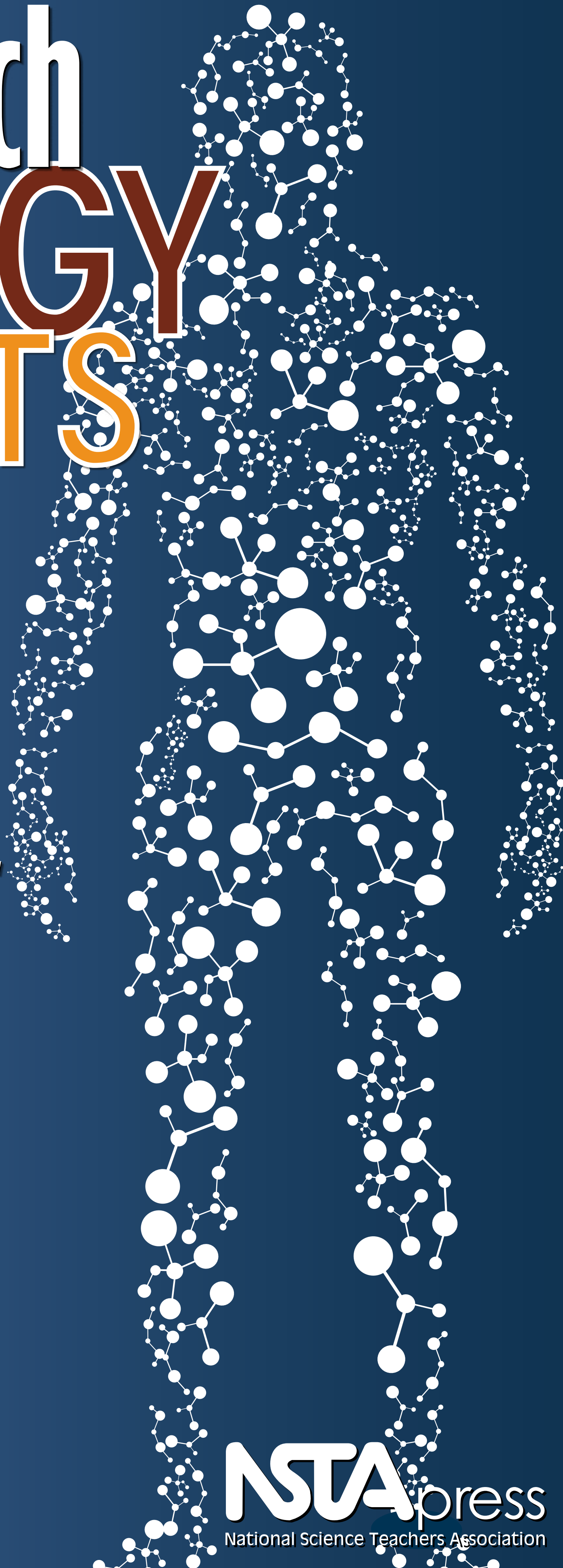
Hard-to-Teach BIOLOGY CONCEPTS

Revised 2nd Edition

Designing Instruction Aligned to the *NGSS*



By Susan Koba and Anne Tweed

NSTA press
National Science Teachers Association

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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.

About the Authors

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*.

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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 Stroupe 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.

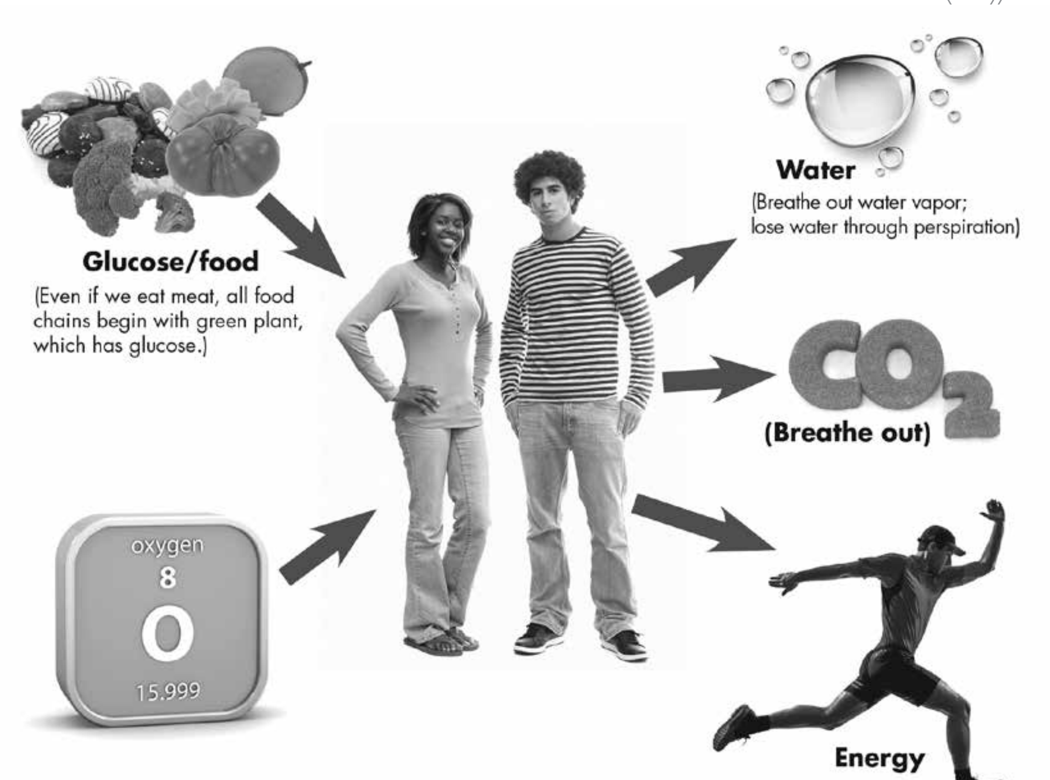
The book is made up of two parts: Part I, The Toolbox: A Framework, Strategies and Connections (Chapters 1–4), and Part II, Toolbox Implementation: The Framework and Strategies in Practice (Chapters 5–8). In Part I, we share our instructional planning framework and tools and outline the connection between 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

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*.



Cellular Respiration takes place in the cell.

Chapter 5

Matter and Energy in Organisms and Ecosystems

By Cynthia Long

As a high school science teacher, research scientist, curriculum and professional developer, and current director of education, one topic that consistently rises to the top of hard-to-teach concepts is cellular respiration, and in the bigger context, matter and energy.

Students need to make the connection between the abstract or unseen and concrete events that are obvious to them. For example, they know they somehow get energy (abstract) and they know they need to eat (concrete). Somehow this "magic" happens in their bodies, but since they can't see it, this leap from eating to energy becomes irrelevant. Helping students understand the relevancy and importance of matter and energy as it relates to human consumption and flow of matter through body systems into cells and then converted into usable energy for their everyday lives is at the heart of this chapter. With this topic, I want students to know why they are studying something called cellular respiration by connecting it to tasks they do every single day. Working with scientists, teachers, and curriculum developers throughout my career has afforded me access to different perspectives, expertise, and backgrounds. Over several years, I tried activities, refined ideas, altered the order, and so on. It was definitely iterative and not everything always worked the first time. Discussing ideas with colleagues and even the students influenced this development. All of this helped me as a teacher put together a unit of study for students that facilitated their learning and guided the development of their understanding in an authentic way. And, it ultimately helped me put together this chapter.

Phase 1: Identifying Essential Content

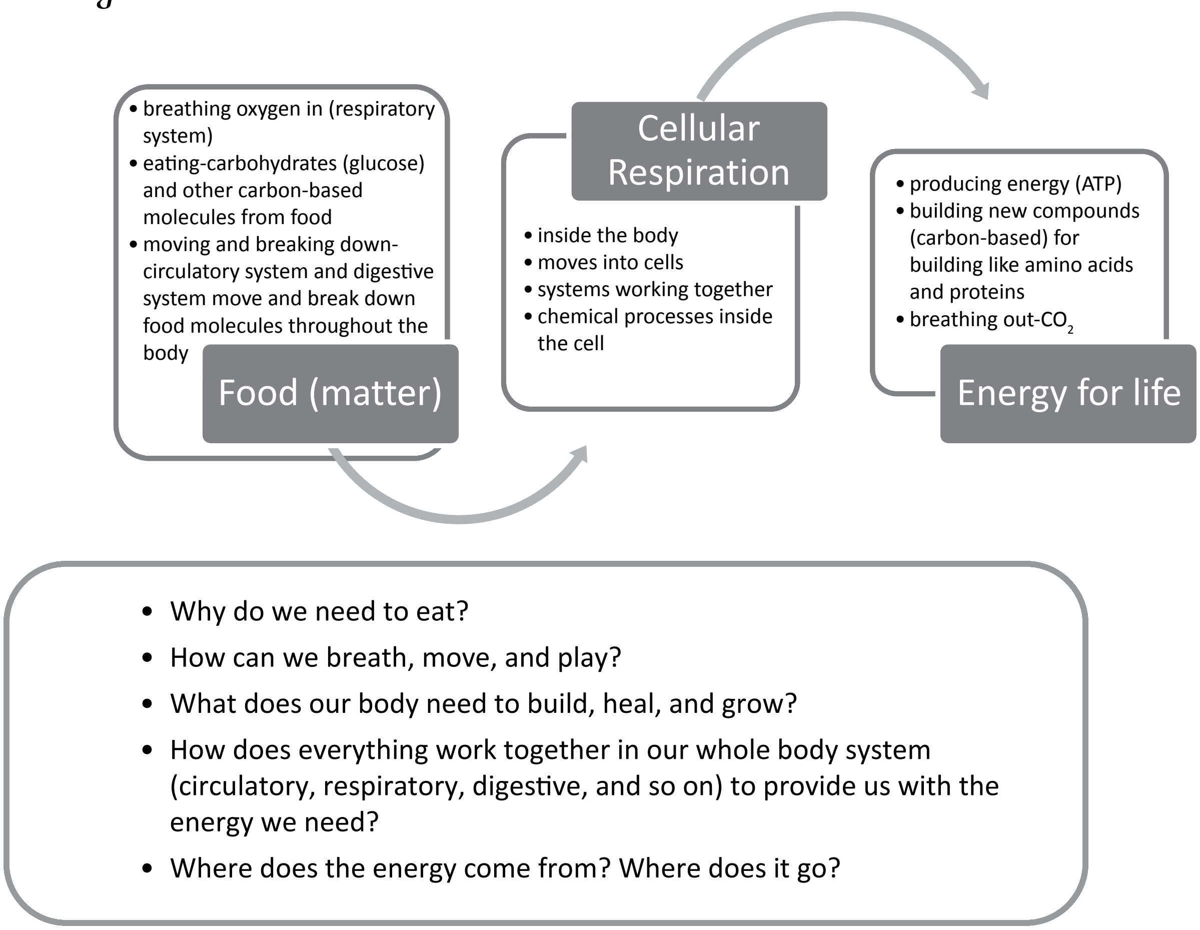
The study of cellular respiration in organisms is one of the most important but often difficult subjects to teach at the high school level. Concepts in biology are expansive and they all link together, so to identify the important content for this particular area of study I realized that I needed to identify the big idea that students should know. Then, I could break it down into chunks that students could grasp. These "chunks" needed to be in an order that made sense. Instead of giving students a thousand Lego pieces jumbled in a box and say, "build something," I would give them a few intentional pieces at a time. They could use these pieces to build a solid foundation for a structure. Additional pieces would fill in gaps and expand the structure. In this way, students would follow a storyline that makes sense, use what they already know, and add to their conceptual understanding of matter and energy.

The big idea for an area of study that challenges students year after year but yet is essential to life processes is the relationship between matter and energy—how we get and use energy for life. If we put a phrase to this, it is all about cellular respiration. But to say this phrase without meaning is just another intimidating biology term. This is how I set out to design a sequence of lessons for my biology students. This area of study comes directly after students have studied photosynthesis. After the lessons described in this chapter, students make connections between photosynthesis and cellular respiration, completing their understanding of matter and energy.

I generated a graphic to help me see connections among concepts, important questions to ask, and ideas to elucidate the big picture for energy and matter (see Figure 5.1).

Figure 5.1

The Big Picture



Stage I: Identify Disciplinary Core Ideas, Practices, and Crosscutting Concepts

I turned to *A Framework for K–12 Science Education* (NRC 2012) and *Next Generation Science Standards* (NGSS Lead States 2013) to provide insight into the big ideas of cellular respiration. These documents helped me identify the performance expectation (PE), or cluster of PEs, that would be the focus for this area of instruction and would give me ideas on what students who demonstrate understanding would be able to do. I also pulled in related disciplinary core ideas (DCI), science and engineering practices (SEP), and crosscutting concepts (CCC). The disciplinary core ideas that drove instruction include Organization for Matter and Energy Flow in Organisms (LS1.C) and Cycles of Matter and Energy Transfer in Ecosystems (LS2.B). The practices that encourage and support the core ideas are Developing and Using Models and Constructing Explanations. The crosscutting concepts that provide an integrating theme that also supports student understanding are System and System Models and Energy and Matter.

These dimensions from *NGSS* helped me get my head around the idea that students need not memorize isolated facts about cellular respiration, but instead should develop a conceptual understanding through modeling, constructing evidence-based explanations, and understanding the relationship between matter and energy in a system. Table 5.1 shows the cluster of related PEs, DCIs, SEPs, and CCCs that I chose for the area of instruction focused on matter and energy: cellular respiration.

The following paragraphs are from *A Framework for K–12 Science Education* (NRC 2012). They helped me grasp main ideas and helped me steer away from detailed facts that may confuse students and inhibit their learning and understanding the big picture. Students can get lost in the minute detail if not connected to the question "Why do I need to know this?" I wanted to provide relevancy and purpose for their learning.

> ***By the end of grade 12.*** The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen. The sugar molecules thus formed contain carbon, hydrogen, and oxygen; their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. For example, aerobic (in the presence of oxygen) cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles.

Table 5.1

PEs, DCIs, SEPs, and CCCs for Respiration

<table>
<tr><th colspan="3">Performance Expectations</th></tr>
<tr><td colspan="3">Students who demonstrate understanding can:
HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules. [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.]

HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy. [Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.]

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions. [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.]</td></tr>
<tr><th>Disciplinary Core Ideas</th><th>Science and Engineering Practices</th><th>Crosscutting Concepts</th></tr>
<tr><td>LS1.C: Organization for Matter and Energy Flow in Organisms
• The sugar molecules thus formed contain carbon, hydrogen, and oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. (HS-LS1-6)
• As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6),(HS-LS1-7)
• As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. (HS-LS1-7)

LS2.B: Cycles of Matter and Energy Transfer in Ecosystems
• Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. (HS-LS2-3)</td><td>• Developing and Using Models
• Constructing Explanations</td><td>• System and System Models
• Energy and Matter</td></tr>
</table>

> Anaerobic (without oxygen) cellular respiration follows a different and less efficient chemical pathway to provide energy in cells. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy loss to the surrounding environment. Matter and energy are conserved in each change. This is true of all biological systems, from individual cells to ecosystems. (NRC 2012, p. 148)
>
> ***By the end of grade 12.*** Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web, and there is a limit to the number of organisms that an ecosystem can sustain.
>
> The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil and are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved; some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. Competition among species is ultimately competition for the matter and energy needed for life.
>
> Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. (NRC 2012, p. 154)

The performance expectation and the dimensions from *NGSS* informed the development of a learning goal that helped me focus this area of study: Living organisms obtain and break down matter to form new compounds and release energy that can be used or stored for life processes. So, what do students need to know to reach an understanding of this learning goal? They need to know that organisms "obtain" matter and what this matter is. Most students have this knowledge—they eat every day and know by high school that all living organisms must eat, either by ingesting or absorbing food (matter). Students need to know what it means to break down matter. A study of the digestive system and enzymes help students grasp that there are proteins (enzymes) in the body that break down food into smaller molecules that can be delivered to cells in the body via the blood stream. Once this "broken down matter" gets to cells, then what?

I think students have a tough time going from the idea that they eat to get energy to the process of cellular respiration. They often understand that the digestive system plays a role but may not realize that many of their body systems work together in this process. But what happens to the "food" to give them energy? How and why does it break down? What is this "energy"? The jump from food being digested to memorizing the steps in cellular respiration leaves a gap in understanding. Students don't understand the relevancy of cellular respiration. And memorizing steps doesn't necessarily get them there.

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

I grappled with stage II for a while, trying to decide how best to describe learning targets that capture the key ideas of this area of study without overwhelming students with details that don't necessarily contribute to their overall understanding. I used *NGSS* and my experience in teaching applied biology, general biology, and AP Biology (three very different levels) to arrive at the four learning targets below.

1. Matter and energy flow through different organizational levels of living systems. Living organisms consume food, which provides energy. Proteins, carbohydrates, and fats (lipids), which are large molecules (macromolecules), are food that can be converted to usable energy. These large molecules contain the elements carbon, hydrogen, and oxygen.
2. These large molecules are broken down by the digestive system into smaller molecules by mechanical processes and by enzymes. Examples of these smaller molecules are glucose (broken down from carbohydrates), amino acids (broken down from proteins), and lipids (into fatty acids and glycerol).
3. These small molecules are absorbed into the bloodstream (circulatory system) through the intestines and delivered to cells throughout the organism. These small molecules transport into cells and undergo chemical reactions. They can be building blocks for new large carbon-based molecules used for cell structure and processes or used in the process of cellular respiration.
4. Cellular respiration occurs inside cells. In cellular respiration, glucose is a common example of a molecule that goes through cellular respiration. Glucose is broken down further in a series of chemical reactions that result in the release and storage of energy. This energy is captured in a molecule called ATP. This process is used by living organisms to transfer energy released from molecules like glucose into a form of energy that is usable by living organisms. For example, the energy stored in ATP is released and used by muscles to contract.

For high-level biology courses, the following ideas will also be addressed through readings, activities, investigations, and explanations, but they are not part of the content storyline for a general life science or biology class. Resist the temptation to add facts and details into the storyline, which might divert students from the four learning targets.

- In a cell, the series of chemical reactions in cellular respiration include glycolysis (occurs in the cytoplasm), Krebs cycle (occurs in the mitochondria), and electron transport chain (occurs in the mitochondria).
- Aerobic respiration occurs in the presence of oxygen and generates a lot of ATP. Glucose + Oxygen → water + energy (ATP)
- Anaerobic respiration occurs in the absence of oxygen and follows a different, less efficient pathway. This generates less ATP.

  *Glucose → lactic acid + energy (small amount of ATP) <u>or</u>

  *Glucose → ethanol + carbon dioxide + energy (small amount of ATP)

Essential Understanding: The flow of energy and matter through different organizational levels of living systems recombine elements in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Photosynthesis and cellular respiration provide most of the energy for life processes. Energy and matter are both conserved.

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

See Table 5.2 (p. 179) for a summary of the work I did to complete Stage III of the design process.

Stage IV: Determine Nature of Science (NOS) Connections

Students know that they need to eat and that eating gives them energy. In thinking about where students are coming from in their understanding of matter and energy, most students have the empirical evidence that supports their understanding that food gives them energy. I thought about other evidence that would support student understanding of this occurring at the cellular level. Students can collect their own evidence, make sense of it, and connect it to science concepts through an investigation in the classroom. *NGSS* connects the Nature of Science to this standard through the following:

Scientific Knowledge Is Open to Revision in Light of New Evidence

- Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. (HS-LS2-3)

I referred to *NGSS* Appendix H to glean a little more information about the Nature of Science. I focused on the matrix presented with the eight themes describing learning outcomes. For cellular respiration, a complex and abstract concept, I felt that students need to make observations and collect data that could provide evidence helping to

Table 5.2

Success Criteria and Aligned NGSS Performance Expectations

<table>
<tr><th>Learning Target</th><th>Success Criteria (from Science and Engineering Practices and Crosscutting Concepts)</th><th>Performance Expectations</th></tr>
<tr><td>#1: Matter and energy flow through different organizational levels of living systems. Food is consumed by living organisms. It contains proteins, carbohydrates, and fats (lipids), which are large molecules (macromolecules). These large molecules contain the elements carbon, hydrogen, and oxygen.</td><td>Construct a diagram (draw and write) that addresses the question, “How do you get energy to live, move, and grow?”

Collect evidence to support the scientific idea about the composition and flow of matter.</td><td rowspan="3">HS-LS1-6. Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.

HS-LS1-7. Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.</td></tr>
<tr><td>#2: These large molecules are broken down by the digestive system into smaller molecules by mechanical processes and by enzymes. Examples of these smaller molecules are glucose (broken down from carbohydrates) and amino acids (broken down from proteins).</td><td>Create a diagram that describes the interactions of systems and how these systems process energy-containing large molecules (contained in food).</td></tr>
<tr><td>#3: These small molecules are absorbed into the bloodstream through the intestines and delivered to cells throughout the organism. These small molecules transport into cells and undergo chemical reactions. They can be building blocks for new large carbon-based molecules used for cell structure and processes or used in the process of cellular respiration.</td><td>Develop and use a model to explain the carbon-based molecules protein, carbohydrates, and lipids and what components make up each.</td></tr>
<tr><td>#4: Cellular respiration occurs inside cells. In cellular respiration, glucose is a common example of a molecule that goes through cellular respiration. Glucose is broken down further in a series of chemical reactions that result in the release and storage of energy. This energy is captured in a molecule called ATP. This process is used by living organisms to transfer energy released from molecules like glucose into a form of energy that is usable by living organisms. For example, ATP is used by muscles to contract.</td><td>Plan and carry out an investigation that examines yeast in the presence of sugar (sucrose) and oxygen, analyze and interpret the data, and construct an explanation about cellular respiration in this organism.</td><td>HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.</td></tr>
</table>

make this concept a little more concrete at the cellular level. At the high school level, students should understand that "Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation." I really wanted to focus on students looking at evidence and using evidence to support scientific ideas.

Stage V: Identify Metacognitive Goals and Strategies

Students need to identify what they already know, what gaps they have in their understanding, and what they can do to fill those gaps. That is easier to say than to actually teach. My goal is for students to recognize what they don't know and be able (and confident enough) to ask the questions that will help guide them. Then, I'd like students to be able to identify and use the resources necessary to fill the gaps in their understanding. In other words, I'd like students to develop self-regulated learning (MERC 2011). This connects well with what they already know about energy and matter at the macro level to developing an understanding and the cellular level. Students will develop a graphic organizer (concept map, mind web, etc.) at the beginning of a lesson and then revisit during and at the end of the lesson (Refer to Instructional Tool 3.7, pp. 127–133). In this way, they will identify what they know and then add to their thinking throughout the lesson using resources and activities that fill in the gaps.

The practices in this area of study include constructing and revising an explanation based on evidence. Teaching students to be metacognitive helps them connect what they already know to evidence and science concepts and ask questions and identify resources that will help them solidify or extend their understanding.

Phase 2: Planning for Responsive Action

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

It is important for me to know what students are thinking as we began to study these concepts. In order to elicit student ideas, I felt that it was important to begin by asking questions and have students discuss, in small groups, what they understand about matter and energy, why they eat, and how they get energy from food. The misconceptions that my students typically had are reflected below. These align with what current research shows about this topic. Student misconceptions around this topic include:

- Cellular respiration means the same thing as breathing.
- Cellular respiration does not occur in plants (only in animals).
- Cellular respiration can only occur in the presence of oxygen.

- Food, calories, and energy are all equal. Students don't understand the relationship among these ideas.

I believe the first three misconceptions can be addressed during class discussion, activities, and student discourse. Breathing in oxygen, a molecule that is involved in the reactions of cellular respiration, and breathing out carbon dioxide, a waste product from cellular respiration, can be examined. Plants use energy for growth and other processes. Therefore they also need the glucose they make to be transferred to a usable form of chemical energy. This concept is important to discuss within this unit of study. However, the fourth misconception is overarching and identifies what I think is the most difficult part of this area of study. I really want students to understand the relationship between what they eat and how the organic molecules in their food contain chemical energy that is transferred to an energy storage molecule (ATP). This link asks students to look at what they know about eating and connect it to the abstract, that which they cannot "see."

Stage VII: Determine Strategies to Identify Students' Preconceptions

For this unit of study, I find it essential to check in and know what students are thinking by eliciting their preconceptions. I identified the Drawing Out Thinking approach as one that would work for my students at the start of Lesson 1, especially in making connections between the food they eat and the energy they get. The strategy I chose to use for this is Drawing and Annotated Drawings (see Instructional Tool 3.8, pp. 134–135). In Lesson 2, students use a diagram to draw what happens to the food they eat. Prior to students working on their diagram, I will provide an anticipation guide that aligns with the resources and expectations for the lesson. This will not only allow me to know what they already understand, but will help them look for important information that will help them develop understanding that they can use for their diagram. Lessons 3, 4, and 5 all begin with probing questions, whole-class and small- group brainstorms, and discourse, asking students to make connections from previous lessons. This approach worked in my classroom because students felt safe to share their ideas and they gained understanding by listening to others. Questions get students thinking about the topic in a way that helps them make connections between big ideas. Listening to student discussions lets me know where they are in their learning, what to focus on, and making explicit connections that may have been missed (see table 5.3, p. 182).

Stage VIII: Determine Strategies to Elicit and Confront Students' Preconceptions

Through a sequence of lessons, I wanted to create a coherent content storyline that would help students build their understanding about cellular respiration, energy, and matter.

Table 5.3

Strategies and Activities for Each Learning Target

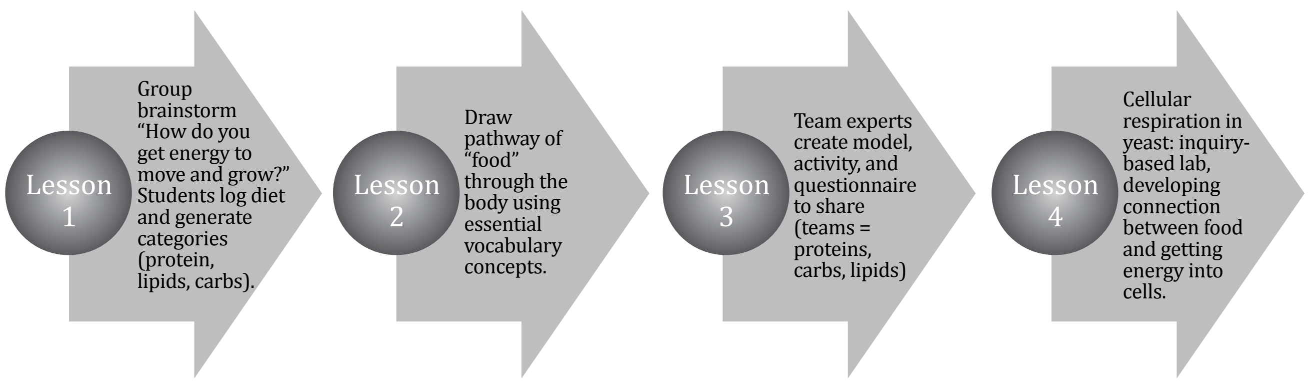
Storyline

Learning Target #1 →	Learning Target #2 →	Learning Target #3 →	Learning Target #4 →	Essential Understanding
Matter and energy flow through different organizational levels of living systems. Food is consumed by living organisms. It contains proteins, carbohydrates, and fats (lipids), which are large molecules (macromolecules). These large molecules contain the elements carbon, hydrogen, and oxygen.	These large molecules are broken down by the digestive system into smaller molecules by mechanical processes and by enzymes. Examples of these smaller molecules are glucose (broken down from carbohydrates) and amino acids (broken down from proteins).	These small molecules are absorbed into the bloodstream through the intestines and delivered to cells throughout the organism. These small molecules transport into cells and undergo chemical reactions. They can be building blocks for new large carbon-based molecules used for cell structure and processes or used in the process of cellular respiration.	Cellular respiration occurs inside cells. In cellular respiration, glucose is a common example of a molecule that goes through cellular respiration. Glucose is broken down further in a series of chemical reactions that result in the release and storage of energy. This energy is captured in a molecule called ATP. This process is used by living organisms to transfer energy released from molecules like glucose into a form of energy that is usable by living organisms. For example, ATP is used by muscles to contract.	The flow of energy and matter through different organizational levels of living systems recombine elements in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Photosynthesis and cellular respiration provide most of the energy for life processes. Energy and matter are both conserved.
In groups, answer "How do you get energy to move, live, and grow?" on chart paper with pictures, arrows, words. Generate whole-class diagram (class discussion). Students record food and exercise in a log and identify "categories" of food and exercise. Show pictures of carbohydrates, proteins, and lipids and students identify similarities.	Students create a diagram that shows the pathway of food to their cells, identifying breakdown and delivery of nutrients to cells. a. Students answer questions on an "exit slip." (What large molecules from food are broken down in your digestive system? b. How do the smaller molecules get to all the cells in your body?)	Opening poll question, "Do all of the cells of your body need energy? Why or why not?" Linking back to Target #2, students develop and use models to explain lipids, proteins, and carbohydrates. Jigsaw expert groups.	Show animation of an overview of cellular respiration. Inquiry investigation of cellular respiration using yeast, glucose, and water. Students identify what they've learned or understand (on green sticky notes), one thing they wonder or have a question about (on yellow sticky notes), and one thing they are still confused about (on pink sticky notes).	Revisit initial chart paper with pictures, arrows and diagrams. Add information that represents the flow of matter and energy through a system (from food to a molecule that stores chemical energy). What is the input? Purpose (why is it there?) How did it get there? What happens to it? What is the output?

I thought about activities that would help me elicit their ideas and preconceptions. Activities that I chose are outlined in Figure 5.2. The activities that I chose to help students confront possible misconceptions and help clarify and deepen their understanding draw on bringing relevance to their own lives and making them the focus of their own learning. They are active participants. I use probing questions; whole-class, small-group, and partner discourse; concept mapping; and drawing/diagramming with explanations, brainstorming, and an investigation. All of these strategies are aligned to the learning goal, or target, for the lesson and link to previous and subsequent ideas and concepts. They also focus on the student—what he/she eats, human digestive (and other related) system, cells in the larger system, and yeast as an example organism. Students will continually confront their ideas as we link together the concepts through discussion and action. These ideas are discussed in more detail in the last section, Instructions to Teachers.

Figure 5.2

Lesson Progression



Stage IX: Determine Sense-Making Strategies

Sense-making strategies will be used in each lesson. This is critical for my students to really develop their understanding. Throughout all of the lessons, students will be using their science notebooks. They will answer questions, sketch ideas and diagrams (lessons 1 and 2), plan their lab investigation, make claims, collect evidence, and write explanations (lesson 4). They will also plan their model before building it (lesson 3) and generate notes for discussion from resources including an online animation. I believe science notebooks are key to students capturing their learning and have seen students gain confidence and knowledge through their notebooks. I will directly teach some vocabulary related to cellular respiration (e.g., enzymes, ATP, glucose, oxygen, carbon dioxide, cells, proteins, carbohydrates, lipids, and so on) and ask students to apply these terms to their understanding of the breakdown of their food into molecules that are distributed throughout the body and into cells to be broken down further. Students will communicate their ideas through pictures, words, and discussion throughout the four lessons, helping them assimilate and make sense of the concepts and connections presented. Using multiple strategies and allowing the time for students to make sense of what they are learning are critical in understanding these difficult and abstract concepts.

Stage X: Determine Responsive Actions Based on Formative Assessment Evidence

To get the most out of the formative assessment strategies I used in this area of study, I determined possible evidence that I could use to inform my instruction. What would the evidence that I collect tell me about my students? And what would I do with that knowledge? I identified ways to follow up with responsive actions that would help fill student gaps in their learning, affirm or extend their understanding. These ideas are shown in Table 5.4.

Table 5.4

Formative Assessments and Responsive Action for Each Learning Target

	Lesson Target #1	**Lesson Target #2**	**Lesson Target #3**	**Lesson Target #4**
Formative Assessment Strategy	Whole-group brainstorming web diagram	Exit slip with two questions: 1. What large molecules from food are broken down in your digestive system? 2. How do the smaller molecules get to all the cells in your body?	Peer-assessed questionnaire on models (proteins, carbohydrates, lipids)	Sticky note news: students write an idea they've learned and understand (green note), one thing they wonder or one question they have (yellow note), and one concept that they still don't understand (pink note).
Responsive Action	Make note of gaps and misconceptions based on student input; provide resources for next lesson that address these.	Categorize answers; address gaps in glass discussion at the beginning of the following class.	Review; Return to students for revision and corrections.	Review notes; Give students questions (yellow notes) to research (provide resources); Revisit pink notes.

In the next section, I've described each lesson as if I was giving instructions to a teacher (myself).

Instructions to Teachers

Lesson 1

Matter and energy flow through different organizational levels of living systems. Living organisms consume food, which provides energy. Proteins, carbohydrates, and fats (lipids), which are large molecules (macromolecules), are food that can be converted to usable energy. These large molecules contain the elements carbon, hydrogen, and oxygen.

In groups of three, ask students to gather around chart paper and draw pictures and write words in answer to the question, "How do you get energy to move, live, and grow?" Suggest using arrows and specific examples. Provide three different colored markers to each group and set the expectation that all students must contribute to this brainstorm.

After all groups have filled their chart papers, begin a diagram on the board (web, flow chart, visual representation). Ask each group to send one person to contribute to the diagram using ideas they generated in their smaller groups. Through this interactive, whole-class activity, formatively assess student preconceptions. Lead a discussion, eliciting their ideas. Students generate ideas such as eating food and the digestive system breaks down the food. Push students through questions such as, "then what happens?" and "how do you actually get the energy from the food?" "how is energy stored in food?" Accept all ideas and generate a curiosity and "need to know" as to how the energy from food is transferred into usable energy for living organisms. Identify misconceptions from student answers.

From the small-group brainstorm, diagrams, and class discussion, students should learn or remember that matter and energy flow through different levels of living systems (for example, from the Sun, to plants, to animals, to us (or from plants to us), and that the original source of energy is from the Sun). Students will have studied photosynthesis before this lesson. Verify that they know what is meant by the term *food* and the kinds of molecules that are considered food. And the light energy provided by the sun helps plants convert carbon dioxide and water into glucose (sugar).

Ask students to record everything that they eat and any type of exercise they do for two days in a log. Students compare their logs with a partner and identify categories of food and categories of exercises. They typically identify these categories: protein, carbohydrates, and fats (lipids) for foods. If not, help guide them to these categories and have them place the types of food they eat into these categories. For exercise, they typically come up with sports, walking or general movement. Using probing questions, ask them to think about how they get the energy to exercise. Some may identify breathing as an action that accompanies exercise (and living in general!) Ask students to remember breathing as part of the flow of energy and matter in cellular respiration (oxygen needed for aerobic respiration and carbon dioxide as a waste product).

Show pictures of the structure of a carbohydrate, a protein, and a lipid. Ask students to identify what all of these molecules (that make up foods) have in common. Students will identify carbon, hydrogen, and oxygen as elements that make up these molecules.

Lesson 2

These large molecules are broken down by the digestive system into smaller molecules by mechanical processes and by enzymes. Examples of these smaller molecules are glucose (broken down from carbohydrates), amino acids (broken down from proteins), and lipids (into fatty acids and glycerol).

Students are each given a large (11 × 17) outline of a person. They are given informational resources and work with a partner to draw the pathway of food from ingestion through digestion and excretion. Students are asked to identify where the food is broken down mechanically, where it is broken down chemically (by enzymes and acids), where it is absorbed into the bloodstream, and how it travels throughout the body. They are given a word list of essential vocabulary (pruned down to only terms that will help them understand the big ideas) to help them identify the key components of their diagram. The teacher checks in with groups as they are working and asks them to explain their diagrams. As an "exit slip," ask students two questions:

1. What large molecules from food are broken down in your digestive system?
2. How do the smaller molecules get to all the cells in your body?

Lesson 3

These small molecules are absorbed into the bloodstream through the intestines and delivered to cells throughout the organism. These small molecules transport into cells and undergo chemical reactions. They can be building blocks for new large carbon-based molecules used for cell structure and processes or used in the process of cellular respiration.

Open up this lesson by asking the question, "Do all of the cells of your body need energy? Why or why not?" Students should already know that cells make up tissues, tissues make up organs, organs make up systems, and systems make an organism. Take this opportunity to link to this past learning.

Transition by revisiting the food logs students created. Ask again what organic molecules make up food. Then, lead into a modeling activity by asking: What are proteins? What are lipids? What are carbohydrates?

Developing and using models for understanding and explanations is a science and engineering practice in *NGSS*. For this activity, group students in teams of three. Each team is assigned "carbohydrate," "protein," and "lipid." Provide materials such as clay, assorted craft supplies, and informational resources. Ask each team to provide a model of their assigned large molecule, identifying key components. Each team is responsible for showing what the large molecule is broken down into (during digestion) and the building of a new large molecule (and what the monomers are that make up the larger polymer—i.e., amino acids to proteins, glucose to carbohydrates). After becoming experts on their molecule, the team develops an activity (game, modeling, and so on) and creates a three to five-part "questionnaire."

Experts from each team join with an expert from another team until each new group has one person representing each large molecule (carbohydrate, protein, lipid). Students share their knowledge by explaining their model, facilitating the activity, and answering questions. At the end of the discussion, each person in the group takes all three developed "questionnaires." Students give their answers to the "expert" to grade. After reviewing student questionnaires, return them to students asking them to revise their answers (if incorrect) and self-assess their understanding.

Lesson 4

Cellular respiration occurs inside cells. In cellular respiration, glucose is a common example of a molecule that goes through cellular respiration. Glucose is broken down further in a series of chemical reactions that result in the release and storage of energy. This energy is captured in a molecule called ATP. This process is used by living organisms to transfer energy released from molecules like glucose into a form of energy that is usable by living organisms. For example, the energy stored in ATP is released and used by muscles to contract.

Show the "big picture" at the beginning of the lesson (*www.sumanasinc.com/webcontent/animations/content/cellularrespiration.html*). Ask students if they know what yeast is. Lead a class discussion focused on if all living organisms (including yeast) require energy. Ask students how they could test this in yeast?

Give an overview of the yeast lab. Show students the equation $C_6H_{12}O_6 + O_2 \rightarrow 6\ CO_2 + H_2O$ and ask what is meant by each component. Ask them what they think is necessary for yeast to undergo cellular respiration (fermentation can also be introduced here). Facilitate an inquiry-based approach to this lab, supporting student questions regarding the necessary components and conditions for cellular respiration. Proceed with the lab. Students discuss the lab and what they discovered in a small group. They summarize the findings of the lab, how it relates to cellular respiration, and to energy required by living organisms. Students support their explanations by engaging in argumentation using results from their lab and connections to scientific knowledge. With their findings, students present a visual representation of this process of energy transfer.

Each student is given three sticky notes (green, yellow, and pink). They write down one idea they've learned and understand on green, one thing they wonder or one question they have on yellow, and one concept that they still don't understand on pink. They attach their notes to the stoplight chart on the way out of the room. Review the notes and have small-group discussions using the yellow and pink sticky notes to guide discussions. Bring any lingering questions from small groups to the whole class, clarifying understanding.

Essential Understanding: The flow of energy and matter through different organizational levels of living systems recombine elements in different ways to form different products. As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Photosynthesis and cellular respiration provide most of the energy for life processes. Energy and matter are both conserved.

For a final assessment, begin by asking students probing questions to connect photosynthesis; cellular respiration; systems; and matter, energy, and life. Ask students to revisit their initial diagram and add to it pictures, words, and arrows to convey their understanding of the flow of energy and matter through a living organism. Their final diagram should include food, large molecules (protein, carbohydrates, lipids) and their components, digestion, cellular respiration, and how "food" is converted to energy in a living organism. By engaging in the four lessons and completing the final assessments, students meet the performance expectations for these standards and gain an understanding of why they need to eat and the processes necessary to convert food (matter) into usable energy for life.

Recommended Resources

Websites

- Cellular Respiration: *www.sumanasinc.com/webcontent/animations/content/cellularrespiration.html*
- Cellular Respiration and Photosynthesis: Important Concepts, Common Misconceptions, and Learning Activities: *http://serendip.brynmawr.edu/exchange/files/CellularRespPhotoOverview.pdf*

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Hard-to-Teach BIOLOGY CONCEPTS

Revised 2nd Edition

Designing Instruction Aligned to the *NGSS*

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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.

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