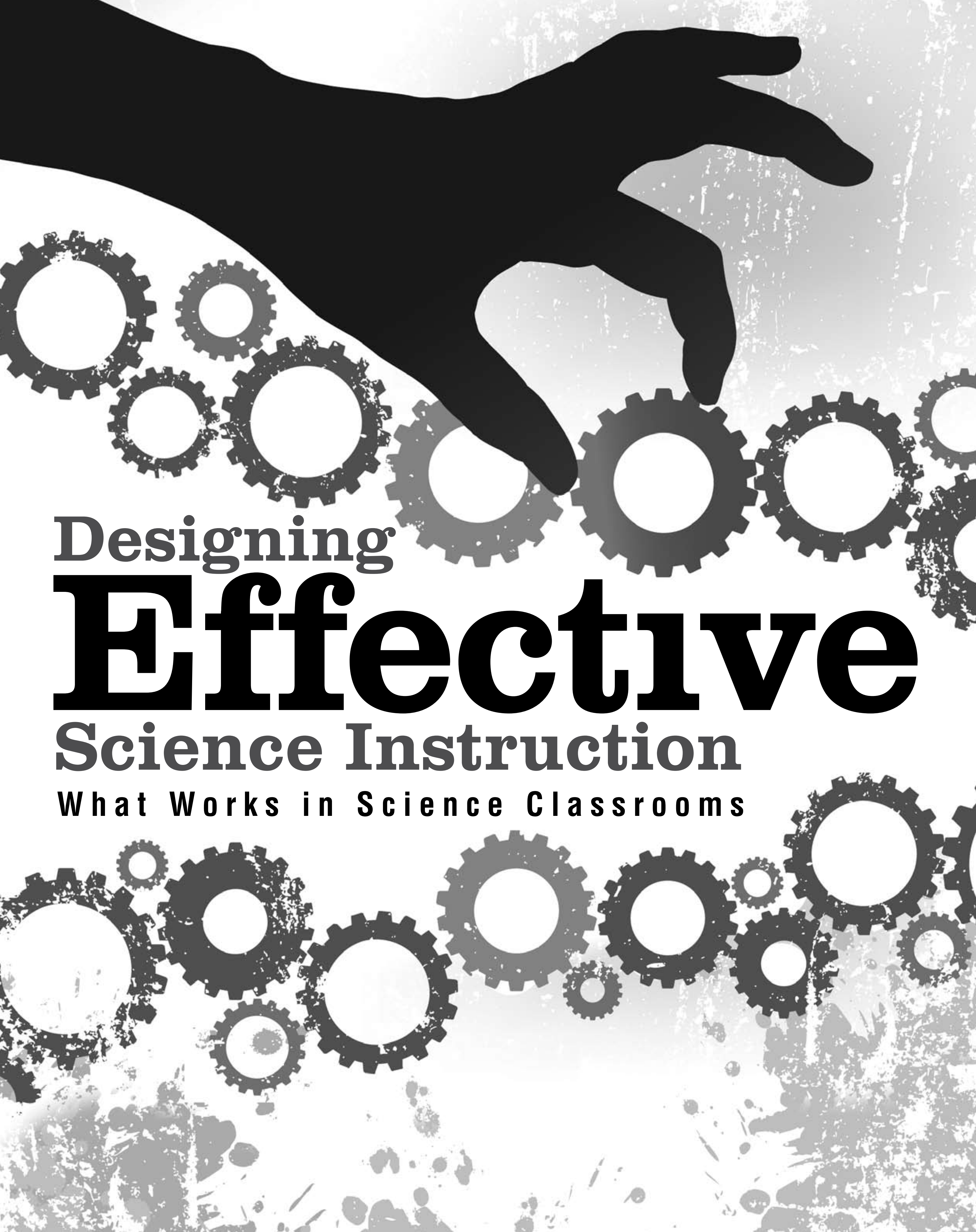

Designing Effective Science Instruction

What Works in Science Classrooms

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Anne Tweed

McREL

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Dedication

This book is dedicated to my parents, Irvin and Jeanette Leerssen. Their hard work, dedication to family, and love of the outdoors has provided me with the inspiration and optimism to pursue science, continue as a learner, and strive to help others. From them I have learned that with planning and preparation, positive results are always possible!

Contents

Foreword

Science teachers everywhere agree: Teaching science, no matter the level, is hard work! To do it well and to be effective requires continuous learning. Not only is the knowledge base that explains science phenomena continuing to increase, research findings that help us understand how students learn are also increasing. The goal for science teachers is to maintain a balance so that it is not about working harder trying to keep up with the new research-based findings, but about working together to implement the best practices in the classroom.

Designing Effective Science Instruction: What Works in Science Classrooms is designed to pull together recent findings from many science education studies and teacher education initiatives. It can be a daunting task for a teacher to learn about each initiative separately and then integrate the new learning within existing instructional frameworks, one initiative at a time. This book presents an instructional framework and includes the separate initiatives (i.e., addressing misconceptions, formative assessments, inquiry approaches) as part of a larger framework of effective science instruction. An individual teacher of science or groups of teachers can use *Designing Effective Science Instruction* to plan and implement changes to his or her science instruction.

Effective Science Instruction: What Does Research Tell Us? (Banilower et al. 2008) summarizes the research foundation for this book. In this report, researchers shed light on possible reasons for poor student performance in science. Most notably, research revealed that in a national sample of science classrooms, science lessons do not often include the features identified as part of effective science instruction. In other words, too many science students are not clear about the learning goal being taught, and they are not being asked to make sense of the content that the teachers deliver. Students cannot, because of this classroom culture and instruction, understand and retain the science concepts they are supposedly learning. If the students are learning, the learning is frequently temporary and often as a response to a quiz or test. The study further indicated that teachers of science are too often unaware of the research that identifies the effective practices they need to implement in their science classrooms.

For the past several years I have worked with teachers of science as they designed and redesigned their lesson plans, examined their craft, and attempted to implement change in their classrooms. The result was often ineffective, with little or no change to the science teachers' overall practice. The reason for this lack of change was simple: Limited information was available to me about effective teaching and I had to turn to a myriad of research articles that had little impact on the teachers themselves. This book will change all that by bridging the gap between research and practice.

The book begins by providing examples of effective strategies that support the development and delivery of science lessons that foster student understanding of the science concepts being taught. It targets one key element found in the (Weiss et al. 2003) research into designing effective lesson plans. The book dives into the characteristics of effective lesson plans, asks teachers to reflect on their current lessons, and then provides strategies for redesigning those lesson plans into even more effective lessons—ones that embody the characteristics of high-quality lessons from the research.

Using the Content-Understanding-Environment (C-U-E) method, this book gives teachers the tools to approach lesson planning with confidence. Teachers will be able to pinpoint aspects of their instructional practice that need improvement. They will understand how to seek out the content knowledge and experiences they need to become more effective science teachers. They will be able to implement changes to their teaching craft, to become effective facilitators of student learning, and to provide their students with rich and active learning environments that allow for successful student achievement.

I know teachers of science will find this book helpful, valuable, and informative. The book will assist as they evaluate science instructional practices, reflect on that practice, and make changes to improve that practice—the hallmarks of being effective science teachers. *Designing Effective Science Instruction* embodies this. Let the journey begin.

—Shelley Lee

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Banilower, E., K. Cohen, J. Pasley, and I. Weiss. 2008. *Effective science instruction: What does research tell us?* Portsmouth, NH: RMC Research Corporation, Center on Instruction.

Weiss, I., J. Pasley, S. Smith, E. Banilower, and D. Heck. 2003. *Looking inside the classroom: A study of K–12 mathematics and science education in the United States.* Chapel Hill, NC: Horizon Research, Inc.

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About the Author

Anne Tweed, a principal consultant with the Mid-continent Research for Education and Learning (McREL) in Denver, Colorado, also serves as the director of the North Central Comprehensive Center. Her work at McREL supports professional development in the areas of effective science instruction, inquiry-based instruction, formative assessment, high-quality instructional practices, teaching reading in content areas, analyzing instructional materials, and audits of science curricula and programs. The work is research based and includes ongoing professional development workshops. In her role as director of the North Central Comprehensive Center, she leads project activities that build the capacity of state education agencies through resource dissemination, group facilitation, building infrastructure and networking, planning and needs assessment, developing solutions that are part of statewide systems of support, and revising tools and templates that support schools in need of improvement. She is currently a co–principal investigator on an NSF DRK-12 project that supports implementation of nanoscale science and technology in secondary classrooms.

Tweed is a past president of the National Science Teachers Association (2004–2005). A veteran high school science educator and department coordinator, she spent the majority of her 30-year teaching career with the Cherry Creek School District in Colorado. Tweed earned an M.S. in botany from the University of Minnesota, a B.A. in biology from Colorado College, and a teaching certificate from the University of Colorado. Tweed has held several leadership positions with NSTA, the Colorado Association of Science Teachers, and the Colorado Alliance for Science. She was on the review committee for the National Science Education Standards and a contributor to the original Colorado Model Content Standards for Science. In addition, Tweed served on the program planning team revising the 2009 NAEP 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, the Outstanding Biology Teacher Award for Colorado, and is a state Presidential Award honoree. She has published many articles, coauthored several books, given more than 150 presentations and workshops at state and national conferences, and continues to be active with state and national science associations.

Introduction

Why This? Why Now?

Science teachers, like all teachers, start each school year with high hopes and expectations for students to succeed. They plan their lessons, scramble to get the necessary equipment, and work hard to engage their students. However, despite good intentions and best-laid plans, not all students do well in science classes, and even fewer achieve mastery. We see the effects of this all around us. Student performance on national and international assessments, including science assessments, is poor. More and more adults are unable to understand the scientific issues that affect their lives and society. The media reports that national economic competitiveness is at stake. It's clear that something must be done now to help science teachers put power behind their hopes and expectations for student achievement.

Designing Effective Science Instruction: What Works in Science Classrooms is meant to help teachers focus on what can and must be done. It draws upon recent research in science education, most notably a well-designed study of science classrooms which sheds light on possible reasons for poor student performance in science (Weiss et al. 2003; Banilower et al. 2008). This research study and subsequent report on effective science instruction revealed that in a national sample of science classrooms, about two-thirds of science lessons observed were of low quality. In other words, too many science students sit passively, never being asked to make sense of the content that teachers deliver. Too many science activities masquerade as science lessons and fail to develop students' understanding of science concepts. Too many teachers lower their expectations and avoid teaching a rigorous science curriculum. The pressure teachers feel to meet student achievement goals is immense. With emerging research findings about how students learn and how to teach effectively, guidance for teachers is available.

The Weiss et al. study also tells us that teachers often are unaware that research has identified teacher knowledge and skills that support the development and delivery of science lessons that foster student learning. This and other research on teaching and learning lead us to believe that designing high-quality science lessons that include research-based instructional practices is a logical first step to improving *all* students' science learning. As a result, *Designing Effective Science Instruction* focuses on strategies that science teachers at all levels can use to make their science lessons better.

Educational research on learning and effective science instruction has much to offer us in meeting the challenges of educating students to high standards. What is missing in previous books on effective science lessons and instruction is a synthesis of the research that focuses on the essential findings and the implications for instructional practice. *Designing Effective Science Instruction* provides that bridge between research and practice, and does so in a format that is easy to learn, use, and continue to apply.

This book will describe the characteristics of high-quality science lessons, help you reflect on what is working well with your current approach to designing lessons, and provide recommendations for improving existing lessons or creating effective new ones. Whether you are a novice or veteran teacher, the self assessments and recommendations in this book will provide guidance that supports and encourages you to refine what you do to become a more effective science teacher. You can use this book to decide what practices will work for you and your students, but you are encouraged to work with others as you plan for and revise instruction, interpret student work, and determine what changes you will make to your teacher practices. Planning for your own professional development is one way to use the information contained in this book. Many resources are available to help you plan for meaningful professional development that is ongoing and uses a model that features reflective practice in the real world of teachers. The National Science Education Standards (NRC 1996) for teaching and professional development provide a starting point and helped to inform this book.

No matter what grade level you teach, you will benefit from learning the Content-Understanding-Environment (C-U-E) instructional framework described in this book. We believe that if you understand and apply this framework, you will be able to approach lesson planning with confidence and develop well-planned, effective science lessons. In addition, you will be able to pinpoint aspects of your instructional practice that need improvement and seek out the content knowledge and experiences that will be most helpful in making you a more effective teacher. Together these will lead to positive teacher and student attitudes toward science learning and positive science achievement results for all students.

Organization of *Designing Effective Science Instruction* book

Designing Effective Science Instruction: What Works in Science Classrooms (DESI) is organized into five chapters. The next four chapters introduce the C-U-E instructional framework and provide details about each of its three elements (Content, Understanding, Environment). The contents of chapters 2 through 5 are described briefly below.

Chapter 1. Building the Framework. This chapter focuses readers on the following questions as the three components of the C-U-E framework are introduced:

- Effective science teaching: What does it mean and how does it look?
- What are the barriers to effective instruction?
- What does research say about effective science instruction?
- Why the Content-Understanding-Environment framework?

This chapter emphasizes that all three elements must be addressed during lesson design and implemented effectively when delivering science instruction.

Chapter 2. Identifying Important Content. This chapter focuses on identifying important content, clarifying student learning goals, sequencing learning activities to achieve those goals, and aligning assessments with content. This necessitates thinking about ways to prune the curriculum and determine student prior knowledge and preconceptions.

Chapter 3. Developing Student Understanding. Using the research on how students learn science, this chapter will help readers learn how to make lessons learner-centered, help students make meaning and build connections among science concepts, and develop each student's ability to learn. To support sense-making, we include strategies that address misconceptions, that make student thinking visible with classroom discourse and that encourage formative assessment processes to identify student learning and provide feedback.

Chapter 4. Creating a Learning Environment. Interactions, routines, and informal feedback that occur every day in the classroom can undermine or enhance learning. This chapter presents strategies related to teaching students to take responsibility for their thinking and learning and to developing positive working relationships with others. Student engagement and motivation are critical components of collaborative classroom environments, and strategies that address these components are included in this chapter also.

Chapter 5. Teacher Learning: A Beginning Teachers continue to learn throughout their lifetimes. All teachers can learn just as all students can learn. To move from "surviving to thriving" we need to look at how the instructional framework applies to us. The key to this work is establishing an environment for ourselves that promotes learning—learning and thinking about the content we teach, learning about content-specific strategies that move students' thinking forward, and learning how to keep a balance but still move forward.

The Audience for *Designing Effective Science Instruction*

First and foremost, this book is valuable for science teachers, both veteran and novice, at all grade levels. It is also of value to anyone concerned with improving science education and nurturing effective science teaching. This latter group includes principals and department heads, curriculum specialists, science mentors, professional development providers, and professors in schools of education. Different science professionals will use the information in this book differently, depending on their goals for improving science instruction.

Teachers at different grade levels and with different levels of experience will focus on different aspects of the book. This is not meant to be a prescriptive, one-size-fits-all book. All teachers will take away lessons that meet their individual needs and promote self-examination of their current instructional practices. For example, if you're a veteran high school teacher, you probably have significant content knowledge; thus, you will benefit most by focusing on lesson design and developing student understanding. In doing so, the biggest change for you may be shifting from a teacher-centered classroom to a student-centered environment. All teachers, though, whether novices or veterans, will want to learn more about how to promote effective science instruction that focuses on important content, engages students in science inquiry, promotes student sense-making using science discourse, and involves students in formative assessments and student self-assessments so that both students and teachers will know if learning is taking place.

Principals and department coordinators, who are responsible for ensuring that science lessons are of high quality, can use the recommendations in this book when analyzing curriculum, providing professional development for staff, and helping teachers create a community of support for instructional change. Without such support from principals and department coordinators, even well-intentioned and highly qualified teachers may become discouraged and some may choose to leave the profession altogether.

Other professional development providers, too, can use the information in *Designing Effective Science Instruction: What Works in Science Classrooms* to create professional development experiences that directly address the strategies in the framework or to help teachers develop a deeper understanding in each area of the framework. All professional development providers who use the research base and proposed strategies in this book, whether principals, department coordinators, or teacher leaders, are responsible for creating the conditions for teachers' success—making the appropriate connections between professional development experiences, helping them understand how all the pieces fit together, and providing them with opportunities to implement, then reflect on, new strategies as they develop a new repertoire of instructional practices.

Last but not least, *Designing Effective Science Lessons* contains valuable information for prospective science teachers. This book could be used as part of a course for preservice teachers, laying the foundation for effective science instruction and high-quality lessons as they learn how to teach. The instructional framework and recommended strategies could help preservice teachers set appropriate goals, envision effective science instruction, and learn how best to approach planning their lessons.

How to Get Started With the Book

The first step to getting started with this book is to get familiar with the C-U-E framework in Chapter 2. Because the C-U-E instructional framework represents a coherent whole, make sure to pay attention to all of its parts. Incorporating any one of the strategies in lesson design will increase lesson effectiveness, but this approach will not be as effective as using the entire framework to design your lessons. At the same time, selecting one or two strategies to practice at a time to see how they work can be a good approach initially. The strategies you choose as a focus will most likely relate to your biggest challenges. Your unique classroom and community context will determine how you will get started. The key to remember is that you will want to be able to answer the following three questions:

1. What essential learning are you including in your lessons and unit of study? (Content—C)
2. What learning experiences will you provide to develop student conceptual understanding? (Understanding—U)
3. How will you and your students support a positive classroom environment that supports learning by all students? (Environment—E)

Depending upon your prior teaching and learning experiences, some of the strategies may not be new to you. So, how do you know what you don't know? The first step is to take the self-assessment found in *Chapter 1: Building the Framework.* The results of this assessment, along with your knowledge of your students' needs, will help you select and prioritize the areas on which you will work first. After working on your highest priority, you can revisit your self-assessment results and pick up the next-highest priority area to reinforce the initial progress you will make.

As with anything new, the first time you try something in class, you may not achieve an instant solution to the instructional problem you were trying to solve. To avoid disappointment, we recommend that you take the approach of a learner when trying to improve your use of these strategies. That is, learn about the strategy, try it, reflect on it, practice and reinforce what is working well. You can also engage your students in a discussion of strategies that you are trying and ask for their feedback and suggestions. This will help students understand what is going on in class and alert them to the possibility of instructional experiences that might be different from what they are used to. And if you have the capacity to work with other teachers, engage in peer discussions and reflection as part of a continuous process of improvement.

Bear in mind that the areas in which educators most need to improve will be those with which they are least comfortable. Tackling areas that are difficult for you can lead to significant changes in instructional practice, but it will take time and practice to use new instructional strategies effectively. Engaging in action research—trying lesson revision strategies, gathering data about their effectiveness, reflecting on implementation, and perhaps involving students in evaluating what's working—is one way to help you persevere. Though the process of change is difficult, relying on the research and experiences behind the recommendations will also help keep you going.

A Personal Note

I believe that if you use the C-U-E framework, you will improve your teaching and your students' learning. I believe this because the C-U-E framework addresses essential aspects of effective science instruction and high-quality science lessons. If the lessons you use every day in your classroom are designed around this framework, positive results are highly likely. Although some of the strategies in this book are ones that you have already mastered, you may find that the way those strategies are organized represents a new approach to instruction for you. All the parts are put together into one complete framework that is easy to follow, practical, and empowering. And it is tried and tested; it reflects what I have learned over three decades of teaching and professional development combined with—and confirmed by—the practices of the best teachers that I know and the most recent research findings available.

Whether you are in a classroom teaching students, working with other science teachers, or learning on your own, I trust that you will find this book informative, relevant, credible, and enjoyable to read. My goal is not to provide an educational "silver bullet" for science teachers but, rather, to help build a community of science teachers willing to try new things and dedicated to helping all students learn.

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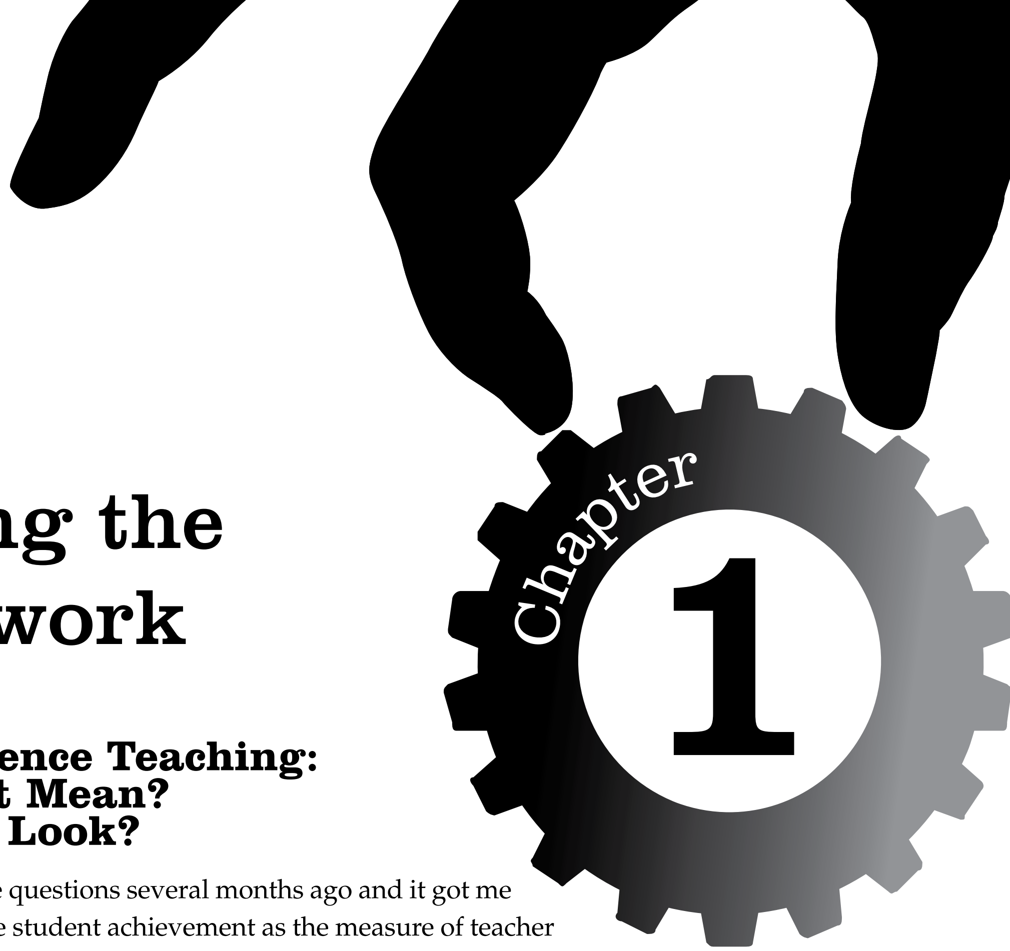

Building the Framework

Effective Science Teaching: What Does It Mean? How Does It Look?

A friend asked me these questions several months ago and it got me thinking. Should we use student achievement as the measure of teacher effectiveness? If improved student achievement is one indicator of effectiveness, we can look at the question of teacher effectiveness with this lens and consider inputs to teachers and outputs as determined by student measures that include engagement, conceptual understanding, and even increased achievement. If we consider science teacher capabilities as part of the inputs, then we need to include teachers' understanding of science concepts and their understanding of when and how to teach the concepts—their pedagogical content knowledge (Shulman 1987). To be more effective as teachers, we need to participate in professional development that increases our content understanding and our ability to decide when and how to present the content to students. But having content knowledge and pedagogical content knowledge is only part of what it means to be an effective teacher.

If we consider teacher effectiveness from the perspective of supporting student learning, then to be effective, teachers need to know instructional strategies that help students learn. In other words, we need pedagogical knowledge. Pedagogical knowledge also includes knowing how to provide learning opportunities that meet the individual needs of students, place the learner at the center of instruction, and facilitate learning opportunities that develop students' conceptual understanding. Since *learner-centered* means different things to different teachers, we use the term to refer to classroom environments that include the existing knowledge, skills, attitudes, and beliefs that our students bring with them. Learner-centered instruction occurs in classrooms that emphasize opportunities for students to construct their own meanings. Instruction begins with what students think and know and bridges their ideas to the subject matter we present (Bransford, Brown, and Cocking 2000).

What Does Research Say About Effective Science Instruction?

If you were to ask science teachers or teachers of elementary school science what effective teaching looks like, the answers would clearly depend upon a variety of factors such as how long they have been teaching, their understanding of learning theory, their ability to understand and apply recent brain research, their content and pedagogical content knowledge, the coaching and mentoring that they received during and after their teacher preparation work, the professional development that they receive, and the professional collaboration and conversations that are part of their day-to-day teaching. This is not a comprehensive list by any means, but it speaks to some of the different influences on teachers' conceptions of effective science teaching and their levels of preparation to design and provide effective teaching and subsequent learning for their students.

When reviewing the research base around effective science teaching there are several resources that provide guidance and insights that can be used to answer the questions "What does effective teaching mean?" and "How does it look?" As mentioned previously, the National Science Education Standards (NRC 1996) provide a framework for what effective science teachers know and do. *Looking Inside the Classroom* (Weiss et al. 2003), a National Science Foundation study, provides additional insights about effective science teaching. According to the study, the goal of all instruction should be to develop students' conceptual understanding. As a result, teachers need to provide students with opportunities to learn the content and be clear about the learning goals for each lesson (specific concepts being addressed). In addition, researchers conducting this study found that lessons judged to be of low quality often lacked meaningful opportunities for discussions or student sense-making and instead consisted of activities for activities' sake, with no clear learning target. As a result of their findings, the observers in the study concluded that "teachers need a vision of effective instruction to guide the design and implementation of their lessons" (p. xiii). It also was clear from the study that teacher content knowledge alone is not sufficient to prepare teachers to provide high quality instruction. A clear understanding of effective instructional practices (pedagogical knowledge) and pedagogical-content knowledge are also needed.

In other words, to adequately develop student understanding of science concepts, we have to go beyond a general understanding of effective instructional strategies and have an in-depth knowledge of the content and common research-based student misconceptions. With that understanding, we need to know when and how to introduce and develop the concepts in class to address students' prior conceptions. We must plan our instruction to engage students beyond a superficial level by using a variety of representations and instructional strategies which make sense to the learner and take into account individual learner needs (Shulman 1986, 1987). We must understand students' scientific thinking and be able to generate effective representations that result in student learning. This cannot happen unless we are prepared with both content and pedagogy and take the time to assess for student thinking.

Figure 1.1 (p. 4) provides lists of the characteristics of effective science lessons that the researchers looked for in the classrooms involved in the *Looking Inside the Classroom* study. The characteristics of effective lessons, along with the research findings, add to our understanding of what it means to offer effective science instruction.

Effective teaching also means assessing what students know as instruction occurs and taking that information into account to adjust instruction. This focus on formative assessment processes in science classrooms is consistent with the research on how students learn science (Minstrell 1989; Donovan and Bransford 2005). Findings from the meta-analysis on how students learn science emphasized the following important principles of learning:

- Assess for prior student understanding of the science concepts.
- Actively involve students in the learning process.
- Help students be more metacognitive so that they can acknowledge the science concepts they understand, the goals for their learning, and the criteria for determining achievement of the learning goals.
- ensure that learning is interactive and include effective classroom discussions.

In a recent publication titled, "Effective Science Instruction," Banilower and colleagues (2008) provide a summary of studies on science learning and suggest an instructional model based on that research. They identify five features of effective science instruction. The first feature is motivating students since students are unlikely to learn without some level of motivation. Second, it is important to elicit students' prior knowledge to find out what their ideas are about the topics or concepts being studied. We know that students have ideas of their own about how the natural world works and some of their ideas will make it difficult for them to learn new ideas. Third, to engage students intellectually with the content, we need to link learning activities to the learning targets. Fourth, effective science instruction helps students think scientifically. This means students are able to critique claims using evidence. Finally, effective science instruction includes opportunities

Figure 1.1
Characteristics of Effective Science Lessons

Quality of Lesson Design	Quality of Noninteractive/Dialogic (NI/D)
❏ Resources available contribute to accomplishing the purpose of the instruction. ❏ Reflects careful planning and organization. ❏ Strategies and activities reflect attention to students' preparedness and prior experience. ❏ Strategies and activities reflect attention to issues of access, equity, and diversity. ❏ Incorporates tasks, roles, and interactions consistent with investigative science. ❏ Encourages collaboration among students. ❏ Provides adequate time and structure for sense-making. ❏ Provides adequate time and structure for wrap-up.	❏ Teacher appears confident in ability to teach science. ❏ Teacher's classroom management enhances quality of lesson. ❏ Pace is appropriate for developmental levels/needs of students. ❏ Teacher is able to adjust instruction according to level of students' understanding. ❏ Instructional strategies are consistent with investigative science. ❏ Teacher's questioning enhances development of students' understanding/problem solving.
Quality of Science Content	**Quality of Classroom Culture**
❏ Content is significant and worthwhile. ❏ Content information is accurate. ❏ Content is appropriate for developmental levels of students. ❏ Teacher displays understanding of concepts. ❏ Elements of abstraction are included when important. ❏ Students are intellectually engaged with important ideas. ❏ Appropriate connections are made to other areas. ❏ Subject is portrayed as dynamic body of knowledge. ❏ Degree of sense-making is appropriate for this lesson.	❏ Climate of respect for students' ideas, questions, and contributions is evident. ❏ Active participation of all is encouraged and valued. ❏ Interactions reflect working relationship between teacher and students. ❏ Interactions reflect working relationships among students. ❏ Climate encourages students to generate ideas and questions. ❏ Intellectual rigor, constructive criticism, and challenging of ideas are evident.

Adapted from Weiss, I. R., J. D. Pasley, P. S. Smith, E. Banilower, D. Heck. 2003. *Looking inside the classroom: A study of K–12 mathematics and science education in the United States*. Chapel Hill, NC: Horizon Research Inc.

for students to make sense of what they are learning by comparing their ideas to those presented by the teacher.

Another significant element of effective teaching comes from the research on formative assessment. Formative assessment provides ways for teachers to focus instruction on student learning. Incorporating formative assessments as part of teacher practices results in teaching and learning that supports an environment focused on learning for all, as Black and colleagues note,

> formative assessment is a process, one in which information about learning is evoked and then used to modify the teaching and learning activities in which teachers and students are engaged.... Feedback can only serve learning if it involves both the evoking of evidence and a response to that evidence by using it in some way to improve the learning. (2003, p.122)

The recent work on learning progressions as part of a formative assessment process provides additional guidance for effective teaching (Heritage 2007). Learning progressions can be created by districts to address coherence across the K–12 curriculum. For our purposes, we are referring to the sequencing of learning targets within a unit of study that leads to student mastery of the big ideas and key concepts. When teachers identify the learning goals (learning targets) in a learning progression and identify criteria for successfully meeting the goals, they can determine student achievement gaps. If students perceive the learning gap as too large, they also perceive the goal as unattainable. If students perceive the gap as too small, they might believe that closing it is not worth their effort (Sadler 1989). Clearly, effective teaching means identifying the "just right" gap for students.

Building a classroom environment that is conducive to learning is essential. Even when teachers clearly understand their content, and design and implement high-quality lessons, teaching will not be effective if the classroom environment does not provide a safe place for students to learn (Marzano 1997). Marzano's work, and that of others (Haertel, Walberg, and Haertel 1981; Bransford, Brown, and Cocking 2000), underscores the idea that effective teaching includes building an environment that is conducive to learning. Teachers' belief systems (how to teach and student accountability) greatly impact their abilities to create an environment where they can work collaboratively with students. That's why it is important to address teacher beliefs, even though it is challenging to do so. Fortunately, research-based strategies are available to help with this task.

As noted previously, effective science teaching develops students' understanding. A recent research-based publication from the National Research Council (NRC), titled *Taking Science to School* (2007), reminds us that in general, students have the capacity to develop understanding of science concepts, but they lack opportunities to do so. This report is not talking about special needs students but the majority of our students who are not achieving in science because they are not provided with sufficient learning experiences. To be effective, science teaching must, first and foremost, provide students with opportunities to learn important concepts. A next logical step is to use research-based instructional strategies to engage students with learning in ways that support development of conceptual understanding (Marzano 2003).

What Do We Know About the Barriers to Effective Instruction?

As science teachers, we have our own ideas about what constitutes effective science teaching. We use a variety of strategies to meet our students' needs and from experience select those that work best for us and our students. It doesn't take very many years of teaching to realize that, even with a clear idea of what effective science teaching is, you will face a variety of challenges that will keep you from being effective with each of your students. Some of these barriers to effective teaching are difficult to address, even when we know what is needed. We may be at a loss for ways to deal with some of the other challenges because we never imagined having to face them.

At a recent teacher workshop, I asked a group of science teachers to identify their current challenges and issues. Their concerns ranged from a lack of resources to a change in students' preparation (e.g., little instruction in science at the elementary levels and a lack of time to teach all of the standards and prepare students for large-scale state assessments). Figure 1.2 provides a visual representation of some of their concerns.

With the No Child Left Behind legislation, there has been a shift in education to a strong system of accountability for schools and districts. This is now a focus area for individual teachers as well. We are now being asked by administrators to be accountable for the learning of all of our students. This shift poses a huge challenge—teachers must find effective ways to differentiate instruction to meet the needs of each student and address gaps in learning. Obviously, many factors influence student achievement. Research, such as that reported in *What Works in Schools* (Marzano 2003), provides guidance about the factors over which schools and teachers have some control, and suggests actions that schools and teachers can take to make a positive difference in student achievement.

Figure 1.2
Challenges Concept Map

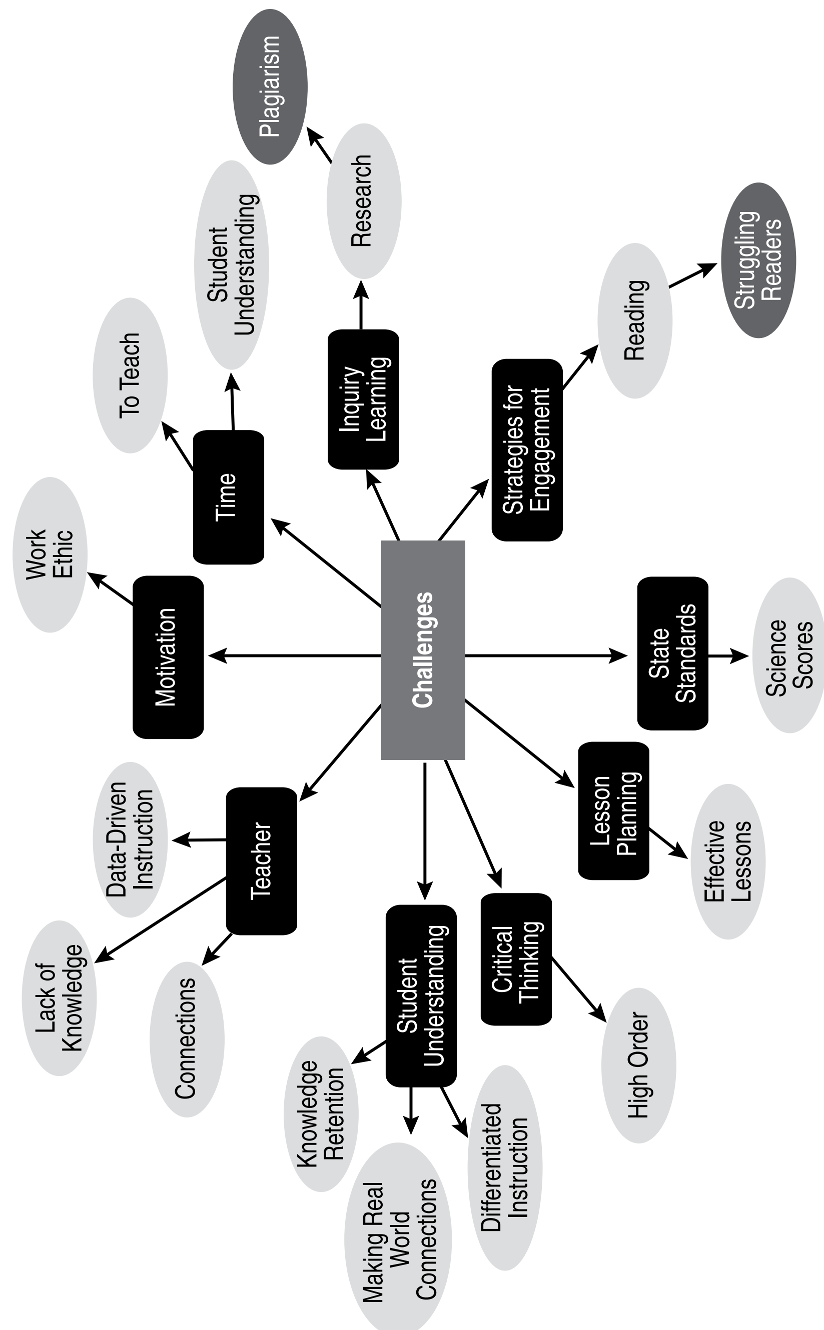

Table 1.1
Influences on Student Learning

 School	1. Guaranteed & Viable Curriculum 2. Challenging Goals & Effective Feedback 3. Parent & Community Involvement 4. Safe & Orderly Environment 5. Collegiality & Professionalism
 Classroom	6. Instructional Strategies 7. Classroom Management 8. Classroom Curriculum Design
 Student	9. Home Environment 10. Learned Intelligence/Background Knowledge 11. Motivation

Adapted from *What Works in Schools: Translating Research into Action,* by R. J. Marzano. Alexandria: VA, ASCD.

Table 1.1 summaries the 11 influences that need to be addressed in effective schools at the school level, classroom level, and student level. Although schools and teachers do not control a student's home life, this research emphasizes that there are actions schools and teachers can take to leverage parents' influence on their children's education. Also on the plus side, we can do something in classrooms to increase students' background knowledge and to motivate them.

Why Did We Develop the Content-Understanding-Environment Framework?

For the past five years, more and more research-based information has been published with clear implications for science teachers. We recognize that it is difficult for teachers to keep up with all of the research reports and revise their teaching to reflect the recommendations from research. To assist teachers with this task, we developed the Content-Understanding-Environment (C-U-E) framework. This framework incorporates key findings from research and is easy to use and remember. Further, current professional development for science teachers usually focuses on only one aspect of teaching and learning, which makes it difficult for teachers to formulate a "big picture" of effective science teaching. The C-U-E framework presents the research in a coherent format that creates a vision of effective science instruction. We acknowledge that the framework does not reflect an exhaustive review of research, but it does include a variety of research from science education and general education and is organized in a way that allows you to readily add new research findings to the ones featured in the book. As a result, the framework is a tool that can serve you well for years to come.

Our goal was to use research findings—those summarized previously in this chapter and other selected research—to create an instructional framework that would be easy for teachers to remember and include recommendations that could be implemented by any teacher. These recommendations are not restricted to K–12 teachers; they can be used by teachers in higher education and, specifically, in teacher preparation programs.

The Content-Understanding-Environment framework is designed to improve science teachers' abilities to deliver effective instruction to diverse student learners. Its effectiveness is due in large part to two qualities. First, all recommended strategies are founded upon a research base with positive links to improved student achievement. Second, the three-part framework helps teachers discern where improvements to their instructional practice are needed and how to take actions that are within their control. This book is based on the premises that delivering 100% effective science lessons is a lifetime professional quest, and immediate and steady improvements can be made by teachers at all stages of their careers.

Before we explain the framework further, we encourage you to reflect on your own teaching practices. To help you do that, we include a self-assessment tool that will prompt you to think about the strategies you currently use to support students' acquisition of significant content, develop student understanding, and create a climate conducive to learning. Figure 1.3, Figure 1.4, and Figure 1.5 encourage you to capture where you are at this moment. There are also places on the documents for you to identify areas you would like to work on or learn more about.

Figure 1.3
Content

Unit of Study/Course/Grade Level
Self-Assessment Rate the following statements using this scale: Not at all 1 2 3 4 5 To a high degree **To what degree do the lessons in my units** __ contain science content that is significant and worthwhile __ contain science content appropriate for the developmental levels of the students __ engage students intellectually with important ideas relevant to the unit's essential understandings __ portray science as a dynamic body of knowledge continually enriched by conjecture, investigation, analysis, and/or proof/justification __ allow for developmentally appropriate sense-making of the science content __ align assessments with the targeted benchmarks __ allow students a variety of ways to demonstrate their knowledge __ promote a context for formative assessments with the purpose of adjusting instruction __ utilize rubrics that help students understand the criteria for quality work __ allow for teacher feedback with the purpose of providing students guidance for improving their performance and clarifying their understanding
My Goals for Improving Instruction Related to Content and Assessment
My Focus During the Book Related to Content and Assessment

Figure 1.4
Understanding

Unit of Study/Course/Grade Level
Self-Assessment Rate the following statements using this scale: Not at all … To a high degree: 1 · 2 · 3 · 4 · 5 **To what degree do I feel comfortable** __ adjusting my own questioning and pacing given the outline of lessons in my unit of study **To what degree do the lessons in my unit of study** __ indicate opportunity for quality questioning __ provide adequate time and structure for wrap-up __ provide strategies and activities that reflect attention to students' preparedness and prior experience __ provide opportunity for students to question, reflect, and challenge ideas __ provide adequate time and structure for "sense-making" __ portray a dynamic body of knowledge continually enriched by conjecture, investigation analysis, and/or proof/justification __ provide opportunities for interactions among students that reflect collegial working relationships
My Goals for Improving Instruction Related to Student Understanding
My Focus During the Book Related to Student Understanding

Figure 1.5
Environment

Unit of Study/Course/Grade Level					
Self-Assessment Rate the following statements using this scale:	Not at all				To a high degree
	1	2	3	4	5

To what degree do the lessons in my unit of study develop and value

- __ active participation of all
- __ a climate of respect for students' ideas, questions, and contributions
- __ a collaborative approach to learning among the students
- __ ______________________________

To what degree do I actively plan instruction to

- __ encourage and allow for critical, creative, and self-regulated thinking
- __ help students develop positive attitudes and perceptions about classroom tasks and climate
- __ provide timely feedback
- __ provide appropriate recognition
- __ reinforce effort
- __ ______________________________

To what degree do I actively plan instruction to

- __ intellectual rigor
- __ constructive criticism and the challenging of ideas
- __ ______________________________

My Goals for Improving Instruction Related to Environment

My Focus During the Convention related to Environment

The C-U-E Framework

The three elements of content, understanding, and environment are equally essential to improving student learning. A weakness in any one will undermine the effectiveness of the other two. We designate **Content** as the first element of the framework to underscore the idea that designing effective science lessons can only occur when we are clear about the big conceptual understandings and key concepts that will be included in the unit. Identifying the significant, worthwhile content also helps us begin thinking about how to sequence lessons as part of a coherent science unit and a coherent science program. We should think first about content at the course of study or grade level and then at the individual unit of study level. Creating that big picture and identifying the big ideas within a course or grade level are necessary steps before going to the smaller grain size of individual lessons.

Teachers have expressed two primary concerns with regard to content: insufficient time for students to develop conceptual understanding and too much content to cover to prepare students for statewide assessments. Aligning the science curriculum, instruction, and assessments to state and district standards is yet another challenge teachers face. To address time and coverage issues, we need tools and clear procedures to identify all of the content embedded in standards and benchmarks. This "unpacking" of standards and benchmarks helps us ensure that we focus instruction on the important learning objectives. Using lesson and unit templates helps us address alignment issues.

Since our focus is clearly on designing effective science lessons with effective science instruction to deliver those lessons, we also talk about some of the features of ineffective practices at the same time we are recommending effective strategies. Some of these ineffective practices are obvious, such as teaching lessons as if students were empty containers to be filled with science knowledge that we tell them, sometimes over and over again. We also want to guard against treating students as passive learners—learning is something students have to *do* themselves. In the remaining sections of this chapter, we introduce the recommended strategies for each component of the framework. Chapters 2, 3, and 4 provide details and tools related to the recommended strategies.

Identifying Important Content

When we talk about identifying important content, we mean starting unit planning and then lesson planning with clarity about the knowledge students should acquire—the information and ideas they should understand and the skills and processes they should be able to perform. Planning also includes identifying the criteria for successful demonstration of learning and deciding how students will demonstrate the required content knowledge. Once the big ideas and key concepts are clearly identified, we can identify specific learning targets as we plan activities that are sharply focused on helping students achieve conceptual understanding and procedural fluency. Intellectually engaging students with the content means that we need to include relevant, emerging content (e.g., plasma state of matter, genetic engineering, nanoscale science and technology) that captures the interests of our students and motivates them to learn. The specific strategies recommended for addressing the content element of the framework are included in Table 1.2 on identifying the important content. The focusing question "Why am I doing this?" asks teachers to reflect on the lesson they are about to teach and to think about the important learning target for that lesson. If a clear learning goal can't be articulated and the answer is "I don't know," then it is time to revise the unit or lesson and work on getting the learning target identified! We do not have time to waste in class, and doing an activity for activity's sake will not support student achievement.

Table 1.2
Identifying Important Content

Strategy 1: Identifying Big Ideas and Key Concepts Identify "big ideas," key concepts, knowledge, and skills that describe what the students will understand.	**Why am I doing this?** **What are the important concepts and scientific ideas included in the lesson?**
Strategy 2: Unburdening the Curriculum Prune extraneous subtopics, technical vocabulary, and wasteful repetition.	
Strategy 3: Engaging Students With Content Create essential questions that engage students with the content.	
Strategy 4: Identifying Preconceptions and Prior Knowledge Identify common preconceptions and prior student knowledge.	
Strategy 5: Developing Assessments: How Do You Know That They Learned? Develop assessments that correlate to the conceptual understanding and related knowledge and skills.	
Strategy 6: Sequencing the Learning Targets Into a Progression Clarify and sequence the learning targets into progressions to focus instruction on building conceptual understanding. Align learning activities with learning targets.	

Developing Student Understanding

Student learning is much better understood today as a result of important research findings over the past 15 years. We know from this research that making lessons more engaging, helping students make meaning and connections among science concepts, and developing each student's ability to learn are all part of developing student understanding.

One significant finding from research is that students come to us with prior knowledge and have ideas of their own to explain the natural world around them. If we do not elicit those ideas and confront the conceptions that are contrary to science knowledge, our students will continue to believe their own misconceptions. Classroom discussion that gets students to think about their thinking is an important strategy for helping them make sense of science concepts. Classroom discussions that promote sense-making are fueled by higher-order questions. Such questions also help students engage intellectually with ideas—a necessary ingredient for students to truly understand science concepts. Intellectual engagement is supported in classrooms that are inquiry-based. In these classrooms, students learn how to develop explanations based on evidence that has been critiqued and

Table 1.3
Developing Student Understanding

<table>
<tr><td>Strategy 1: Engaging Students in Science Inquiry
Engage students in science inquiry to develop understanding of science concepts and the nature of science.</td><td rowspan="6">Who's working harder?

A learner-centered classroom is necessary to develop conceptual student understanding.</td></tr>
<tr><td>Strategy 2: Implementing Formative Assessments
Make use of formative assessments to gather feedback on student progress toward understanding.</td></tr>
<tr><td>Strategy 3: Addressing Preconceptions and Prior Knowledge
Build on prior knowledge and address preconceptions.</td></tr>
<tr><td>Strategy 4: Providing Wrap-Up and Sense-Making Opportunities
Provide daily opportunities for wrap-up that support student sense-making.</td></tr>
<tr><td>Strategy 5: Planning for Collaborative Science Discourse
Develop student understanding through collaborative science discourse.</td></tr>
<tr><td>Strategy 6: Providing Opportunities for Practice, Review, and Revision
Teach concepts in depth by allowing students to continually refine their understanding through practice, review, and revision.</td></tr>
</table>

discussed in the classroom. The specific strategies recommended for developing student understanding are provided in Table 1.3 (p. 15).

Creating a Positive Learning Environment

Interactions, routines, and informal feedback that occur every day in the classroom can undermine or enhance learning. Research on learning environments and reflection on decades of my own and other teachers' experiences have yielded very specific advice on practices that support learning. The strategies included in this part of the framework address how to motivate students, support students in taking responsibility for their learning, and develop positive working relationships with and among students.

Elementary teachers often are expert at creating positive classroom climates. They know what kinds of reinforcement and feedback students need. In elementary school, students usually want to please their parents and teachers and are intrinsically motivated to learn science. When students reach middle school and high school, they often are more interested in listening to and pleasing their friends. As a result, secondary teachers often find it challenging to motivate their students. Fortunately, there are some clear recommendations about how to engage these students collaboratively to create a positive classroom climate.

Table 1.4
Creating a Positive Learning Environment

Strategy 1: Believing All Students Can Learn Show through your actions that you believe all students have the ability to learn.	**What's really important?** **How do I create a positive learning environment?**
Strategy 2: Thinking Scientifically Teach students to think scientifically.	
Strategy 3: Developing Positive Attitudes and Motivation Develop positive student attitudes and motivation to learn science.	
Strategy 4: Providing Feedback Give timely and criterion-referenced feedback.	
Strategy 5: Reinforcing Progress and Effort Keep students focused on learning by reinforcing progress and effort.	
Strategy 6: Teaching Students to be Metacognitive Involve students in thinking about their ideas and assessing their own progress.	

From a science perspective, we need to help students think scientifically, which includes taking risks in class by sharing their explanations and ideas about scientific concepts and phenomena. They must be able to share their ideas without fear of being ridiculed by their peers. Helping them act and think like scientists provides the structure for classroom discussions where it is safe for them to take such risks. The specific strategies recommended for creating a positive learning environment are included in Table 1.4. Remember, if we do not have a positive classroom environment, all of our efforts to provide instruction that addresses important content and to develop student understanding will likely not be effective.

Tools for Using the Framework to Design Lessons

To support your work with lesson revision and improvement, this chapter includes two "tools." The first tool is a lesson design template that includes abbreviated versions of the strategies included in the framework. This tool can be used as a "guiding document" for designing lessons. In addition to the tool for designing new lessons, we provide another template that can be used for revising existing lessons. This second lesson design template can also be used with existing activities, such as those provided in textbook-based materials; it asks you to be explicit about how you will address the C-U-E components. Some of the components of the lesson design framework are featured in Figure 1.6. This provides a quick reflection tool to help you determine what revisions are needed to improve the existing activity.

Figure 1.7 (p. 18) is a second tool to evaluate an existing lesson or activity that once again asks you to focus on the key characteristics of content, understanding, and positive classroom environment. This tool could be used by teachers who teach the same course or grade level to prompt discussions about the important learning targets, strategies that could be used to support student understanding, and ways to provide a supportive learning environment for all students.

Figure 1.6
Lesson Design Framework

1. **Content—Identifying Important Content**
   a. Identify key concepts and lesson objectives.
   b. Identify common preconceptions (misconceptions) and prior knowledge.
   c. Identify knowledge (facts and vocabulary) and skills.

2. **Understanding—Developing Student Understanding**
   a. Use inquiry-based activities that engage students.
   b. Implement formative/summative assessments to determine if students are learning (application).
   c. Provide sense-making and wrap-up activities (open-ended questions).
   d. Provide time for collaborative science discourse (discussion of multiple points of view and sharing of ideas).

3. **Environment—Creating a Positive Learning Environment**
   a. Include opportunities for students to work and think like scientists—reasoning, gathering data, using evidence-based thinking, communicating results.
   b. Reinforce progress and effort.
   c. Plan for criterion-referenced feedback.
   d. Provide multiple opportunities to learn.
   e. Ask students to assess their own progress.

Figure 1.7
Key Characteristics of Content, Understanding, and Positive Classroom Environment

Lesson: ____
Evaluator: ___________________________________ **Date:** __________

1. Make notes of the strengths and weaknesses of this lesson.
2. Use your notes to prepare a summary and specific recommendations for improvement of the lesson design.
3. Keep in mind that our goal is to improve student understanding of important content.

1. **Big idea, key concepts, knowledge and skills** are described in terms of student understanding ➔ are accurate ➔ don't reinforce misconceptions
2. **Summative assessment** provides evidence of learning ➔ has to relate back to key concept ➔ students can demonstrate high cognitive ability when demonstrating conceptual understanding
3. **Essential questions or activities** engage students in the content and motivate them to learn ➔ may be a discrepant event ➔ should be age appropriate
4. **Students' prior knowledge** is acknowledged and built upon ➔ background info on the concept for teachers ➔ what are the prerequisite student learning's ➔ how do we know what the students know (drawing, prediction, response to essential question…) ➔ what are the common preconceptions
5. **Formative assessments** measure progress toward student understanding and inform instruction ➔ include a variety of opportunities ➔ give example and invite teachers to create their own

Figure 1.7 (cont.)
Lesson Design Framework

Lesson: ______________________________
Evaluator: ______________________ **Date:** __________

6. Activities provide students with opportunities to **make sense of key concepts** ➔ wrap-up supports student sense-making ➔ summary, oral or written ➔ quality questioning by teacher or re-engaging with essential question ➔ probing questions or problems ➔ analogies, visual representations
7. Students are involved in **collaborative science discourse** ➔ is a community of learners being developed? ➔ are there questions that encourage collaborative discourse? ➔ are student ideas encouraged?
8. Students engage in **thinking scientifically** ➔ hypothesizing/inferring ➔ reasoning based on evidence ➔ critique and defend answers ➔ gives priority to evidence

Mid-continent Research for Education and Learning. 2005. *Classroom instruction that works: Facilitator's manual.* Aurora, CO: McREL.

Many districts are currently adopting and implementing kit-based instruction for elementary science. It is not always clear what key concepts are being taught during the kit-based lessons and students often get focused on facts and vocabulary rather than on understanding the science ideas. This tool will help you move beyond a focus on the activities of the science kit to a focus on the important ideas that students should learn as a result of the activities.

In Summary

Becoming a good science teacher doesn't just happen; it develops as a result of a variety of experiences over time. It is a result of continuous reflection about our practice that incorporates lessons learned. In the beginning, our college preparation provides theory, practice, and role-modeling by our professors. Student teaching provides some of our first mentoring and hands-on experiences. As novice teachers we observe and mimic the practices of our more experienced colleagues, and benefit from the advice and mentoring of the principal, fellow teachers, and—for the lucky few—professional development designed specifically for us as new science teachers. We then begin to collect resources—books on recommended topics, textbooks and materials, professional development experiences, and a mental checklist or a journal of what works and what doesn't work. We also learn from feedback about the quality of our practice. This feedback comes from supervisor evaluations, the students' test performance, and student and parent comments. All of these experiences contribute to our instructional skill, but as you'll learn throughout this book, there are specific actions we can take to further enhance the quality of our instruction and the effectiveness of our lessons.

During this journey from new teacher to professional science educator, how do we know if we are doing a quality job? What is the standard for effective science teaching and how good is good enough? How well are we meeting the NSES Teaching Standards (NRC 1996)? Is there a "state of the art" level of teaching that can be achieved? How do we know what we don't know—but should? And if research tells us what we should do to improve teaching and learning, how can we incorporate those findings into our teaching practices? All are good questions without simple answers.

Partial answers can be found in standards documents. For example, the National Science Education Standards describe professional teaching standards. These standards provide descriptions of what a professional science teacher should know and be able to do. The NSES document provides information that teachers can use to determine a level of science literacy that teachers must have, not just to prepare an informed citizenry, but as the baseline for teacher content knowledge.

Research provides additional guidance about effective science teaching, although that guidance is limited with regard to some aspects of teaching. The information and tools provided in this book reflect the standards for science teaching and the results of research on effective science instruction. Thus, this book can help you add to your understanding of effective science teaching so that you can reflect on your own practice and determine areas where you can use the information presented to increase your effectiveness.

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Note: **Boldface** page numbers indicate figures.