Hard-to-Teach SCIENCE CONCEPTS

A Framework to Support Learners, Grades 3–5

By Susan Koba with Carol T. Mitchell

Hawker Brownlow EDUCATION

Contents

Foreword by Linda Froschauer v

Acknowledgments vii

About the Authors ix

Introduction xi

Part I: The Toolbox: A Framework and Instructional Tools 1

Chapter 1. An Instructional Planning Framework to Address Conceptual Change 3

- Why Are Some Science Concepts Hard to Teach? 4
- Introducing the Instructional Planning Framework 6
- Comparing the Framework to Other Models 9
- Putting the Instructional Planning Framework Into Practice 12

Chapter 2. Implementation of the Framework Using the Topic "The Flow of Matter and Energy in Ecosystems" 17

- Overview 18
- Application of the Predictive Phase to "The Flow of Matter and Energy in Ecosystems" 20
- Application of the Responsive Phase to "The Flow of Matter and Energy in Ecosystems" 35
- Instructional Tool 2.3: Instructional Strategy Selection Tool 42
- Time for Reflection 56
- Resulting Lessons for Learning Targets #1–4 56
- Instructional Tool 2.1: Teaching the Five Essential Features of Inquiry 74
- Instructional Tool 2.2: Three Strategies That Support Metacognition 81
- Instructional Tool 2.4: Sense-Making Approaches: Linguistic Representations—Writing to Learn 88
- Instructional Tool 2.5: Sense-Making Approaches: Linguistic Representations—Reading to Learn 96
- Instructional Tool 2.6: Sense-Making Approaches: Linguistic Representations—Speaking to Learn 101
- Instructional Tool 2.7: Sense-Making Approaches: Nonlinguistic Representations—Six Kinds of Models 105
- Instructional Tool 2.8: Sense-Making Approaches: Nonlinguistic Representations—Visual Tools 112
- Instructional Tool 2.9: Sense-Making Approaches: Nonlinguistic Representations—Drawing Out Thinking 119
- Instructional Tool 2.10: Sense-Making Approaches: Nonlinguistic Representations—Kinesthetic Strategies 123

Chapter 3. The Framework and Instructional Tools at the Elementary Level 125

- Responding to the Needs of All Learners 127
- Ties to Literacy and Numeracy (Mathematics) 141
- Variations in Third, Fourth, and Fifth Grades 151
- Build Your Library 152

Part II: Toolbox Implementation—Using the Framework and Instructional Tools With Hard-to-Teach Science Topics 155

Chapter 4. Matter and Its Transformations: Gas Is Matter 157
- Overview 158
- Why This Topic? 158
- The Predictive Phase 159
- The Responsive Phase 162
- The Lessons: Teaching and Learning About "Gas Is Matter" 164
- Time for Reflection 167
- Ties to Literacy and Numeracy (Mathematics) 167
- Consideration Across the Grades 168
- Build Your Library 168

Chapter 5. Earth's Shape and Gravity
(by Cary I. Sneider with Susan Koba) 169
- Overview 170
- Why This Topic? 171
- The Predictive Phase 173
- The Responsive Phase 185
- The Lessons: Teaching and Learning About "Earth's Shape and Gravity" 191
- Time for Reflection 196
- Responding to the Needs of All Learners 197
- Ties to Literacy and Numeracy (Mathematics) 199
- Consideration Across the Grades 201
- Build Your Library 201

Chapter 6. Understanding Changes in Motion
(by Rand Harrington with Susan Koba) 203
- Overview 204
- Why This Topic? 205
- What Makes These Ideas Difficult? 206
- The Predictive Phase 207
- The Responsive Phase 212
- The Lessons: Teaching and Learning About "Understanding Changes in Motion" 218
- Time for Reflection 221
- Responding to the Needs of All Learners 221
- Ties to Literacy and Numeracy (Mathematics) 225
- Consideration Across the Grades 227
- Build Your Library 228

Appendix A: Planning Template for the Predictive Phase 231

Appendix B: Strategy Selection Template 232

Appendix C: Planning Template for the Responsive Phase 233

References 235

NST2830 • 9781760012830 • © 2016 Hawker Brownlow Education

Introduction

> "Except for children (who don't know enough not to ask the important questions), few of us spend much time wondering about why nature is the way it is; where the cosmos came from, or whether it was always here; if time will one day flow backward and effects precede causes; or whether there are ultimate limits to what humans can know.... In our society it is still customary for parents and teachers to answer most of these questions with a shrug."
>
> —*Carl Sagan, in Hawking 1988, p. ix*

Science is a subject that warrants study and understanding by all learners as early in their schooling as possible. Research indicates over and over that children have a natural curiosity that is critical in science (Bruner and Haste 1987; Carey 1985; Dewey 1902; Eyon and Linn 1988; Martin 2006). Carl Sagan captures this idea in the above quote. So how can teachers tap into this natural resource more effectively?

In this book, *Hard-to-Teach Science Concepts: A Framework to Support Learners, Grades 3–5*, the authors use their cumulative experiences of more than 70 years of classroom teaching to share ways that teachers can make the most of children's curiosity. Unfortunately, as we know, science education has been minimal or totally lacking in U.S. elementary schools. One reason for this is the limited preparation in science received by many elementary school teachers in colleges of education, whose job it is to prepare teachers to teach many disciplines in addition to science. A second reason is that the time allocated for science during the elementary school day varies and is usually negligible (Michaels, Shouse, and Schweingruber 2008).

The good news is that over the past 10 years more attention has been given to these problems in the elementary grades. Increasingly, inservice professional development to effectively teach science is being provided to elementary school teachers. In addition, postsecondary institutions have been enhancing their programs of study for elementary majors relative to science content courses.

Hard-to-Teach Biology Concepts: A Framework to Deepen Student Understanding (Koba with Tweed 2009) addressed topics that were considered difficult to teach in high school biology courses. Stressing the importance of understanding how students learn, that book introduced the Instructional Planning Framework and included instructions and resources for implementing the framework.

This book is for elementary teachers, who, as we have noted, must teach all subjects, science among them. It is so important for elementary classroom teachers to increase their focus on science and to understand more fully how elementary students learn. The intent of this book is to support you in both those efforts. The same framework found in *Hard-to-Teach Biology Concepts* is used in this book. Here, the chapters that describe implementation of the framework, as well as Chapters 4–6 (plus parts of 2 and 3) that are related to content typically taught in elementary schools, were specifically developed to support elementary teachers in grades 3 through 5 and those who work with them.

This book is not a container of answers, or "fixes," to the many questions that elementary teachers have about teaching science. But it does provide the Instructional Planning Framework (Fig. 1.2, p. 8); explanations about how to use the framework; numerous figures and tables and 10 Instructional Tools (pp. 42–44 and pp. 76–126), which contain many references; and examples of application of the framework. In addition, Chapters 3–6 have extensive lists of print and online resources in the sections called Build Your Library.

Both novice and veteran teachers can use the framework and tools to develop students' conceptual understanding of four hard-to-teach and hard-to-learn science topics: a life science topic, *the flow of matter and energy in ecosystems;* two physical science topics, *matter and its transformations* and *understanding changes in motion;* and an Earth and space science topic, *Earth's shape and gravity.* You do not need to completely change what you already do to implement these ideas. However, by using the examples and the resources in the content chapters (Chapters 4–6) and parts of Chapters 2 and 3 as guides, you should be more comfortable and confident as you approach the teaching of science in what will perhaps be a new way for you. Tackle one concept or topic at a time, reflect more on your teaching, and make adjustments to your planning and teaching. This process should result in improved conceptual understanding for all your students.

Science Education Reform and Conceptual Understanding

The National Science Education Standards (NRC 1996) provide guidelines for the content to be taught and some ideas about successful instruction. Research cited in *How Students Learn: Science in the Classroom* (Donovan and Bransford 2005) extends the thinking found in the standards and reinforces the ideas that teaching science is not "telling" science and that instructing students in the scientific method and having them follow the steps is not a way to develop understandings and knowledge of how to do science. The authors of *How Students Learn* also emphasize that science educators have not done enough to support metacognitive instruction to help students learn how to learn. More recently, *Ready, Set, Science! Putting Research to Work in K–8 Science Classrooms* (Michaels, Shouse, and Schweingruber 2008) and *Taking Science to School: Learning and Teaching in Grades K–8* (Duschl, Schweingruber, and Shouse 2009) reported on research that shows that K–8 learners come to school with far more capacity to learn science than was previously thought. With this research in hand, this book provides a framework so that elementary teachers can begin to focus not only on *what* is taught in science classes but also, and as important, on *how* it is taught.

Difficult Topics—*Why* Are They Hard to Teach and Learn?

If you reflect back on science lessons you have taught, we are sure that you can develop a list of topics that you found difficult to teach. Among the hard-to-teach topics reported in science education literature and by teachers themselves, many fall into the physical science category. (Two of those topics in physical science are addressed in this book: Chapter 4, matter and its transformations, and Chapter 6, understanding changes in motion.)

Chapter 1 discusses the possible reasons that certain topics are difficult to teach. Among these reasons is the fact that the more abstract a science topic is, the harder it is to learn for many people, including teachers! As we noted, telling science to students is not teaching science. Students learn by "doing" science, and abstract topics need to be made concrete. Students are better able to face their misconceptions and preconceptions when they are engaged in instructional activities that put science into a context they can understand.

Elementary teachers may also find physical science topics hard to teach because of the limited science content courses they took in elementary science programs of study (Michaels, Shouse, and Schweingruber 2008), as well as limited mathematics preparation. Elementary teachers may have weak areas of concentration in their backgrounds, but they have little time when they are teaching to focus on these weak areas. Science, more than other subjects, is likely to be a weak area.

We chose the hard-to-teach topics for this book in two ways: by examining the research on elementary science teaching and by determining topics that we believe are foundational to future learning. As noted, we selected four topics: one in life science, two in the physical sciences, and one in Earth and space science.

Organization of the Book

Part I. The Toolbox: A Framework and Instructional Tools

This section shares the authors' research-based framework to address conceptual change (the Instructional Planning Framework), as well as a process and Instructional Tools to put the framework into practice.

Chapter 1 explores further why some topics are hard to teach and learn, presents the Instructional Planning Framework and the research behind it, compares the framework to other models, and helps the reader understand how to transition from the theoretical framework to practice.

In Chapter 2, implementation of the framework and tools is modeled, based on a life science topic, the flow of matter and energy in ecosystems. Instructional Tools (pp. 42–44 and 76–126) outline various instructional approaches and specific instructional strategies that promote student understanding. By *approach,* we mean a broad method used in instruction (e.g., writing as a linguistic approach and drawing as a nonlinguistic approach). The chapter addresses metacognitive and standards-based approaches as well as various linguistic and nonlinguistic approaches. *Strategies* are specific ways to achieve a specific goal (e.g., the use of concept cartoons is one specific strategy discussed in the section on drawing as a nonlinguistic approach).

Chapter 3 provides a general overview of differentiation in the classroom and discusses numerous introductory steps for differentiating science instruction in grades 3, 4, and 5. The chapter continues to focus on the flow of matter and energy in ecosystems as these ideas are explored. It also makes connections among science, literacy, and numeracy (mathematics) and provides suggestions for their integration into the science classroom.

Part II. Toolbox Implementation—Using the Framework and Strategies With Three Hard-to-Teach Science Topics

This section is organized to model the use of the Instructional Planning Framework in three additional hard-to-teach elementary science topics: matter and its transformations, Earth's shape and gravity, and understanding changes in motion. The contributing authors of these chapters studied the framework and tools and interpreted them in their own ways. Each chapter does follow basically the same format, however, and includes three or more sample lessons on the topic.

The Five Natural Learning Systems

The five natural learning systems—emotional, social, physical, reflective, and cognitive (Given 2002; Gregory and Hammerman 2008)—are referred to frequently in this book. Chapter 3 discusses the emotional and social learning systems required to establish a safe learning environment and to engage each student in the learning process. The physical system is addressed through the active learning typical of inquiry and several strategies that are provided in Instructional Tool 2.10 (p. 125). The reflective system (metacognition) is addressed through the metacognitive tools; in fact, the process outlined in Chapter 2 calls for teachers to identify a metacognitive goal for *each* instructional unit.

The book focuses most deeply on the cognitive system, as developed in the conceptual change model (Chapter 1) and the vast array of research-based strategies. The strategies help you remain aware of your students' understandings about the targeted content before and during instruction, elicit and confront those conceptions during a lesson, and provide sense-making experiences to move student conceptions closer to the scientific explanations you expect of them. Using the framework, process, and tools will help you effectively address all five learning systems.

NST2830 • 9781760012830 • © 2016 Hawker Brownlow Education

An Instructional Planning Framework to Address Conceptual Change

"It is important for science educators to balance a deep appreciation of what is genuinely conceptually difficult, 'non obvious' and novel about many central principles of modern science, with an equally deep appreciation of the many intellectual resources that children bring to the science learning task."

—Duschl, Schweingruber, and Shouse 2007, p. 82

Consider the various science topics that you teach during the course of the school year. Are some harder for your students to learn and for you to teach? Your answer is probably "yes" if you are like many science teachers. Yet it is your responsibility to effectively teach these topics and provide students with a solid foundation for additional science learning—both while they are still in school and when they go out into the world.

Your students' understandings about science are important partly because some of those students will become scientists. But the many who do not pursue science as a vocation will still use their knowledge of science to make informed decisions as adults and in their careers. More and more, our nation depends on technical and scientific abilities, and science is central to our culture. In addition, science provides a great context for your students to develop language, logic, and problem-solving skills (Duschl, Schweingruber, and Shouse 2007). Students' science experiences in your classroom set a foundation for their future content understandings and their comfort with science as a way of thinking. Thus, the choices you make in planning for science instruction are extremely important.

To be an effective teacher, you must focus on standards and on identifying what students should know and be able to do in core science areas. This is the case with existing standards and will continue to be important with the emerging Next Generation Science Education Standards (NRC 2010). These reforms call on you to place more emphasis on learning important concepts than on rote learning. This is not always an easy task, especially for the hard-to-teach topics and for concepts that even you might struggle to understand. The Instructional Planning Framework, on which this book is based (the framework was developed by author Susan Koba with Anne Tweed; see *Hard-to-Teach Biology Concepts: A Framework to Deepen Student Understanding* [2009]), incorporates research findings and implications for teaching, including teaching the four hard-to-teach concepts that are the focus of this book: the flow of matter and energy in ecosystems, matter and its transformations, Earth's shape and gravity, and understanding changes in motion.