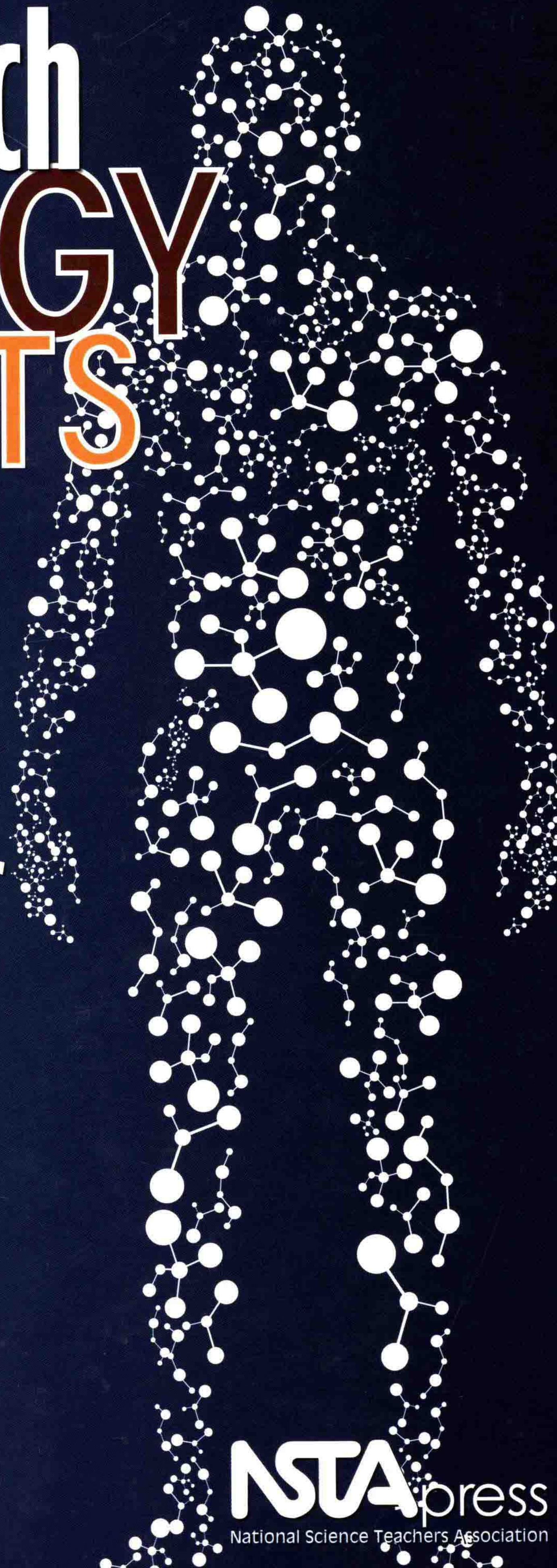
Hard-to-Teach BIOLOGY CONCEPTS

Revised 2nd Edition

Designing Instruction Aligned to the *NGSS*



By Susan Koba and Anne Tweed

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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.

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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.

Introduction

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

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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*.

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PART I

The Toolbox: A Framework, Strategies, and Connections

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