt to reach consensus as a class when there are multiple candidate models or candidate explanations of cases proposed by students (Reiser, Berland, and Kenyon 2012). Teachers will need to manage classroom discussion to attempt to push continually for mechanism in students’ diagrammatic models and written explanations. Questions such as “But why does that happen?” and “What is going on with the chromosome that would allow that to happen?” will be key in pushing students to go beyond simply labeling things and attempting to reason through how the mutation could happen or why it would have the effect it does.

Conclusion

The general subject matter of heredity is a great example of the way that the shifts in NGSS have real implications for classroom instruction. Too often through traditional instruction students learn the details of the structure of DNA, and learn about the process of transcription and translation at the algorithmic level, without engaging in developing explanatory models that use these structures and processes to explain how and why various heredity phenomena occur. For example, many students learn to work out Punnett squares to calculate probabilities of various trait combinations and
learn to name and describe the steps of meiosis, and yet they are not able to explain how it is possible for a parent to pass on genetic information to a child for a trait that the parent does not possess. Students may learn the steps of translation and transcription or the names of particular types of mutations (such as deletion, substitution), without being able to explain how mutations can occur or why these types of mutations would lead to effects on the organism.

The strategies presented in this chapter are intended to help students achieve the type of learning targeted by NGSS, in which students tackle the core explanatory ideas by engaging in the science and engineering practices. The focus on models and explanations is intended to help students develop these explanatory accounts so that they can use the disciplinary core ideas of LS3 to explain how variation arises across generations, how new variations can appear, and ultimately how genetics determines our traits.

**Resources**

- Genetic Science Learning Center: [http://learn.genetics.utah.edu](http://learn.genetics.utah.edu)
- The Concord Consortium: Digital learning for science, math, and engineering: [http://concord.org](http://concord.org)
- The Talk Science Primer can be found online at TERC ([http://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf](http://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf)). The primer, written by Sarah Michaels and Cathy O’Connor, presents a set of talk moves teachers can use to help students articulate their thinking and to help students build on each others’ ideas in science discussions.
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The book is organized into two parts that feature an instructional framework and resources that support framework implementation. The content is suitable for both veteran teachers and newcomers to the classroom.

Part I, The Toolbox, introduces a research-based Instructional Planning Framework that helps you understand the learning needs your students bring to class, incorporate appropriate teaching strategies, and interpret the framework and teaching tools through the lens of NGSS.

Part II, Toolbox Implementation, models use of the framework with four hard-to-teach topics, all different from the ones in the book’s first edition. Contributing authors show you how the framework helps you teach four NGSS disciplinary core ideas: growth and development of organisms, ecosystems, heredity, and biological evolution.

As the contributing authors make clear, the teaching models are specific and help make student thinking visible, but they don’t presume to dictate what’s right for you. Rather, the book will open your mind to fresh, effective ways to help biology students deepen their conceptual understanding based on what works best for them and you in today’s classrooms.
IT'S DEBATABLE!

USING SOCIO-SCIENTIFIC ISSUES TO DEVELOP SCIENTIFIC LITERACY

K-12

Dana L. Zeidler and Sami Kahn

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USING SOCIO-SCIENTIFIC ISSUES TO DEVELOP SCIENTIFIC LITERACY

K-12
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Contributors

The authors are grateful for the expert contributions of the following outstanding educators:

“Voices From the Field”: Teacher Perspectives

Scott Applebaum
Palm Harbor
University High School
Palm Harbor, FL

Hyunsook Chang
Kuksabong Middle School
Seoul, South Korea

Thomas Dolan
Pride Elementary School
Tampa, FL

Kisoon Lee
Sinam Middle School
Seoul, South Korea

Unit Plan Contributors

Brian Brooks
University of South Florida
Tampa, FL

Christina Cullen
University of South Florida
Tampa, FL

Daniel Majchrzak
University of South Florida
Tampa, FL

Tammy Modica
University of South Florida
Tampa, FL

Michael Caponaro
University of South Florida
Tampa, FL

Thomas Dolan
Pride Elementary School
Tampa, FL

Andrea Churco
Marshall Hillsborough County School District
Florida

Crystal Nance
University of South Florida
Tampa, FL

Kory Bennett
University of South Florida
Tampa, FL

Katie Frost
University of South Florida
Tampa, FL

Lisa Clautti Mistovich
University of South Florida
Tampa, FL

Ashley Schumacher
University of South Florida
Tampa, FL

Jessica Croghan-Ingraham
University of South Florida
Tampa, FL

Bryan Kelly
University of South Florida
Tampa, FL

Hayley Sweet
Florida College Academy
Tampa, FL

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About the Authors

Dana L. Zeidler (first author) earned his PhD from Syracuse University. His research program incorporates aspects of socioscientific issues as a means to facilitate scientific literacy. His work has attracted international attention and is cited widely both within and external to the field of science education. His line of extensive research can be found in numerous journal articles, book chapters, keynote addresses and international conference proceedings. He works closely with doctoral students and other leaders in the science education community. He is a Professor and Program Coordinator of Science Education at the University of South Florida, Tampa Bay. Dana has long-standing ties to the science education community including working closely with other leaders, faculty, and graduate students. Some of his most recent honors include:

- President of National Association for Research in Science Teaching (NARST): A worldwide organization for improving science teaching and learning through research, 2010–2011
- Recipient for the Outstanding Mentor Award (2008), Association for Science Teacher Education (ASTE)
- Executive Board of Directors, NARST, 2006–2009
- At Large Board of Directors, ASTE (2008–2011)
- Distinguished Visiting Professor of Science Education, Ewha Womans University, Seoul, South Korea (2012–2013)
- Honorary Professor of Science and Environmental Studies, The Hong Kong Institute of Education, The University of Hong Kong, China (2013–2016)
- Attained level of Master (7th-degree Black Belt) from the Okinawa Isshinryu Karate Association, Okinawa, Japan (1982 to present)
Sami Kahn (second author) is a 26-year veteran science educator with extensive experience in classroom teaching, professional development, and curriculum development. Currently serving as a Presidential Doctoral Fellow in Science Education at the University of South Florida, she has authored numerous journal articles, including several in Science and Children, and has coauthored three books on enhancing scientific inquiry experiences for children and adults. She has served as an invited and keynote speaker at several state and national conferences, and most recently at an international STEM conference in Thailand. She is particularly known for her work in ensuring quality science opportunities for all children, including those with disabilities. In that capacity, she has served as president of Science Education for Students with Disabilities (SESD), an NSTA Associated Group dedicated to inclusive science practices, chair of the National Science Teachers Association’s Special Needs Advisory Board, and chair of the national awards committee for the Scadden Science Teaching Award. She also had the honor of serving as a delegate to the National Congress on Science Education, from which she was elected to represent the Congress as an NSTA national convention planning committee member. Ms. Kahn has successfully taught grades Kindergarten through college, as well as inservice professionals, and has won numerous awards for outstanding science teaching. She holds an MS in ecology and evolutionary biology and a JD with an emphasis in environmental law from Rutgers University. Prior to coming to University of South Florida, she most recently served as lower school science coordinator/teacher and K–12 science department chair at Collegiate School in New York City.
Ms. C. left the school office in a hurry, hastily grabbing her mail before heading to her first period biology class. Mondays were always a challenge, but today seemed especially so. It wasn’t even 8:00 and she had already been involved in a heated discussion of the new accountability measures being implemented in her school district; more tests, more requirements to meet Common Core, and more pressure to make sure her students made Adequate Yearly Progress or her performance evaluations would be on the line. “When did teaching become so stressful?” she thought. It was never an easy job, but the last few years felt especially weighty … less focused on the subject and students she loved, less creative, and definitely more stressful.

She took a deep breath as she entered her classroom. “Good morning!” she said with a somewhat forced smile. Almost immediately, she sensed something was different today… her ninth graders, usually sleepy on Monday mornings, were talkative and animated. The energy in the room was palpable.

“Hey, Ms. C, we were just arguing about the vaccine question from last week. I still think it’s wrong to make teenagers take vaccines!” said Alex.

“But they protect us!” exclaimed Janelle.

“That’s what the drug companies want you to think. What’s your evidence?” asked Vincent.

Ms. C’s ears pricked up as she was shocked to hear her students suddenly engaged in an impromptu discussion of … science!

“My group read an article about how the vaccine protects against cervical cancer, so it’s a good thing!” Janelle retorted.

“Yeah, but what was the source? Did you evaluate the source?” pressed Vincent.

Ms. C. smiled in awe. She didn’t know if the discussion on evaluating sources of evidence would sink in. It didn’t sound like the most exciting topic when she read about it, and yet, the students really enjoyed evaluating different websites and articles using the rubric she had provided. Maybe this new curricular approach was working.

“But our group found an article that said that vaccines were bad for you. There are side effects … even death!” replied Alex.

“Yeah, that’s the problem with science. There are always different reports. You never know what to trust!” added Crystal, in an exasperated tone.
“But that doesn’t mean you can’t trust it. Remember the whole nature of science thing? There’s always new information,” added Miguel.

Ms. C. felt a tingling feeling she hadn’t felt in years: that combination of pride and excitement that comes with knowing you’ve impacted your students’ lives.

“I don’t think it matters whether the vaccine helps or not. No one has the right to make me take a vaccine if I don’t want it. It’s my body! And I talked about this with my parents this weekend and they agree!” exclaimed Karla.

Ms. C. couldn’t believe her ears. She had never heard a peep from Karla, her quietest student. Yet today Karla was taking a stand, and she had clearly been talking (and thinking) about it over the weekend.

“Maybe this new SSI approach I’m trying is making a difference,” Ms. C. thought. In fact, her friend Mr. Alvarez, a Language Arts teacher, did mention that he heard some of Ms. C’s students discussing the vaccine argument in his class last Friday … science seemed to be spilling over into other parts of the day. And yet, Ms. C. really hadn’t made a huge change in her teaching. She had just decided to tweak her already-existing curriculum to include a few extra lessons that put the science content into a personal context that really motivated and challenged her students … and her.

Ms. C hated to interrupt the students, who at this point were engaged in a full debate. “Let’s take a look at what we’ve learned so far and see what we still need to discover!” she said.

It was going to be a good day … and a good year!
Unit 5

A Fair Shot?

Should Gardasil vaccines be mandatory for all 11–17-year-olds?

Unit Overview

During this unit, students will gain a rich understanding of the human immune system by studying the interactions between immunity and vaccinations, relationships between certain viruses and cancer, and the mechanisms of allergic reactions. By embedding this content into a controversial question about a mandatory vaccine, students gain insight into the personal, societal, and economic impacts of scientific innovations and learn the importance of informed participation in scientific policy debates.

Key Science Concepts

Human Immune Function, Allergic Response, Mechanisms of Antibiotics, Relationship of Genetics and Viruses to Cancer, Transmission and Prevention of STDs

Ethical Issues

Personal Freedom, Privacy Rights, Paternalism, Issues of Minors, Legal Consent, Economics of Medicine

Science Skills

Organizing Information, Observing, Understanding Cause and Effect, Communicating Results, Interpreting and Representing Data, Forming Arguments From Evidence
Grade Levels

High School Advanced Biology or Anatomy; can be adjusted for General Biology

Time Needed

The unit is comprised of five lessons of approximately 50 minutes each. Time can be adjusted depending on student content background.

Lesson Sequence

Lesson 1. Introduction: Should the Gardasil Vaccination Be Required for All 11–17 Year Olds? An Immune System Research Project
Lesson 2. The Biology of Cancer
Lesson 3. It Can’t Happen to Me! Sexually Transmitted Infection/Diseases
Lesson 4. The Art of Argument: Research and Debate
Lesson 5. Rethinking Positions and Relating the Gardasil Debate to the Nature of Science (NOS)

Background on the Issue

The goal of this unit is to promote respectful discourse among students while learning about vaccinations, the immune system, and cancer, as well as a current topic of global debate. The controversial aspect of this unit deals with the requirement of the Gardasil vaccine. The Gardasil vaccine protects against 4 of the 30–40 HPV (Human Papilloma Virus) types. Two of the four HPV types it protects against cause 90% of genital warts cases in males and females. The other two HPV types cause 75% of cervical, 70% of vaginal, and 50% of vulvar cancer cases in females (www.Gardasil.com). Gardasil is also effective in protecting against HPV-related anal and penile cancer in males. Several states have implemented requirements of vaccination for girls, with current pending legislation in many states for all students. Although the vaccine is highly efficacious against HPV, several groups have opposed mandatory legislation based on fears about vaccines in general, as well as privacy and personal autonomy rights. Equity and economic issues have also emerged given the fact that the vaccine is effective against genital warts and cancers for both males and females, but legislation has focused primarily on females due in part to the fact that penile and anal cancers in males are less common than the cancers in females, thus making the male vaccine less cost-effective. With that
said, the socioscientific issue (SSI) in this unit is: Should the vaccine be required for all males and females ages 11–17?

The methods that will be used to explore this SSI will include, but are not limited to, the use of technology, collaborative and cooperative groups, evoking ethos in order to engage students, videos, student presentations (students teaching students), inquiry-based microscope activities, discussions, student-based research, and student-led debates. This issue is a most timely and relevant one for young adults and is sure to inspire curiosity about the immune system, vaccinations, and the numerous considerations involved in rendering health care policies.

**Connecting to NGSS**

**HS-LS1-1.** Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.

**HS-LS1-2.** Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.

**HS-LS1-4.** Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

**HS-LS3-2.** Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) new genetic combinations through meiosis, (2) viable errors occurring during replication, and/or (3) mutations caused by environmental factors.

**HS-ETS1-3.** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

**Accommodations for Students With Disabilities**

**Visual Impairments:** This unit involves extensive research from print and online sources. Be sure to provide large-print handouts for low-vision students, use closed-circuit television for projection, or allow students to do all tasks on large computer monitors with screen magnification or enhancement software; blind students will require screen reading software or printed materials translated to Braille; if adaptive microscopes are not available, tactile models of cells can be created out of clay, puffy paints, or Wikki Stix; during the Lesson 3 simulation activity, have
all students describe their results verbally as they are appearing (i.e., “My liquid stayed clear!”) so that the visually impaired student(s) can fully participate.

**Hearing Impairments:** Give instructions in written and verbal formats; be sure to face the student when you are speaking to him/her (or the class); remind teammates and classmates to face student when speaking; during debates or class discussions, have student speakers give a signal (such as a slight hand wave) to alert student to the source of the sound; ask student to alert you to any confusion she or he is having with vocabulary word pairs that might sound alike or appear alike to a lip reading student (such as HPV and STD, B cells and T cells, and so on).

**Learning Disabilities:** Provide graphic organizers to help students keep track of the facts they learn and the arguments those facts support; use “wait time” for all students; provide students with highlighters, sticky notes, or other aids for organizing notes and readings; display group “Journeys Through the Immune System” projects in the classroom so that they can act as visual cues for important information during the remainder of the unit.

**Motor/Orthopedic Impairments:** Allow student to utilize alternative note-taking devices including voice-to-text software if writing is not feasible; microscope knobs can be enlarged by placing plastic wrap around the knob (for protection) and then covering the plastic with clay, making the microscope easier to manipulate; during the Lesson 3 simulation, make sure that the student has ample space for “mingle;” the cup can be attached to a wheelchair arm using Velcro so that the student can move around freely and mix the liquids as needed.

**Emotional Disabilities:** This unit involves several group activities. Remind all students that a large part of the process in working through meaningful socioscientific issues is practicing cooperative skills such as consensus-building, collaboration, compromise, and communication; allow students “time out” if discussions become too heated or behavior becomes inappropriate; allow students to express frustrations or challenges in appropriate ways, such as journaling, drawing, one-on-one conversations, or online discussion boards with you.

**Resources for Teachers**

- Gardasil: [www.gardasil.com](http://www.gardasil.com)
- National Institute of Allergy and Infectious Diseases: [www.niaid.nih.gov](http://www.niaid.nih.gov)
- Public Broadcasting Service: [www.pbs.org](http://www.pbs.org)
- National Cancer Institute: [www.cancer.gov](http://www.cancer.gov)
• PBS Learning Media: www.teachersdomain.org

Note: This unit is based on material submitted by Ashley Schumacher, Michael Caponero, Brian Brooks, and Bryan Kelly.
Lesson 1

Introduction

Should the Gardasil Vaccination Be Required for All 11–17-Year-Olds?
An Immune System Research Project

To the Teacher

In this initial lesson, students are confronted with a challenging issue that will evoke emotional reactions, but requires more scientific background than students will likely have to make a thoughtful, reasoned decision. After a brief introduction and discussion of the question, students will perform research on the human immune system and try to develop 10 evidence-based arguments for or against the issue. Students will discover that they need more information to complete this task. Students will then develop a project to communicate their understandings of the human immune system.

Objectives

Part 1

- Students will begin to consider the moral, ethical, scientific, and societal implications of this controversy and will attempt to formulate a sound decision on the issue.

Part 2

- Students will be assigned a creative project that will actively engage the students in learning about the immune system. Project Science Content objectives:
  1. The students will describe the function of the immune system.
2. The students will explain how the skin functions as a defense against disease.

3. The students will distinguish between a specific and nonspecific response.

4. The students will describe the actions of B cells and T cells in an immune response.

5. The students will describe the relationship between vaccination and immunity.

6. The students will describe what happens in an allergic response.

7. The students will describe at least one immune disorder.

8. The students will explain (diagram) the antigen-antibody reaction.

**Time Needed**

One period for Part 1; Part 2 can be done in class over 2–3 periods or as a group homework assignment using fewer class periods.

**Materials**

**Part 1**

- Student position statement handout

**Part 2**


- Computers with internet connection

**Procedure**

**Part 1**

1. Begin by asking the students if they would take a vaccination that would almost certainly prevent them from getting cancer. (Most students will say “yes.”) Then inform them that although there is a “high chance” that the
vaccine will prevent them from getting cancer, there is also a “small chance” that it may also cause them to become ill and even die in a different way. The students who answered “yes” might reconsider their answers, or they may find that the “high chance” outweighs the “small chance.” Provide time to hear the opinions of the students.

2. Present students with some general background information regarding the Gardasil vaccination (i.e., helps protect against certain viruses that can cause cancer, allergic reaction is possible, does not protect against all viruses, effective in both males and females who have not gotten exposed to virus).

3. Explain that several states are considering mandatory Gardasil vaccination program for all students ages 11–17. Allow the students to provide feedback regarding this scenario.

4. Distribute a copy of the “Student Position Paper” on which students will write their position on the issue for or against the mandatory vaccination program.

5. Ask the students if they are able to come up with the 10 supporting statements for their positions. It is assumed that most students were unable to meet this requirement; discuss statements to evaluate whether they are able to support their arguments with facts, or simply opinions.

6. Ask, “Do you have enough information to make an informed decision?” “If not, what other types of information do you need?”

Part 2

1. Assign the students to groups of 3 or 4.

2. Challenge groups to create a poster/PowerPoint/pamphlet/performance describing a “Journey Through the Immune System,” which will be presented to the class. The groups will be given a handout detailing the assignment and the required objectives. In order to prepare, groups will be given the “Understanding the Immune System” booklet and computers with internet access.

3. Allow two periods for the group research, development, and presenting of team projects.

4. Allow teams approximately 10 minutes to present their project followed by 5 minutes of questions and answers.
5. Ask students to revisit their argument sheets regarding the Gardasil question. Do they have enough information yet? If not, what is lacking? (understanding of cancer, relationship between virus and cancer, the nature of STDs)

**Closure**

Inform students that over the next several lessons, they will be learning more about the immune system, vaccinations, and cancer in order to make informed decisions about the Gardasil vaccine.

**Assessment (Homework)**

Students will watch the following video: [www.teachersdomain.org/asset/frntc10_vid_vaccines](http://www.teachersdomain.org/asset/frntc10_vid_vaccines).

The students will answer the following questions:

1. Through a published schedule and set of guidelines, the Centers for Disease Control and Prevention (CDC) and public health officials recommend that every child receive certain vaccinations by age 6. What are the benefits of this recommendation to public health officials, to the community, and to other children?

2. Some parents and health care professionals question the CDC’s recommendations and decide not to vaccinate their children, while others, like Jennifer Margulis, choose to vaccinate their children along an alternative schedule. How might her decision affect both her own children and others?

3. In what ways is vaccination different from other types of personal health decisions? Who should be involved in deciding whether children receive a specific vaccine?

4. Should the government have the right to compel vaccination? Should parents have the right to refuse it?
Student Position Statement

Should Gardasil be made a mandatory vaccination for all students ages 11–17? (Check one)

Yes (   ) No (   )

Provide at least 10 reasons or statements of evidence to support your claim:

1. ____________________________________________________________
   ____________________________________________________________

2. ____________________________________________________________
   ____________________________________________________________

3. ____________________________________________________________
   ____________________________________________________________

4. ____________________________________________________________
   ____________________________________________________________

5. ____________________________________________________________
   ____________________________________________________________

6. ____________________________________________________________
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7. ____________________________________________________________
   ____________________________________________________________

8. ____________________________________________________________
   ____________________________________________________________

9. ____________________________________________________________
   ____________________________________________________________

10. ____________________________________________________________
“Journey Through the Immune System”
Project Requirements

Using your prior knowledge, the “Understanding the Immune System” booklet (www.niaid.nih.gov/topics/immuneSystem/Documents/theimmunesystem.pdf) and valid internet sources, come up with a 10-minute presentation detailing a “journey” through the immune system that covers the following objectives:

1. Describe the function of the immune system.

2. Explain how the skin functions as a defense against disease.

3. Distinguish between a specific and nonspecific response.

4. Describe the actions of B cells and T cells in an immune response.

5. Describe the relationship between vaccination and immunity.


7. Describe at least one immune disorder.

8. Explain (diagram) the antigen-antibody reaction.

All presentations should include the following vocabulary:
Immunology, antigen, antibody, lymphocyte, leukocyte, thymus gland, bone marrow, B-cell, T-cell, macrophage, vaccine, antibiotic, inflammatory response, immune response, antihistamine, autoimmune disease, fever, helper T cell, pathogen, killer T cells, interferon

Be creative with your presentations! You may make them entertaining but they must include valid science knowledge and adhere to the specifications above.

Some suggestions: Posters, PowerPoint presentations, pamphlets, performances. Add graphics, cartoons, diagrams, or props that help convey the information.
### Journey Through the Immune System Scoring Rubric

| Did the project convey the required information? | ____ 30 pts. |
| Did the project include the required vocabulary? | ____ 20 pts. |
| Was the project's information accurate? | ____ 20 pts. |
| Did the members of the group participate equally? | ____ 10 pts. |
| Was the project presented clearly? | ____ 10 pts. |
| Was the project creative? | ____ 10 pts |

**Total Pts.__________ / 100**
Lesson 2
The Biology of Cancer

To the Teacher

Since the Gardasil vaccine protects against the HPV viruses that cause many vaginal, cervical, and vulvar cancers in women, as well as penile and anal cancer in men, it is essential that students understand the nature of cancer, the relationship between cancer and cellular reproduction, and the genetic mechanisms involved in cancer growth in order to understand the potential impact of the vaccine. In this lesson, students will compare normal and cancerous biopsy cells under the microscope, view an interactive website on cancer, and view a cancer PowerPoint handout to gain an understanding of the nature of cancer.

Objectives

• Students will apply their prior knowledge of cell reproduction.
• Students will learn about the cell biology of cancer based on cell reproduction.
• Students will learn about benign and malignant tumor cells.
• Students will learn there are many causes of cancer.
• Students will learn cancer stops the normal regulation of cell growth.
• Students will learn cancer develops as genetic damage of cells.

Time Needed

One class period

Materials

• Slides of biopsies positive for cancer
• Slides of healthy cells of same area as cancer biopsy slides
• Computers with internet access for groups of two
• Cancer PowerPoint handout (This can be found in the Resource section.)
• Links to videos (will be linked into the procedure at the accurate time)

Procedure

1. Students will be given two slides (one slide of healthy cells and one of cancer cells)

2. Students will be given no instructions other than “You are getting two slides of cells from the same area of the body.”

3. After students have been given time to observe and draw the two different types of cells they should come to the conclusion that there is something different with the two slides of cells. The teacher should lead them with a series of questions to the idea that the one of the slides shows cancer.

4. Students will then, in groups of two, go to the computers and view the interactive website: www.pbs.org/wgbh/nova/cancer/grow_flash.html.

5. Students will work together to answer the “Questions to Ponder” on the PowerPoint handout.

Closure

Ask, “How does our study of cancer relate to the question of whether the Gardasil vaccine should be mandated?”

Assessment

Students will be assessed on cell slide observations and responses to “Questions to Ponder” PowerPoint handout.
Cancer PowerPoint Questions to Ponder

(from www.cancer.gov/cancertopics/understandingcancer/cancer/page1)

Questions to Ponder

What within the cell has mutated to cause the mutated cell?

What might you expect to happen if the uncontrolled growth does not become controlled?

How might the uncontrolled growth be controlled?

Questions to Ponder

What causes cells to die?

Is cell death a good thing?

What happens if no cells die?
Questions to Ponder

Are cancerous growths green?

Do you think the cancerous groups from the first to the second picture and the second to the third picture happens in one cell division?

Questions to Ponder

What is a tumor (aka a neoplasm)?

Why is the green in picture three moving into the underlying tissue?

What does the green moving to the underlying tissue in picture three signify?
Questions to Ponder

What do the cancer cells invade?

What does metastasis mean?

What do you expect to happen after the cancer cells have started to grow in the new location?

Questions to Ponder

Do these pictures look like anything we saw in class today?

Which column do you think is the cancerous cells? Which column represents the normal cells?
Questions to Ponder

What do you think hyperplasia and dysplasia mean (without looking it up, try to use the pictures to figure it out)

What causes the cancer (invasive) to leave the area of cells?

Questions to Ponder

Using your prior knowledge, name three causes of cancer (preferably one of each type but if you can’t come up with one of each you can state multiple causes of the same type)
Questions to Ponder

What is a kind of virus linked with cancer we have discussed in this unit?

Questions to Ponder

What do you notice from this slide?

Does this slide encourage you to get the Gardasil vaccination?
Questions to Ponder

Which Pap smear resembles which slide we looked at during class today?

Questions to Ponder

What does benign mean?

What does benign mean in regards to a tumor?

Do benign tumor cells turn into malignant tumor cells?
Lesson 3

It Can’t Happen to Me!

Sexually Transmitted Infections and Diseases

To the Teacher

In this powerful simulation activity, students will model the spread of STDs through populations. By using water and indicators to mimic the sharing of bodily fluids tainted with infection, students will experience the vulnerability of being a recipient, the responsibility involved in potentially spreading a disease to others, and the swiftness with which these diseases can travel. Students will then engage in research to debunk common misconceptions about these diseases.

Objectives

• Students will learn how STDs can travel undetected through a population.
• Students will learn about common misconceptions involving STDs.
• Students will learn about valid science vs. pseudoscience.

Time Needed

One class period

Materials

Part 1: Simulation Activity

• 1 clear plastic cup for each student
• Phenolphthalein
• Sodium hydroxide (tablet)
Part 2: Myth-Busting Research

- STDs Fact or Fiction sheet
- Computers with internet access

Preparation for Activity

Before students arrive to class, fill *one plastic cup per student* a little less than half-full with water. Numbers may be written on the bottom of each cup to complete a transmission diagram afterward; however, this is not necessary. Add one NaOH tablet to ONE of the half-filled cups and allow it to dissolve. It will look and smell like water. The person who receives this cup will be the source of the infection!

Procedure

Part 1

1. As students enter the class, have each student select a plastic cup.

2. After students are seated, explain to them that this liquid represents their immune systems. Ask, “Does your fluid look suspicious?” Does it smell funny?” “Does it look different than your neighbors?’”

3. Instruct them that they are to mingle as if they were at a party while music is playing. Once the music stops they will share the fluids in their cups with the student closest to them by completing the following procedure. (Model this.) They will pour the contents of their cup into the other student’s cup. Now the other student’s cup will be full. The second student will then pour all of the contents of his cup into the first student’s cup. Finally, the first student will fill the second student’s cup half-full and be seated.

4. Repeat the music, mingle, and mix procedure several times (three times is sufficient but more can be done).

5. Once you stop the music for the last time, have students return to their seats and ask the following questions: “Does your fluid look ‘infected’ now?” “Does anybody feel like a ‘risk-taker’?” “Knowing that one of you is
infected, and assuming that you are the one, how do you feel about having shared your infection with others?"

6. Begin testing for STDs by the following process: Drop one drop of phenolphthalein into a student’s cup. If it turns pink, then he or she has been infected. If it stays clear, he or she is healthy.

Closure for Part 1

1. Ask, “Do we know which person was first infected?” (No, but the first transmission might be able to be determined by how deep a color their liquid turned.)

2. Ask, “How does this activity mimic the transmission of communicable disease?”
   - A person who is infectious frequently does not exhibit any outward symptoms at the beginning of an illness so it is not always possible to tell who is ill by sight;
   - Communicable diseases are easily spread through a variety of methods including simply touching an area that an infectious person has recently touched. This activity mimics the rapidity with which a communicable disease can move through a population.

Extension for Part 1

This activity can be repeated by having students “mix” with half of the original number of partners. Students will see the vast reduction in the number of infections.


Procedure

Part 2

1. Students will be divided into groups of four students. Each group will be given four statements from the “Fact or Fiction” list.

2. The groups will have 10 minutes to research the statements to determine if they are fact or fiction.
3. Students will come back together to present their conclusions to the class.

4. Review answers for the fact or fiction sheet.

**Assessment**

Students write a reflection paper about their experience with the simulation and the “fact or fiction” discussion. Papers should include thoughts about knowledge gained, insights into their own behaviors or feelings, and any questions they still may have.

**Scoring Rubric**

<table>
<thead>
<tr>
<th>1 pt.</th>
<th>2 pts.</th>
<th>3 pts.</th>
<th>4 pts.</th>
<th>5 pts.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflection fails to convey information on knowledge gained or reflect on student's own behaviors or feelings, or remaining questions.</td>
<td>Reflection includes some insights into student's own behaviors or feelings, but fails to include any information on knowledge gained or questions remaining.</td>
<td>Reflection conveys information on knowledge gained, but fails to reflect on student's own behaviors or feelings.</td>
<td>Reflection conveys information on knowledge gained, insights into student's own behaviors or feelings, and any remaining questions, but does so in an unclear or confused manner.</td>
<td>Reflection conveys information on knowledge gained, insights into student's own behaviors or feelings, and any remaining questions in a clear and thoughtful manner.</td>
</tr>
</tbody>
</table>
STDs: FACT OR FICTION

STD facts

1. Birth control pills do not prevent sexually transmitted diseases from being contracted.
2. Over 95% of all STDs are contracted through sexual intercourse.
3. Most STDs can be treated.
4. There is no cure for herpes or AIDS.
5. STDs cannot be transmitted by touching doorknobs, drinking fountains, or swimming in a public pool.
6. Once you are cured of an STD, you can get it again.
7. The AIDS virus must pass from one person’s body fluids into another’s bloodstream for the second person to get the disease.
8. Most AIDS patients in the United States are homosexual or bisexual men.
9. AIDS can be spread by heterosexual contact between men and women.
10. AIDS can be spread through contaminated needles.
11. An unborn fetus can be infected with syphilis while in the uterus.
12. An unborn fetus cannot contract gonorrhea while in the uterus, but may contract the disease when an infected mother’s “bag of water” breaks before delivery.
13. An estimated 40% of males and 80% of females infected with gonorrhea have no visible symptoms, but they may pass the disease to a sexual partner.
14. If a woman receives no treatment or insufficient treatment for gonorrhea, sterility may occur.
15. A person can still be infected with syphilis even though the syphilitic chancre goes away.
16. Syphilis can remain dormant for years and then cause heart or brain damage, or even cause death.
17. Mental illness, blindness, paralysis, and heart disease are all symptoms of syphilis.
18. If a woman has an active case of genital herpes, she may infect her baby during delivery.
19. The doctor of a woman with genital herpes may suggest a cesarean delivery so the baby does not have to pass through the infected birth canal.
20. Women who are infected with genital warts or herpes may develop cancer of the cervix.
21. Condoms help protect against many STDs, but are not 100% effective.
22. If two people are free from STDs and have no other sexual partners, they will likely never have any STDs.
23. Chlamydia can cause pelvic inflammatory disease (PID) which can lead to infertility.
24. Genital warts are caused by a virus and spread by sexual contact.
25. An individual who has been exposed to genital warts may not notice any symptoms for 6–8 months.
26. Some STD strains are becoming resistant to present medications that are available.
27. Many STDs have latent stages where no visible symptoms are present.
28. A baby born to a mother with active genital herpes may not survive, or may be physically or mentally damaged.

Source: www.uen.org/Lessonplan/downloadFile.cgi?file=4357-6-10096-Fact_or_Fiction.pdf&filename=Fact_or_Fiction.pdf
Lesson 4
The Art of Argument
Research and Debate

To the Teacher

During this final phase of the unit, students will be assigned to roles either for or against the mandatory vaccination of 11–17 year olds. They will collaboratively research their sides of the debate, which will be held during the next class period.

Objectives

• Students will review the information they have learned about the human immune system, vaccines, STDs, and cancer.
• Students will produce valid arguments supported by scientific evidence.
• Students will learn about listening to each other’s points of view in a critical manner.

Materials

Computers with internet access

Procedure

1. Inform students that they are randomly being assigned to teams for the mandatory vaccine debate. Reassure them that they will have a chance to voice their actual opinions after the debate.

2. Instruct the students of common sides to get together and subdivide the debate into the following smaller groups:
   a. Opening Statement Group will make introductory claims present evidence.
b. *Cross Examination Group* will ask clarifying questions of the opposing group (this group must try to anticipate the claims and evidence of the other team and must listen *very carefully* during the debate in order to develop additional questions).

c. *Rebuttal Group* will present rebuttals to the opposing team (this group also must try to anticipate the claims and evidence of the other team and must also listen *VERY CAREFULLY* during the debate in order to develop additional rebuttals).

d. *Closing Statement Group* will summarize the points and try to make a final, persuasive argument for the “judge.”

3. The students should have an opportunity to reconvene with their entire team to review the debate roles.

4. On the day of the debate, allow students 5 minutes to review their roles and notes.

5. Each group will have 3 minutes (for a combined time of 24 minutes for both teams) to make their arguments or pose their questions.

6. At the completion of the debate, distribute the grading rubric to students and ask them to assess the various roles.

7. Compare student assessments with your assessment.

**Closure**

Ask, “What were the most compelling arguments? Why?” “Did the opposing team make any arguments or present evidence that you did not anticipate?” “What, if anything, surprised you during this process?”

Remind students that they will have a chance to discuss their actual opinions on the issue during the next class.

**Assessment**

Students will be assessed on the debate rubric (see Debate Assessment Sheet, p 216).
# Debate Assessment Sheet

<table>
<thead>
<tr>
<th></th>
<th><strong>Affirmative</strong> (Vaccine should be mandatory.)</th>
<th><strong>Negative</strong> (Vaccine should not be mandatory.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opening Statement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strength of claims and evidence</td>
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<tr>
<td></td>
<td>Clarity</td>
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<tr>
<td><strong>Cross-Examination</strong></td>
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<td></td>
<td>Strength of questions</td>
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<td>Clarity</td>
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<tr>
<td><strong>Rebuttal</strong></td>
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</tr>
<tr>
<td></td>
<td>Strength of arguments and evidence</td>
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<td>Clarity</td>
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<tr>
<td><strong>Closing Statement</strong></td>
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<tr>
<td></td>
<td>Strength of arguments and evidence</td>
<td></td>
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<tr>
<td></td>
<td>Clarity</td>
<td></td>
</tr>
<tr>
<td><strong>Total Score</strong></td>
<td></td>
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</tbody>
</table>

**Scoring:** Scale of 1 (low) to 5 (high)

**Maximum Score:** 40 points per team
Lesson 5
Rethinking Positions and Relating the Gardasil Debate to the Nature of Science (NOS)

To the Teacher

During this final lesson, students will have an opportunity to revisit their original position statement from the first lesson in order to form more complete arguments and reassess their positions. They will also discuss possible compromises in regard to the issue. Finally, students will consider the Nature of Science (NOS) aspects of the Gardasil debate, particularly the qualities of scientific evidence, the source(s) of scientific authority, the differences between scientific and non-scientific reasoning, and the impact of science in society. Students will work in groups to create an NOS/Gardasil poster.

Objectives

• Students will evaluate their previous positions and reflect on any changes.
• Students will submit an updated position worksheet.
• Students will work in groups to discuss NOS and create group posters regarding their conceptions of NOS in relation to the Gardasil controversy.

Materials

• Student original position statement handout and a fresh copy of the handout
• Student NOS reflection handout
• Poster paper
• Markers
Procedure

1. Begin by asking the class to review their original position statement on Gardasil and ask whether their positions on the controversy may have changed from the first day of this unit to the current day. Time will be provided to any students who wish to disclose their responses to the class. Ask, “Are there any ‘compromises’ that could be made to bring the group to an agreement?” (mention that many states have, “opt-out” policies for families who object to the vaccine, perhaps a narrower age requirement, and so on).

2. Distribute a fresh copy of the position statement and provide students with ample time to give their current position as well as the required 10 statements of evidence or reasoning that support their position.

3. Divide the class into small groups. Assign the groups the task of discussing the NOS topics on the handout (attached resource), which relate to the controversy.

4. Each group will then compose a poster on their ideas regarding the NOS questions they discussed.

5. Groups will present their posters and a closing discussion on NOS will take place.

Closure

Ask, “How did you feel about this unit?” “What is the most important thing you learned?”

Assessment

The students will be evaluated by

- the quality of their position statements,
- their responses to class discussion questions, and
- the NOS group discussions and presentations.
NOS Group Discussion/Presentation Rubric

<table>
<thead>
<tr>
<th></th>
<th>1 pt.</th>
<th>2 pts.</th>
<th>3 pts.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sources of Evidence</strong></td>
<td>Group fails to demonstrate understanding of the importance of credibility of sources.</td>
<td>Group conveys understanding of the analysis of credibility assigned to different sources, but fails to accurately identify factors impacting credibility.</td>
<td>Group conveys understanding of the analysis of credibility assigned to different sources of evidence and is able to accurately identify factors impacting credibility.</td>
</tr>
<tr>
<td><strong>Diversity of Conclusions</strong></td>
<td>Group fails to recognize different conclusions on the issue.</td>
<td>Group conveys that different conclusions can be reached on an issue, but attributes it to a lack of valid research.</td>
<td>Group conveys understanding that different conclusions can be validly reached on the same issue.</td>
</tr>
<tr>
<td><strong>Scientific vs. Nonscientific Claims</strong></td>
<td>Group fails to distinguish between scientific and non-scientific claims.</td>
<td>Group attempts to distinguish between scientific and non-scientific claims but does so with inaccuracies.</td>
<td>Group accurately distinguishes between scientific and non-scientific claims.</td>
</tr>
</tbody>
</table>

Nature of Science Discussion Guide

Use these questions to guide your discussion and the creation of your poster.

- What does the controversy regarding Gardasil show us about the nature of scientific claims and their relevance to society? Do some scientific claims hold more weight than others in societal decisions? Do some other claims and forms of reasoning hold more weight in societal decisions?

- There are proponents for mandatory Gardasil vaccinations who hold valid scientific arguments and reasoning, and there are opponents who also have valid scientific arguments and reasoning. Is a differing of scientific inferences and interpretations of data a strength of science or is it a weakness?

- What makes a scientific claim different than a non-scientific claim? What are the necessary components of a scientific claim?

- What are valid sources of scientific information? What is required for valid scientific knowledge to become produced? Does valid scientific knowledge come from a singular authority, with a set method?
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Page numbers printed in **boldface** type refer to tables or figures.

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This book encourages scientific literacy by showing you how to teach the understanding and thinking skills your students need to explore real-world questions like these:

- Should schools charge a “fat tax” to discourage kids from eating unhealthy foods?
- Should local governments lower speed limits to reduce traffic fatalities?
- Should pharmaceutical companies be allowed to advertise prescription drugs directly to consumers?

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

Both practical and content-rich, It’s Debatable! doesn’t shy away from controversy. Instead, the authors encourage you and your students to confront just how messy the questions raised by science (and pseudoscience) can be. After all, as the authors note, “The only way for our students to be prepared for participation in societal discourse is to have practice in their school years, and what better place than the science classroom?”

"Functional scientific literacy requires an understanding of the nature of science and the skills necessary to think both scientifically and ethically about everyday issues."

—from the introduction to It’s Debatable!
USING PHYSICS
GADGETS & GIZMOS
GRADERS 9–12
PHENOMENON-BASED LEARNING

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Matthew Bobrowsky, PhD

Dr. Matt Bobrowsky has been involved in scientific research and science education for several decades. He served for four years at the University of Maryland as director of the Physics Lecture Demonstration Facility—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’s teaching is always innovative because he uses pedagogical techniques that are based on current science education research and known to be effective. 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 and the Board of Regents’ Faculty Award for Excellence in Teaching.

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 that high school book.)

Mikko has obtained numerous grants for his school and students, including those from the NOT science school and the Viksu science competition, 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 Fulbright Distinguished Awards in Teaching, which brought him to the University of Maryland, where he worked with Matt Bobrowsky. Most recently, Mikko received the Distinguished Science Teacher Award in 2013 from the Technology Industries of Finland Centennial Foundation.

JUKKA KOHTAMÄKI

Jukka Kohtamäki obtained his master of science 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 that high 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.

In science, there are many phenomena that are difficult to understand at first. Most physics books are written so that the theory—that is, the mathematical description—comes first, and demonstrations and applications are presented only afterward. In this book, by contrast, the goal is for you to first watch something happen and then to 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 (Champagne, Gunstone, and Klopfer 1985; Crouch and Mazur 2001; Chi and Roscoe 2002). 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. Ideas for how to approach the phenomena can be found in the introductions to the chapters. 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; Verley 2008; Gray et al. 2008). In our PBL approach, we don’t artificially create boundaries within phenomena. Rather, we try to look at physical phenomena very broadly.

PBL is different from project-based or problem-based learning. In project-based learning, the student is given a project that provides the context for learning. The problem with this is that the student is not necessarily working on the project out of curiosity but simply because they are required to by the teacher. To avoid having students view the project as a chore or just a problem that they have to solve, we employ PBL: The student’s own curiosity becomes the drive for learning. The student explores not by trudging through a problem to get to the correct answer but by seeing an interesting phenomenon and wanting to understand what’s going on. This works because interest and enthusiasm do not result from the content alone; they come from the students themselves as they discover more about a phenomenon. Personal experience with a phenomenon is always more interesting and memorable than a simple recitation of facts (Jones 2007; Lucas 1990; McDade 2013).

The goal in project-based learning is for the students to produce a product, presentation, or performance (Moursund 2013). PBL does not have that requirement; students simply enjoy exploring and discovering. This is the essence of science, and it is consistent with the philosophy of the Next Generation Science Standards (NGSS). Rather than simply memorizing facts that will soon be forgotten, students are doing real science. They are engaged in collaboration, communication, and critical thinking. Through this, students obtain a deeper understanding of scientific knowledge and see a real-world application of that knowledge—exactly what was envisioned with the NGSS. This is why, at the end of each chapter, we provide a list of relevant standards from the NGSS, further emphasizing our focus on the core ideas and practices of science, not just the facts of science.

The objective of PBL is to get the students’ brains working with some phenomenon and have them discussing it in groups. A gizmo’s functions, in most cases, also make it possible for teachers to find common misconceptions that students may harbor. It is important to directly address misconceptions because they can be very persistent (Clement 1982, 1993; Nissani 1997). Often the only way to remove misconceptions is to have students work with the problem, experiment, think, and discuss, so that they can eventually experience for themselves that their preconception is not consistent with what they observe in the real world.

We must also keep in mind that students can’t build up all the physics laws and concepts from scratch by themselves—unless you are lucky enough to have the next Newton or Einstein as one of your students. Students will definitely need some support and instruction. When doing experiments and learning from them, the students must have some qualitative discussions (to build concepts) and some quantitative work (to learn the measuring process and make useful calculations). Experience with both reveals the nature of physical science.

“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, you might be struck by the fact that there is not very much textual material. That is 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 (Pressure Power) 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 physics with other group members, practice using the “language of physics,” and internalize the physics 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.

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. 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 group 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 physics 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. Out of 74 countries, in 2009 Finland ranked 2nd in science and 3rd in reading. (The United States ranked 23rd and 17th, respectively.) In 2012, Finland ranked 5th in science and 6th in reading. (The United States ranked 28th and 24th, respectively.) 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 even 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 the students 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

Hands-on activities in science classrooms and laboratories help make learning science fun. In order to also make the activities safer, certain precautions must be followed based on legal standards and professional best practices. In this book, activities have appropriate and important safety notes listed that need to be followed for a safer experience. Prior to any activities taking place, students need to receive safety training, have a safety assessment, and sign and date (along with parents or guardians) a safety acknowledgement form.

REFERENCES


Energy is an essential part of all branches of physics. In mechanics, energy appears as both potential and kinetic energy. Gravitational potential energy depends on an object’s weight and how high the object is raised. An object has kinetic energy if it is moving from one place to another (translational kinetic energy) or if it is rotating (rotational kinetic energy). When sound is produced, mechanical waves carry energy, while in light waves the photon—a massless particle—carries the energy. With electrical devices, we can change electrical energy to many other forms of energy. Heat energy is involved in changes in temperature and states of matter. The law of conservation of energy tells us that energy does not vanish but only changes form. We encounter this when we speak about energy consumption or energy use.

In the following experiments, we will examine the conservation of energy and how energy can change from one type to another.
ENERGY ON WHEELS

The Introductory Energy and Motion Lab, with its car on a track (Figure 3.1), is used to study conservation of mechanical energy. When discussing mechanical energy, it is useful to distinguish between two types of energy: kinetic energy and potential energy.

**Procedure**

1. Set up the car track so that you can adjust the inclination.
2. Place the speedometer and photogate at the end of the track.
3. Measure the height from which the car starts.
4. Measure the speed of the car with the photogate.
5. Write down the values of the height, \( h \), and the final velocity, \( v \).
6. Repeat the test, but change the car’s starting height.

**Questions**

- Does the car’s starting height affect its final speed? Explain.
- Draw a graph showing the final speed as a function of starting height.
- Calculate the square of the final speed values, \( v^2 \), and draw a graph of the square of the final speed as a function of starting height.
- Determine the slope of the curve from the graph. Derive the value of the slope theoretically, assuming that the car’s starting potential energy changes completely to kinetic energy.

▼

**SAFETY NOTE**

Wear safety glasses or goggles.

**FIGURE 3.1: Car on a track**
DANCING DISC

Kinetic energy can be translational, rotational, or both. In this experiment with Euler's Disc (Figure 3.2), we learn what factors affect the magnitude of the rotational energy as well as its conservation.

Procedure
1. Place the mirrored surface securely on a flat surface.
2. Spin the metal disc on the mirrored surface so that it rotates rapidly.
3. Watch the rotation of the disc.

Questions
- Why does the disc spin for so long?
- What determines how much rotational energy there is?
- Does the disc eventually stop? Explain.

SAFETY NOTES
- Wear safety glasses or goggles.
- Use caution when handling the glass and metal mirrors; they may have sharp edges that can cut skin.
HOT SHOT

The physics of collisions is always interesting. In a collision, kinetic energy quickly changes into other forms of energy such as sound or heat. Here we use the Colliding Steel Spheres (Figure 3.3) to learn about this phenomenon.

Procedure

1. Bang the spheres together so that they collide while holding a sheet of paper between them.
2. Repeat the test by changing the force on the spheres and the thickness of the paper.
3. Repeat the test using aluminum foil instead of paper.

Questions

• What happens to the paper where the balls collide? How does the thickness of the paper or the speed of the balls affect the outcome?
• What happens when you use foil instead of paper? How can the pattern in the foil be explained?
RADIANT ROTATION

Crookes Radiometer (Figure 3.4) was originally designed to measure radiation pressure. A few years after its invention, it was found that the explanation that had been given for the rotation of the vanes in terms of radiation pressure was not correct. It turned out that the radiometer does not measure radiation pressure, but it does demonstrate some interesting physics.

Procedure

1. Observe the radiometer in direct sunlight outside.
2. Take it inside and warm it up with a hairdryer.
3. Move the radiometer to a place much colder than the room, such as a freezer.

Questions

• What are some possibilities for why the radiometer vanes are rotating?
• Is the direction of rotation in a cold place different from the direction when the radiometer is in the sunlight or heated by the hairdryer?

SAFETY NOTE

Wear safety glasses or goggles.

FIGURE 3.4: Crookes Radiometer
Magnetic Accelerator

In nature, the amount of energy in an isolated (or closed) system does not increase or decrease. The energy can only be converted from one form to another. Balls normally lose a lot of kinetic energy during collisions. In the following experiment using the Magnetic Accelerator (Figure 3.5), you will investigate whether that is always the case.

Procedure

1. Set aside the magnetic ball.
2. Put one of the other balls at the top of the track and let it go.
3. When the first ball has settled on the bottom of the track, put the second ball at the top of the track and let it go.
4. Repeat this with the third ball.
5. Repeat this with the magnetic ball that you set aside earlier.
6. Finally, place the fifth ball at the top of the track and let it go.

Questions

• What forms of energy was the potential energy of the first ball converted to?
• How do you explain the results from the last two balls?
HAPPY / UNHAPPY BALLS

In elastic collisions, the kinetic energy remains unchanged, whereas in inelastic collisions at least some kinetic energy gets transformed to other forms of energy. The properties of the materials that the colliding bodies are made of determine whether the collision is more elastic or inelastic. The Happy / Unhappy Balls (Figure 3.6) are used to demonstrate this.

Procedure

1. Drop the two balls onto the floor and see what happens.
2. Simultaneously roll the balls on the floor or down an incline and see what happens.
3. Place the balls in a freezer for at least a few hours and perform the drop and rolling tests again.

Questions

• Describe the behavior of each ball when you bounce it. Why does the unhappy ball act differently than the happy ball? Where does the energy of the unhappy ball go?
• Describe the behavior of each ball when you roll it. Why does the unhappy ball act differently than the happy ball?
• Does the same explanation work for both the balls’ bouncing behavior and their rolling behavior?
• Did the results change when the balls were frozen? Explain.

SAFETY NOTES

• Wear safety glasses or goggles.
• Use caution when balls are dropped on the floor as they can cause a slip, trip, or fall hazard.

FIGURE 3.6: Happy / Unhappy Balls
The Dropper Popper (Figure 3.7) works somewhat like a super ball. It is dropped onto the floor, and it bounces back from the floor.

Procedure
1. Load the Popper by turning its edges down.
2. Drop the Popper from a height of 1 m.

Questions
- How high does the Popper bounce relative to its starting height? Why?
- What are the Popper’s sources of energy?
ASTROBLASTER

The Astroblaster (Figure 3.8) is a toy consisting of five bouncy balls of different sizes stacked on a stick.

Procedure
Drop the Astroblaster from a height of about 0.5 m.

Questions
• One of the balls acts differently from the rest. Explain what it does and why.
• Explore what percentage of the initial energy the ball can end up having. (A video camera might help you with this investigation.)

SAFETY NOTE
Wear safety glasses or goggles.
The car in the Introductory Energy and Motion Lab (Figure 3.9) demonstrates how potential energy becomes partly transformed to kinetic energy. You perform work when you lift an object (in this case, the car) because you are working against the force of gravity. The work \( W \) done by a constant force, \( F \), is equal to the force times the distance, \( x \), over which the force is applied:

\[
W = Fx
\]

As the object is raised, the energy from the work done is stored as additional potential energy, \( \Delta E_p \):

\[
\Delta E_p = W
\]

The average lifting force equals the weight of the object, \( mg \).

\[
F = mg
\]

When lifting an object, the distance, \( x \), equals the height, \( h \), so, combining these equations, we have that the change in potential energy is

\[
\Delta E_p = mgh
\]

When the car rolls down the track, potential energy is converted to kinetic energy. A greater starting height means that the car has more potential energy, so when the car gets to the bottom of the track, more energy has been transformed to kinetic energy. Therefore, increasing the starting height will increase the final speed of the car.

In reality, not all of the potential energy gets converted into kinetic energy. Some of the energy is lost due to friction, air resistance, sound, and heat. However, these losses are fairly small and, because the length of the track doesn’t change, these losses are approximately constant as the starting height is changed.

The resultant kinetic energy is equal to the potential energy:

\[
mgh = \frac{1}{2}mv^2
\]

From this, the lifting height can be related to the final velocity:

\[
h = \frac{v^2}{2g}
\]

or

\[
v^2 = 2gh
\]

When the square of the final velocity is graphed as a function of the starting height, a straight line is formed with a slope of \( 2g \).
DANCING DISC

Euler’s Disc (Figure 3.10) is edge-rounded and polished so that the frictional force is minimized during its rotation on the mirrored surface. The rotation continues not only because there is little friction but also because the metal disc has a large mass. A large mass increases the moment of inertia and therefore the rotational energy. The rotational energy, $E_{\text{rot}}$, is related to the moment of inertia, $I$, and the angular velocity, $\omega$, as follows:

$$E_{\text{rot}} = \frac{1}{2} I \omega^2$$

Finally, the rotation of the metal disc eventually stops because of work done by friction and air resistance. Some of the energy gets converted to sound and some to heat.

Extension

If you have the toys that go with Chapter 8 (“Angular Momentum”), then you have a plastic stick called a rattleback or celt (it is flat on the top and curved on the bottom). Spin the rattleback first clockwise and then counterclockwise. What happens?

In the rattleback, the center of mass does not exactly coincide with the rotational axis, and the point at which the rattleback touches the table is not located on the rotational axis. This means that the friction at this point produces a torque. This torque slows the rotation, makes the rattleback wobble, and then causes the rattleback to turn in the opposite direction. The wobbling movement changes the rotational motion because of the shape of the rattleback, which produces a torque that makes the rattleback twist a little bit as it wobbles, and this twisting makes it rotate more. Watch it closely to see the motion change among all three axes.
HOT SHOT

In the “Hot Shot” exploration, students watch as two metal spheres collide (Figure 3.11). The impact of steel spheres is very close to a perfectly elastic collision, meaning very little of the balls’ kinetic energy is lost. Some of the kinetic energy, however, is converted to other forms of energy such as heat and sound. The spheres are massive (weighing about 1 lb each), and therefore the kinetic energy in the collision is rather high. The spherical shape of the steel spheres and their small radii causes the energy to be concentrated in a very small volume. Heat energy in the collision burns the paper or melts the aluminum foil.

Hitting the spheres together with more force increases the amount of heat energy. When the collision energy increases, a larger hole is burned in the paper or the pattern of waves in the aluminum is larger. In that case, the greater amount of energy melted more of the aluminum and made a larger wave pattern. The heat is quickly transmitted to the environment as the aluminum solidifies.

RADIANT ROTATION

Crookes radiometer (Figure 3.12; also known as a light mill) is a good example of the conversion of heat energy to kinetic energy. In this case, the explanation is not quite so simple. The radiometer contains a partial vacuum, with an air pressure of perhaps only $10^{-5}$ that of normal atmospheric pressure. The vanes in a radiometer are white on one side and black on the other. The black surfaces absorb radiation (e.g., either visible light, such as sunlight, or infrared) better and warm up faster than the white surfaces.

One of the earliest explanations was that, because of the warmth of the black surface, the air molecules near that surface heat up and begin to move faster. Some of the molecules then bounce away from the surface, causing an impulse that pushes the vane. A sufficient number of air molecules bouncing off is what causes the vanes of the radiometer to rotate in the direction of the white surfaces.

The problem with this explanation is that it turns out that even though the faster-moving air molecules on the black side create more force, those fast-moving molecules also do a better job of keeping other air molecules from hitting the black surface. The net effect is that there should be no extra force pushing on the black side. But it turns out that there is an excess force on the black side at the edges of the vanes. That’s actually where the force arises that turns the vane. (One can’t deduce this just by watching the radiometer. Here you are mainly looking for plausible explanations that have some supporting evidence based on the observations and the students’ prior knowledge.)

When the radiometer is cooled, the black surfaces emit heat more efficiently and therefore become cooler than the white surfaces. Then, with the edge effects working in the opposite direction, the direction of the rotation is opposite, so that the black sides are the leading sides.
MAGNETIC ACCELERATOR

The Magnetic Accelerator (Figure 3.13) activity explores the impact magnets have on potential energy. Each ball’s potential energy is converted into kinetic energy and then into sound energy and, due to resistance forces such as friction and air resistance, into heat. The fourth ball, which is magnetic, accelerates just before its impact with other balls, thereby producing enough energy to cause the end ball to fly off the end of the ramp. The same occurs with the last ball, for which the magnetic ball is at rest, because the approaching ball accelerates rapidly because of the magnetic force pulling it forward.

The collisions are almost elastic, and the kinetic energy of the ball is transferred to the last ball in line, which is far enough from the magnetized ball to not be noticeably affected by its magnetic field. The last ball has so much energy from the collision that it easily leaves the ramp.

HAPPY / UNHAPPY BALLS

The two balls in this exploration look similar (Figure 3.14). However, the balls are made of different materials. The difference is detected when the balls are dropped or rolled on the floor. The “happy” ball bounces, but the “unhappy” ball does not bounce. In addition, the happy ball rolls more easily than the unhappy ball. Conversely, if the balls are frozen, the unhappy ball bounces higher than the happy ball.

Rubber is characterized by the fact that it rapidly returns to its original shape after it is deformed. Deformation occurs when the ball strikes the ground. The happy ball is made of a kind of rubber that returns to its original form much faster than the rubber of the unhappy ball. The kinetic energy that the balls have before a collision is converted to heat (due to friction causing random motion of the molecular structures), and also to potential energy of molecular structure (like compressing a spring), and back again to kinetic energy. With the happy ball, more potential energy is converted to kinetic energy. With the unhappy ball, a lot of the energy is converted to heat because of internal friction.

The balls’ different responses are related to the level of elasticity in the collision. The happy ball bounces because the collision is elastic. The unhappy ball does not bounce; the collision is inelastic. When the balls roll on the floor, the unhappy ball rolls more slowly than the happy ball because there is more friction between the unhappy ball and the floor. The properties of the different rubber compounds change as the balls are frozen. The happy ball loses its elasticity, whereas the unhappy ball’s elasticity is increased.
**DROPPER POPPER**

At the start of the experiment, the edges of the Dropper Popper (Figure 3.15) are turned down. This takes energy, and that energy is stored in the Popper. When the Popper hits the ground, the stored (potential) energy is released as the edges return to their original position. This means that not only is the gravitational potential energy converted to kinetic energy as the Popper falls, but that additional kinetic energy is also obtained from the stored potential energy in the flexed edges of the Popper. Consequently, the Popper jumps to a height greater than its original height.

**ASTROBLASTER**

The balls of the Astroblaster (Figure 3.16), which are stacked on a stick, are very elastic and bouncy, making the collisions between them almost elastic. When the Astroblaster hits the floor, kinetic energy is transferred from the lower, more massive balls, up to the higher, smaller balls. If the kinetic energy is transferred from a more massive ball to a less massive ball, the less massive ball must move faster. In other words, if \( \frac{1}{2}mv^2 \) is constant, then the ball with the lower mass must have the higher velocity. The ball that bounced highest did so for that reason and because it ended up with much of the kinetic energy.

Another experiment you can perform with the Astroblaster is to measure how high the stack of balls bounces with and without the top ball. This will tell you something about the amount of energy taken from the other balls, since they won’t bounce as high when the top ball is included.
Web Resources

Some basic concepts and terminology of kinetic energy.
www.physicsclassroom.com/Class/energy/USL1c.cfm

Learn about kinetic energy, potential energy and friction by creating simulations of skateboarding ramps.
http://phet.colorado.edu/en/simulation/energy-skate-park-basics

See how a pendulum gains and loses kinetic and potential energy as it swings.
www.cirln.org/weblinks/details.cfm?id=6646

Explore elastic collisions of balls in two dimensions. Change the mass ratio and the impact parameter.
http://physics.usask.ca/~pywell/p121/Notes/collision/collision.html

Investigate the translation and rotation of a rolling disk.
www.schulphysik.de/suren/Applets/Kinematics/Roll/RollApplet.html

See the position, velocity, and acceleration vectors for a point on the rim of a rolling object.
www.phys.hawaii.edu/~teb/java/ntnujava/FreeRolling/FreeRolling.html
Relevant Standards

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

**PERFORMANCE EXPECTATIONS**

**HS-PS3-1**
Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

**HS-PS3-2**
Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects).

**HS-PS3-3**
Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy. [Integrates science and engineering]

**HS-PS3-5**
Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

**SCIENCE AND ENGINEERING PRACTICES**

**Developing and Using Models**

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.
Planning and Carrying Out Investigations

Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Create a computational model or simulation of a phenomenon, designed device, process, or system.

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

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

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system’s total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.

- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.

- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

PS3.B: Conservation of Energy and Energy Transfer

- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.

- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.

- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.

- The availability of energy limits what can occur in any system.

- Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
PS3.C: Relationship Between Energy and Forces

- When two objects interacting through a field change relative position, the energy stored in the field is changed.

PS3.D: Energy in Chemical Processes

- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

CROSSCUTTING CONCEPTS

Energy and Matter

- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

- Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.
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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 waaaaaay more cool

What student—or teacher—can resist the chance to experiment with Rocket Launchers, Drinking Birds, Dropper Poppers, Boomwhackers, Flying Pigs, and more? The 54 experiments in *Using Physics Gadgets and Gizmos, Grades 9–12*, encourage your high school students to explore a variety of phenomena involved with pressure and force, thermodynamics, energy, light and color, resonance, buoyancy, two-dimensional motion, angular momentum, magnetism, and electromagnetic induction.

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 physics facts. *Using Physics Gadgets and Gizmos* can help them learn broader concepts, useful critical-thinking skills, and science and engineering practices (as defined by the *Next Generation Science Standards*). And—thanks to those Boomwhackers and Flying Pigs—both your students and you will have some serious fun.
Argument-Driven Inquiry in Biology

Lab Investigations for Grades 9–12

Victor Sampson, Patrick Enderle, Leeanne Gleim, Jonathon Grooms, Melanie Hester, Sherry Southerland, and Kristin Wilson

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Argument-Driven Inquiry in Biology

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The *Next Generation Science Standards* (NGSS Lead States 2013) outline a new set of expectations for what students should know and be able to do in science. The overarching goal of the NGSS, as defined by the National Research Council (NRC) in *A Framework for K–12 Science Education* (NRC 2012), is

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

To accomplish this goal, teachers will need to help students become proficient in science by the time they graduate from high school. The NRC suggests that students need to understand four core ideas in the life sciences, be aware of seven crosscutting concepts that span the various disciplines of science, and learn how to participate in eight fundamental scientific practices in order to be considered proficient in science (NRC 2012). The three dimensions of the Framework, which form the basis for the NGSS, are summarized in Figure 1.

**FIGURE 1**

The three dimensions of the framework for the NGSS

<table>
<thead>
<tr>
<th>Life Sciences Core Ideas</th>
<th>Crosscutting Concepts</th>
<th>Scientific Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>From molecules to organisms: Structures and processes</td>
<td>• Patterns</td>
<td>• Asking questions</td>
</tr>
<tr>
<td>Ecosystems: Interactions, energy, and dynamics</td>
<td>• Cause and effect: Mechanism and explanation</td>
<td>• Developing and using models</td>
</tr>
<tr>
<td>Heredity: Inheritance and variation of traits</td>
<td>• Scale, proportion, and quantity</td>
<td>• Planning and carrying out investigations</td>
</tr>
<tr>
<td>Biological evolution: Unity and diversity</td>
<td>• Systems and system models</td>
<td>• Analyzing and interpreting data</td>
</tr>
<tr>
<td></td>
<td>• Energy and matter: Flows, cycles, and conservation</td>
<td>• Using mathematics and computational thinking</td>
</tr>
<tr>
<td></td>
<td>• Structure and function</td>
<td>• Constructing explanations</td>
</tr>
<tr>
<td></td>
<td>• Stability and change</td>
<td>• Engaging in argument from evidence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Obtaining, evaluating, and communicating information</td>
</tr>
</tbody>
</table>
The NRC also calls for teachers to use new instructional approaches that are designed to foster the development of science proficiency. This book will help teachers accomplish this task by providing a set of 27 lab investigations that were designed using an innovative approach to laboratory instruction called Argument-Driven Inquiry (ADI). The lab investigations are aligned with the content, crosscutting concepts, and scientific practices outlined in the NRC Framework. These lab investigations allow students to develop the disciplinary-based literacy skills outlined in the Common Core State Standards, for English language arts (NGAC and CCSSO 2010), because the ADI instructional model calls for students to give presentations to their peers; respond to questions; and then write, evaluate, and revise reports as part of each lab. Thus, this book can help teachers make lab instruction more meaningful for students and enable students to learn more inside the school science laboratory.

References


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ABOUT THE AUTHORS

Victor Sampson is an associate professor of science education and the director of the Center for Education Research in Mathematics, Engineering, and Science (CERMES) at Florida State University (FSU). He received a BA in zoology from the University of Washington, an MIT from Seattle University, and a PhD in curriculum and instruction with a specialization in science education from Arizona State University. Victor taught high school biology and chemistry for nine years before taking his current position at FSU. He specializes in argumentation in science education, teacher learning, and assessment. To learn more about his work in science education, go to www.vicsampson.com.

Patrick Enderle is a research faculty member in CERMES at FSU. He received his BS and MS in molecular biology from East Carolina University. Patrick then spent some time as a high school biology teacher and several years as a visiting professor in the Department of Biology at East Carolina University. He then attended FSU, where he graduated with a PhD in science education. His research interests include argumentation in the science classroom, science teacher professional development, and enhancing undergraduate science education.

Leeanne Gleim received a BA in elementary education from the University of Southern Indiana and a MS in science education from FSU. While at FSU, she worked as a research assistant for Dr. Sampson. After graduating, she taught biology and honors biology at FSU Schools, where she participated in the development of the Argument-Driven Inquiry (ADI) model. Leeanne was also responsible for writing and piloting many of the lab investigations included in this book.

Jonathon Grooms received a BS in secondary science and mathematics teaching with a focus in chemistry and physics from FSU. Upon graduation, Jonathon joined FSU’s Office of Science Teaching, where he directed the physical science outreach program Science on the Move. He entered graduate school at FSU and earned a PhD in science education. He now serves as a research scientist in CERMES at FSU.

Melanie Hester has a BS in biological sciences with minors in chemistry and classical civilizations from Florida State University and an MS in secondary science education from FSU. She has been teaching for more than 20 years, with the last 13 at the FSU School in Tallahassee. Melanie was a Lockheed Martin Fellow and a Woodrow Wilson fellow and received a Teacher of the Year award in 2007. She frequently gives presentations about innovative approaches to teaching at conferences and works with preservice teachers. Melanie was also responsible for writing and piloting many of the lab investigations included in this book.

Sherry Southerland is a professor at Florida State University and the co-director of FSU-Teach. FSU-Teach is a collaborative math and science teacher preparation program between the College of Arts and Sciences and the College of Education.
She received her BS and MS in biology from Auburn University and her PhD in curriculum and instruction from Louisiana State University, with a specialization in science education and evolutionary biology. Sherry has worked as a teacher educator, biology instructor, high school science teacher, field biologist, and forensic chemist. Her research interests include understanding the influence of culture and emotions on learning—specifically evolution education and teacher education—and understanding how to better support teachers in shaping the way they approach science teaching and learning.

Kristin Wilson attended Florida State University and earned a BS in secondary science teaching with an emphasis in biology and Earth-space science. Kristin teaches biology at FSU School. She helped develop the ADI instructional model and was responsible for writing and piloting many of the lab investigations found in this book.
INTRODUCTION

The Importance of Helping Students Become Proficient in Science

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

In the past decade, however, the importance of learning how to participate in scientific practices has not been acknowledged in state standards. In addition, many states have attempted to make their science standards “more rigorous” by adding more content to them rather than designing them so they emphasize the core ideas and crosscutting concepts described by the National Research Council (NRC) in *A Framework for K–12 Science Education* (NRC 2012). The increasing number of science standards, along with the pressure to “cover” them that results from the use of high-stakes tests targeting facts and definition, has unfortunately forced teachers “to alter their methods of instruction to conform to the assessment” (Owens 2009, p. 50). Teachers, as a result, tend to focus on content and neglect the practices of science inside the classroom. Teachers also tend to move through the science curriculum quickly to ensure that they cover all the standards before the students are required to take the high-stakes assessment.

The current focus on covering all the standards, however, does not seem to be working. For example, *The Nation’s Report Card: Science 2009* (National Center for Education Statistics 2011) indicates that only 21% of all 12th-grade students who took the National Assessment of Educational Progress in science scored at the proficient level. The performance of U.S. students on international assessments is even bleaker, as indicated by their scores on the science portion of the Programme for International Student Assessment (PISA). PISA is an international study that was launched by the Organisation for Economic Co-operation and Development (OECD) in 1997, with the goal of assessing education systems worldwide; more than 70 countries have participated in the study. The test is designed to assess reading, math, and science achievement and is given every three years. The mean score for students in
the United States on the science portion of the PISA in 2012 is below the international mean, and there has been no significant change in the U.S. mean score since 2000 (OECD 2012; see Table 1). Students in countries such as China, Korea, Japan, and Finland score significantly higher than student in the United States. These results suggest that U.S. students are not learning what they need to learn to become proficient in science, even though teachers are covering a great deal of material.

**TABLE 1**

<table>
<thead>
<tr>
<th>Year</th>
<th>U.S. mean score*</th>
<th>U.S. rank/Number of OECD countries assessed</th>
<th>Top three performers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>499</td>
<td>14/27</td>
<td>Korea (552)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Japan (550)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Finland (538)</td>
</tr>
<tr>
<td>2003</td>
<td>491</td>
<td>22/41</td>
<td>Finland (548)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Japan (548)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hong Kong-China (539)</td>
</tr>
<tr>
<td>2006</td>
<td>489</td>
<td>29/57</td>
<td>Finland (563)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hong Kong-China (542)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Canada (534)</td>
</tr>
<tr>
<td>2009</td>
<td>499</td>
<td>15/43</td>
<td>Japan (552)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Korea (550)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hong Kong-China (541)</td>
</tr>
<tr>
<td>2012</td>
<td>497</td>
<td>36/65</td>
<td>Shanghai-China (580)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hong Kong-China (555)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Singapore (551)</td>
</tr>
</tbody>
</table>

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

Source: OECD 2012

In addition to the poor performance of U.S. students on national and international assessments, empirical research in science education indicates that a curriculum that emphasizes breadth over depth and neglects the practices of science can actually hinder the development of science proficiency (Duschl, Schweingruber, and Shouse 2007; NRC 2005, 2008). As noted in the Framework (NRC 2012),
K–12 science education in the United States fails to [promote the development of science proficiency], in part because it is not organized systematically across multiple years of school, emphasizes discrete facts with a focus on breadth over depth, and does not provide students with engaging opportunities to experience how science is actually done.” (p. 1)

The NRC goes on to recommend that science teachers spend more time focusing on key ideas to help students develop a more enduring understanding of biology content. They also call for science teachers to start using instructional strategies that give students more opportunities to learn how to participate in the practices of science. Without this knowledge and these abilities, students will not be able to engage in public discussions about scientific issues related to their everyday lives, to be consumers of scientific information, or to have the skills needed to enter a science or science-related career. We think the school science laboratory is the perfect place to focus on key ideas and engage students in the practices of science and thus to help them develop the knowledge and abilities needed to be proficient in science.

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

Laboratory activities look rather similar in most high school classrooms (we define a school science laboratory activity as “an opportunity for students to interact directly with the material world using the tools, data collection techniques, models, and theories of science” [NRC 2005, p. 3]) (Hofstein and Lunetta 2004; NRC 2005). The teacher usually begins a laboratory activity by first introducing his or her students to a concept through a lecture or some other form of direct instruction. The teacher then gives the students a hands-on task to complete. To support students as they complete the task, teachers often provide students with a worksheet that includes a procedure explaining how to collect data, a data table to fill out, and a set of analysis questions. The hope is that the experience gained through completion of the hands-on task and worksheet will illustrate, confirm, or otherwise verify the concept that was introduced to the students at the beginning of the activity. This type of approach, however, is an ineffective way to help students understand the content under investigation, learn how to engage in important scientific practices, improve communication skills, or develop scientific habits of mind (Duschl, Schweingruber, and Shouse 2007; NRC 2005). Most laboratory activities therefore do little to promote the development of science proficiency.

One way to address this problem is to change the focus of laboratory instruction. A change in focus will require teachers to place more emphasis on “how we know” (i.e., how new knowledge is generated and validated) in addition to “what we know” about life on Earth (i.e., the theories, laws, and unifying concepts). Science teachers will also need to focus more on the abilities and habits of mind that students
need to have in order to construct and support scientific knowledge claims through argument and to evaluate the claims or arguments made by others (NRC 2012). As explained in the Framework (NRC 2012), argumentation (i.e., the process of proposing, supporting, and evaluating claims) is essential practice in science:

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

The NRC therefore calls for argumentation to play a more central role in the teaching and learning of science.

In addition to changing the focus of instruction, teachers will need to change the nature of laboratory instruction to promote and support the development of science proficiency. To change the nature of instruction, teachers need to make laboratory activities more authentic by giving students an opportunity to engage in scientific practices instead of giving them a worksheet with a procedure to follow and a data table to fill out. These activities, however, also need to be educative for students in order to help student develop the knowledge and abilities associated with science proficiency; students need to receive feedback about how to improve and teachers need to help students learn from their mistakes.

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

Organization of This Book
The remainder of this book is divided into two parts. Part I begins with two text chapters describing the ADI instructional model and the development and components of the ADI lab investigations. Part II contains the lab investigations, including notes for the teacher, student handouts, additional information for students, and checkout questions. Four appendixes contain standards alignment matrices, timeline and proposal options for the investigations, and a form for assessing the investigation reports.
References


Lab 7. Transpiration: How Does Leaf Surface Area Affect the Movement of Water Through a Plant?

**Teacher Notes**

**Purpose**
The purpose of this lab is for students to apply their understanding of transpiration in plants to determine how the structure of leaves can influence the rate of transpiration. This lab also gives students an opportunity to design and carry out a controlled experiment. Students will also learn about the nature of scientific investigation and the difference between observation and inference.

**The Content**
Plants have pores, or stoma, on the underside of leaves. The stomata allow carbon dioxide (CO₂) to enter the plant. Plants need CO₂ for photosynthesis and to prevent desiccation. However, plants also lose a great deal of water through the stomata due to evaporation. The evaporation of water from the plant drives transpiration, but too much water loss can dry out the plant and kill it (especially when there is very little water available in the soil). Although this may seem like a huge problem for the plant, the stomata will open and close in relationship to the turgor pressure of the guard cells around it to help control water loss. Plants have also adapted various structural characteristics to prevent water loss, including thick waxy cuticles, change in leaf shape (decreasing the surface area of leaves decreases water loss), and change in leaf size (having lots of small leaves actually reduces overall surface area).

**Timeline**
The instructional time needed to implement this lab investigation is 180–250 minutes. Appendix 2 (p. 391) provides options for implementing this lab investigation over several class periods. Option E (250 minutes) should be used if students are unfamiliar with scientific writing because this option provides extra instructional time for scaffolding the writing process. You can scaffold the writing process by modeling, providing examples, and providing hints as students write each section of the report. Option F (180 minutes) should be used if students are familiar with scientific writing and have the skills needed to write an investigation report on their own. In option F, students complete stage 6 (writing the investigation report) and stage 8 (revising the report) as homework.
**Materials and Preparation**

The materials needed to implement this investigation are listed in Table 7.1. The bean plants should be germinated and growing approximately 3 weeks prior to the start of the investigation. A minimum of three seedlings with leaves is needed for each group (nine is ideal, six is recommended). Plants need to be seedlings. Bean plants work the best and germinate easily, but other plants can be used. Plants with fibrous root systems work best.

**TABLE 7.1**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test tubes, 150 mm × 15 mm</td>
<td>6 per group</td>
</tr>
<tr>
<td>Test tube rack</td>
<td>1 per group</td>
</tr>
<tr>
<td>Graduated cylinder, 25 ml</td>
<td>1 per group</td>
</tr>
<tr>
<td>Beaker, 600 ml</td>
<td>1 per group</td>
</tr>
<tr>
<td>Bean plants (3 weeks old)</td>
<td>6 per group</td>
</tr>
<tr>
<td>Graph paper</td>
<td>6 sheets per group</td>
</tr>
<tr>
<td>Ruler</td>
<td>1 per group</td>
</tr>
<tr>
<td>Electronic balance</td>
<td>3 per class</td>
</tr>
<tr>
<td>Floodlight or plant stand with light</td>
<td>1 per group</td>
</tr>
<tr>
<td>Glass stirring rod</td>
<td>1 per group</td>
</tr>
<tr>
<td>Student handout</td>
<td>1 per student</td>
</tr>
<tr>
<td>Investigation proposal A*</td>
<td>1 per group</td>
</tr>
<tr>
<td>Whiteboard, 2’ × 3†</td>
<td>1 per group</td>
</tr>
<tr>
<td>Peer-review guide and instructor scoring rubric</td>
<td>1 per student</td>
</tr>
<tr>
<td>Safety goggles and aprons</td>
<td>1 per student</td>
</tr>
</tbody>
</table>

* It is recommended but not required that students fill out an investigation proposal for this lab; it is not necessary to do so if students already know how to design a controlled experiment.

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

**Topics for the Explicit and Reflective Discussion**

**Concepts That Can Be Used to Justify the Evidence**

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

- The process of evaporation
- The process of transpiration
- The role that water and CO₂ play in the process of photosynthesis
- Why calculating a rate (change over a period of time) of water loss is useful for making comparisons

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

**How to Design Better Investigations**

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

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

**Crosscutting Concepts**

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

- *Cause and Effect: Mechanism and Explanation*: One of the main objectives of science is to identify and establish relationships between a cause and effect. It is also important to understand the mechanisms by which these causal relationships are mediated.
- *Scale, Proportion, and Quantity*: Students need to understand that it is critical for scientists to be able to identify what is meaningful or relevant at different scales or time periods.
- *Energy and Matter: Flows, Cycles and Conservation*: Scientists often strive to learn more about how energy and matter move into, out of, and within an organism to develop a better understanding of how that organism functions.
• *Structure and Function:* Students need to understand that the way an object is shaped or an organism is structured will influence what the object or organism is able to do or how it responds to changes. Scientists can examine the structure of a living thing and make inferences about how it functions.

**The Nature of Science and the Nature of Scientific Inquiry**

It is important for students to understand the difference between observations and inferences in science. An observation is a descriptive statement about a natural phenomenon, whereas an inference is an interpretation of an observation. Students should also understand that current scientific knowledge and the perspectives of individual scientists guide both observations and inferences. Thus, different scientists can have different but equally valid interpretations of the same observations due to differences in their perspectives and background knowledge.

It is also important for students to understand that **scientists use different methods to answer different types of questions.** Examples of methods include experiments, systematic observations of a phenomenon, literature reviews, and analysis of existing data sets; the choice of method depends on the objectives of the research. There is no universal step-by-step biology vs. physics) and fields within a discipline (e.g., ecology vs. molecular biology) use different types of methods, use different core theories, and rely on different standards to develop scientific knowledge.

You should discuss and provide examples of these two important concepts of the nature of science (NOS) and the nature of scientific inquiry (NOSI) during the explicit and reflective discussion.

**Hints for Implementing the Lab**

• Review structures of a plant before starting the investigation.
• Review the definition and calculation of surface area before starting the investigation.
• Students need to be very careful with the seedlings so as not to harm the root system when putting them in the test tubes. Larger test tubes are preferred.
• It is important for future calculations that students carefully record the total amount of water they place in each test tube.
• Remind students to measure the total water left in the tube using a graduated cylinder.
• Encourage students to think of different ways to test total surface area, such as small leaves versus large leaves, number of leaves on the seedlings (none, one, two, or three), and one-size leaves versus mixed-size leaves.
LAB 7

• As an alternative to tracing leaves on graph paper, groups can use mass to determine leaf surface area. This method requires an electronic balance. Use the following procedure:
  1. Cut all the leaves (not stems) off the plant and determine their mass using a balance.
  2. Estimate the total leaf surface area in square centimeters for the plant by cutting out a section of leaf 5 cm × 5 cm.
  3. Determine the mass for this leaf section and divide by 25 cm² to find the mass of 1 cm² of leaf.
  4. Divide the total mass of the leaves by the mass of 1 cm² to find the total leaf surface area.

• When groups measure surface area using graph paper, make sure they remove all the leaves. Partial boxes will require them to estimate; be sure to have students think about ways to reduce measurement error due to estimation. One way is to have multiple students in the group make an estimate and then take an average.

Topic Connections
Table 7.2 provides an overview of the scientific practices, crosscutting concepts, disciplinary core ideas, and supporting ideas at the heart of this lab investigation. In addition, it lists NOS and NOSI concepts for the explicit and reflective discussion. Finally, it lists literacy and mathematics skills (CCSS ELA and CCSS Mathematics) that are addressed during the investigation.
## Transpiration

**How Does Leaf Surface Area Affect the Movement of Water Through a Plant?**

### TABLE 7.2

<table>
<thead>
<tr>
<th>Lab 7 alignment with standards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scientific practices</strong></td>
</tr>
<tr>
<td>• Asking questions</td>
</tr>
<tr>
<td>• Developing and using models</td>
</tr>
<tr>
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Lab 7. Transpiration: How Does Leaf Surface Area Affect the Movement of Water Through a Plant?

Lab Handout

Introduction

Plants, just like other organisms, must be able to transport materials from one part to another. Plant transport systems consist of two large tubes made of vascular tissue that run from the roots through the shoots and to the tips of the plant. Sugars produced through the process of photosynthesis are transported through plants from leaves to roots via the vascular tissue known as the phloem. Cells use these sugars to produce the energy needed for the rest of the plant’s functions. Sugars move through the plant because they are in highest concentration in the leaves, where photosynthesis takes place, and in lowest concentration in the roots. Many plants will store excess sugars in specialized root structures called tubers.

Water is transported in plants from the roots to the leaves through the vascular tissue known as the xylem. The water then enters the leaf and is used in the process of photosynthesis. In a tree such as the giant redwood of California, water must ascend over 300 ft. to reach the highest leaves. The water moves through the plant because the concentration of water is highest in the roots of a plant and lowest in the leaves. Transpiration, or loss of water from the leaves due to evaporation, helps to create a lower concentration of water (or lower osmotic potential) in the leaf. The differences in water concentration are also responsible for the movement of water from the xylem to the mesophyll layer of the leaves and subsequently out to the atmosphere (see the figure on the next page).

The transpiration rate of a plant (or how quickly water is lost from the leaves due to evaporation) is influenced by a number of environmental factors. One of the most important factors is air temperature; evaporation rates increase as the temperature goes up. Plants that live in hot locations, therefore, can lose large amounts of water from their leaves because of transpiration. When there is plenty of water in the soil, like after a heavy rain, replacing the water that is lost from the leaves because of transpiration is not a problem. However, when water is scarce and the temperature is high, plants can quickly dry out and die. Some plants, therefore, have specific adaptations that enable them to help control water loss. One such adaption could be the number or size of leaves found on a plant.

Your Task

Determine if there is a relationship between leaf surface area (i.e., the total number of leaves or the size of the leaves found on a plant) and transpiration rate.

The guiding question of this investigation is, How does leaf surface area affect the movement of water through a plant?
Transpiration

How Does Leaf Surface Area Affect the Movement of Water Through a Plant?

The structure of a leaf featuring the major tissues: the upper and lower epidermis, the palisade and spongy mesophyll, and the guard cells of the stoma.

Vascular tissue (veins), made up of xylem and phloem are also shown. The light green circles within cells represent chloroplasts and indicate which tissues undergo photosynthesis.

Materials

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

- 6 Test tubes (150 mm × 15 mm)
- Test tube rack
- Graduated cylinder (25 ml)
- 6 Bean plants (about 3 weeks old)
- Graph paper
- Ruler
- Beaker (600 ml)
- Electronic balance
- Floodlight or plant stand with light
- Glass stirring rod
- Safety goggles and aprons

Safety Precautions

1. Safety goggles and aprons are required for this activity.
2. Use caution when working with electrical equipment. Keep away from water sources in that they can cause shorts, fires, and shock hazards. Use only GFI-protected circuits.
LAB 7

3. Lightbulbs can get hot and burn skin. Use caution and handle with care!
4. Wash hands with soap and water after completing this lab.
5. Follow all normal lab safety rules.

Getting Started

To answer the guiding question, you will need to design and conduct an experiment. To accomplish this task, you must be able to measure the transpiration rate of a plant. You can use the following procedure to measure a transpiration rate (see the figure to the left):

1. Pour 15 ml of tap water into a test tube.
2. Place one plant without soil on the roots into the test tube of water (be careful not to damage the roots).
3. Gently push the roots to the bottom of the tube. (The eraser end of a pencil works well for this, as does a glass stirring rod.)
4. Place this tube into a test tube rack in a warm and lighted place in the room for at least 24 hours (48 hours is better).
5. Remove the plant from the tube.
6. Remove leaves and trace on graph paper to determine total surface area.
7. Measure the amount of water left in the test tube.
8. Calculate the transpiration rate using the following equation:

\[
\text{Transpiration rate} = \frac{\text{original amount of water} - \text{amount of water left}}{\text{minutes}}
\]

This procedure will allow you to measure the rate at which water moves through the plant. Now you must determine what type of data you will need to collect, how you will collect it, and how will you analyze it for your actual investigation. To determine what type of data you will need to collect, think about the following question:

- What type of measurements will you need to record during your investigation?

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

- What will serve as a control (or comparison) condition?
- What types of treatment conditions will you need to set up and how will you do it?
- How many trials will you need to do?
- How often will you collect data and when will you do it?
Transpiration

How Does Leaf Surface Area Affect the Movement of Water Through a Plant?

• How will you keep track of the data you collect and how will you organize the data?

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

• How will you determine if there is a difference between the treatment conditions and the control condition?

• What type of calculations will you need to make?

• What type of graph could you create to help make sense of your data?

**Investigation Proposal Required?**   □ Yes   □ No

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

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

• the importance of identifying the underlying cause for observations,

• what is and what is not relevant at different scales or time frames,

• how matter moves within or through a system,

• how structure determines function in living things,

• the difference between observations and inferences in science, and

• the different methods scientists can use to answer a research question in science.

**Argumentation Session**

Once your group has finished collecting and analyzing your data, prepare a whiteboard that you can use to share your initial argument. Your whiteboard should include all the information shown in the figure to the right.

To share your argument with others, we will be using a round-robin format. This means that one member of your group will stay at your lab station to share your group’s argument while the other members of your group go to the other lab stations one at a time to listen to and critique the arguments developed by your classmates.

The goal of the argumentation session is not to convince others that your argument is the best one; rather, the goal is to identify errors or instances of faulty reasoning in the arguments so these mistakes can be fixed. You will therefore need to evaluate the content of the claim, the quality of the evidence used to support the claim, and the strength of the justification of the evidence included in each argument that you see. In order to critique an argument, you will need more information...
than what is included on the whiteboard. You might, therefore, need to ask the presenter one or more follow-up questions, such as:

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

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

**Report**

Once you have completed your research, you will need to prepare an investigation report that consists of three sections that provide answers to the following questions:

1. What question were you trying to answer and why?
2. What did you do during your investigation and why did you conduct your investigation in this way?
3. What is your argument?

Your report should answer these questions in two pages or less. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!
Lab 7. Transpiration: How Does Leaf Surface Area Affect the Movement of Water Through a Plant?

Checkout Questions

1. Plant A and plant B both have the same number of leaves; however, plant B leaves are overall larger in size. If both plants were placed in a hot environment, which plant would undergo transpiration at greater rate?
   a. Plant A
   b. Plant B
   Why?

2. Observations and inferences are the same.
   a. I agree with this statement.
   b. I disagree with this statement.

   Explain your answer, using examples from your investigation about transpiration.

3. The investigation that you conducted is an example of a controlled experiment.
   a. I agree with this statement.
   b. I disagree with this statement.

   Explain your answer, using information from your investigation about transpiration.
4. An important goal in science is to explain the underlying cause for observations. Explain why this is important, using an example from your investigation about transpiration.

5. Scientists often need to be aware of the issue of time when designing an investigation. Explain why time frames can influence the outcomes of an investigation, using an example from your investigation about transpiration.

6. Scientists often need to track how matter moves in, out, and through a system during an investigation. Explain why this is important, using an example from your investigation about transpiration.

7. Structure is related to function in living things. Explain why, using an example from your investigation about transpiration.
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Are you interested in using argument-driven inquiry for high school lab instruction but just aren’t sure how to do it? You are not alone. This book will provide you with both the information and the instructional materials you need to start using this method right away. *Argument-Driven Inquiry in Biology* is a one-stop source of expertise, advice, and investigations.

The book is broken into two basic parts:

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