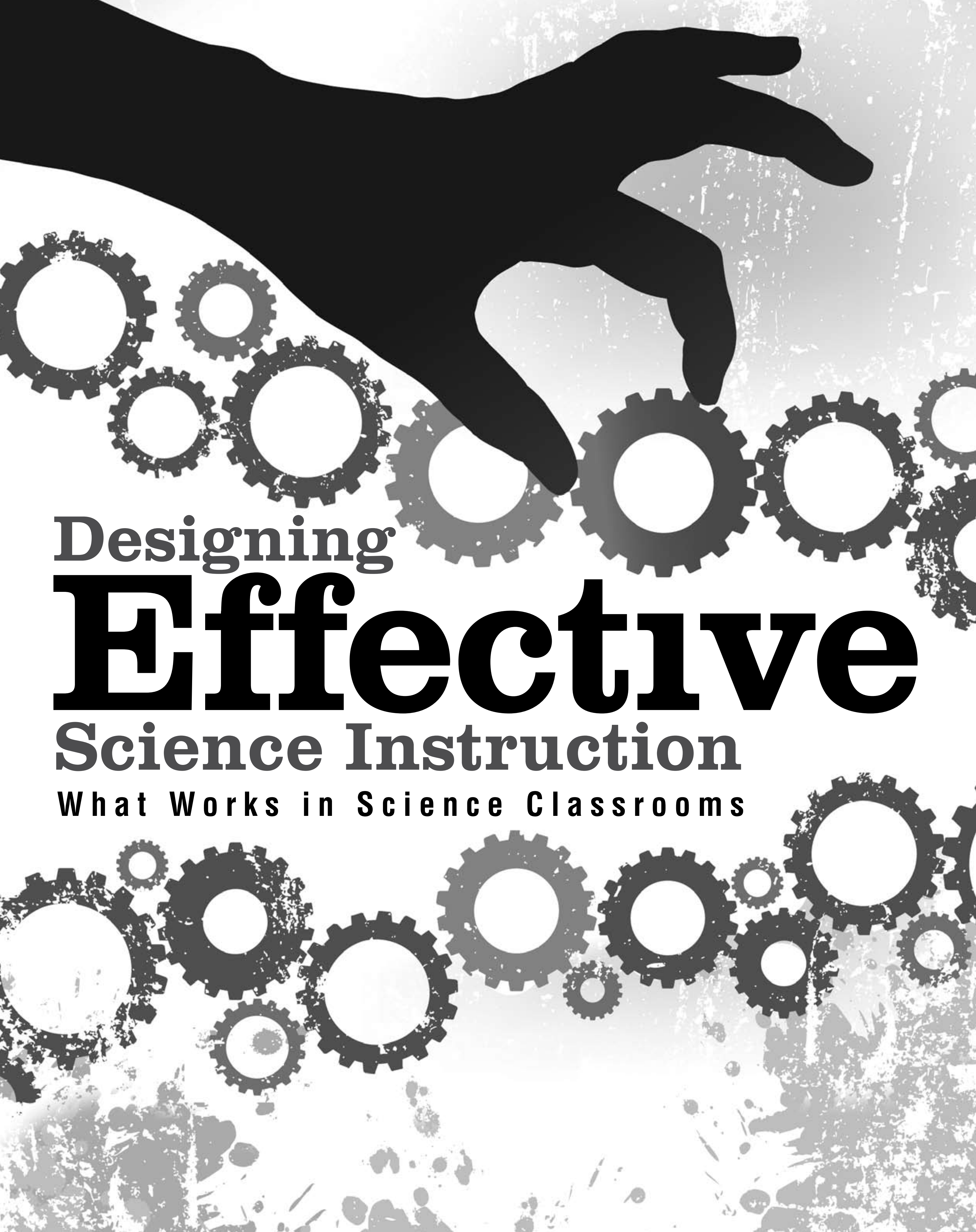

Designing Effective Science Instruction

What Works in Science Classrooms

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Anne Tweed

McREL

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Mid-continent Research for Education and Learning (McREL) is a nonprofit education R&D organization (*www.mcrel.org*) that offers staff development and consulting services to school districts nationwide, including workshops and other professional support for *Designing Effective Science Instruction*. To learn more, e-mail McREL at *info@mcrel.org/desi* or call 1-800-781-0156.

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!

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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

References

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.

References

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.

National Research Council. 1996. *National science education standards*. Washington, DC: National Academy Press.

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.

Environment

Content and understanding strategies contribute in large measure to the instruction we provide. Yet the effectiveness of the most carefully crafted lessons and instruction will be enhanced or undermined by the classroom climate—including relationships among students and between students and the teacher. Therefore, the learning environment is the third essential element of effective science lessons. Strategies that compose this element of the framework help you focus on the question "What's really important in science lessons?" Ultimately, what matters is student learning, and the educational setting of student learning is the classroom environment.

As a result of this chapter, you will

- understand the strategies for creating a positive learning environment and be able to apply them to your own classroom; and
- improve the environment in your classroom and the quality of your science lessons in general.

Table 4.1 provides an overview of six strategies for creating a positive learning environment.

Environment Strategy 1: Believe All Students Can Learn

The Issue

No Child Left Behind (NCLB) legislation requires that all students be proficient in science by 2014. This legislation has caused a shift in thinking for those science teachers who believe that it is not their responsibility if students choose not to learn. Under NCLB, we *are* accountable for all students learning science—even the

Table 4.1
Creating a Positive Learning Environment

Strategy 1: Believe 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: Think Scientifically Teach students to think scientifically.	
Strategy 3: Develop Positive Attitudes and Motivation Develop positive student attitudes and motivation to learn science.	
Strategy 4: Provide Feedback Give timely and criterion-referenced feedback.	
Strategy 5: Reinforce Progress and Effort Keep students focused on learning by reinforcing progress and effort.	
Strategy 6: Teach Students to Be Metacognitive Involve students in thinking about their ideas and assessing their own progress.	

ones who choose not to learn or believe that it is "way too hard" to learn science. Our attitudes, as well as students' lack of belief in their abilities, contribute to students' difficulties learning science. How can we address both our belief systems and those of our students?

The DESI Approach

Good things happen in every classroom, but do they happen for all students? In other words, are teachers deliberately creating a positive environment that promotes learning for *all* students? All teachers consciously and unconsciously make judgments about their students, and vice versa. The DESI approach is to reflect on current beliefs about how you should interact with students and how students should interact with one another. Articulating these beliefs and addressing both our behaviors and students' behaviors can help promote a positive classroom environment focused on learning for all students. We recognize that this strategy is one of the most difficult to implement because it asks you to take a deep look at your own beliefs and consider their implications for student achievement. We know that changing beliefs can be challenging, but we believe you can make such changes. To help you do so, this chapter presents a number of recommended actions.

Selected Research Related to the Issue

In the research report *Looking Inside the Classroom* (Weiss et al. 2003), trained classroom observers went into science and mathematics classes and recorded data about teacher practices in four areas, one of which was classroom culture. Figure 4.1 (p. 130) captures the elements of high-quality instruction that they observed. A review of the indicators of quality indicates that many of the characteristics of high-quality instruction (e.g., climate of respect for students' ideas, questions, and contributions; intellectual rigor; constructive criticism; and challenging of ideas) are strongly influenced by the climate in the classroom.

1. "Teachers must attend to designing classroom activities and helping students organize their work in ways that promote the kind of intellectual camaraderie and the attitudes toward learning that build a sense of community. In such a community, students might help one another solve problems by building on each other's knowledge, asking questions to clarify explanations, and suggesting avenues that would move the group toward its goal. Both cooperation in problem solving and argumentation among students in such an intellectual community enhance cognitive development." (Donovan, Bransford, and Pellegrino 1999)
2. In a self-fulfilling prophecy, you form an expectation of a student, which is communicated nonverbally through your behavior. The student then responds to your behavior, behaving in ways that conform to your expectation, and the expectation then becomes reality. Self-fulfilling prophecies can be positive or negative. For example, high expectations can lead to high student performance, and low expectations to low performance. (Rosenthal 1998)
3. Whether we are aware of it or not, we all make split-second judgments about people that are affected by physical characteristics, speech, name, and socioeconomics. (Tauber 1997)
4. The four factor theory (Rosenthal 1998) helps explain how teachers convey their expectations to students. The four factors are:
   - *Climate***.** Climate is communicated nonverbally by smiling and nodding (or frowning and shaking your head), eye contact, and body position. Climate is the tone you set in which all the teacher-student interactions take place.

Figure 4.1
Elements of High-Quality Instruction

Lesson Design	Lesson Implementation
❏ Available resources contribute to accomplishing the purpose of the instruction. ❏ Lesson 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. ❏ Lesson incorporates tasks, roles, and interactions consistent with investigative science. ❏ Lesson encourages collaboration among students. ❏ Lesson provides adequate time and structure for sense-making. ❏ Lesson 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.
Science Content	**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.

- *Feedback***.** Feedback is both affective (e.g., praise or criticism) and cognitive (e.g., detail and quality of the content). Feedback is your response to a student action or communication.
- *Input.* Input is the quantity and quality of information you provide the student. Observations of classrooms have shown that teachers actually teach more (provide greater input) to students of whom they have high expectations.
- *Output.* Output is the responsiveness of the student. You encourage greater or lesser responsiveness through verbal and nonverbal cues.

5. Virtually every aspect of science teaching is influenced by attitudes and beliefs. These aspects include acquiring and interpreting content knowledge, designing and selecting instructional strategies and activities, choosing assessments, engaging in professional development, and interacting with peers, parents, and students (Keys and Bryan 2001).

What Is the Strategy?

More research that addresses the complexities of teacher attitudes and beliefs is needed, but we are convinced that teachers can change their beliefs and use the self-fulfilling prophecy idea to elicit improved performance from students. There are a variety of factors, including the school and department culture, that shape teachers' belief systems (e.g., homework practices and make-up work), but this strategy focuses on actions individual teachers can take to change their beliefs. In our view, if you are cognizant of your beliefs about students and positively change how you behave toward them, you may find that students' performance improves. And when this happens, your beliefs about students' abilities will change. Because beliefs are usually developed over time and are strongly held, the first step is to identify what you believe and why. Second, ask whether the belief has an impact on student learning. If so, then it is important to examine that belief because beliefs influence attitudes, which are revealed in behaviors (Simpson et al. 1994).

If your beliefs result in behaviors that negatively affect student performance, then the third step is to identify and use a different behavior and observe how students respond. Deliberately behaving in a different way can feel "artificial" at first, but with practice, the behavior will seem more natural and become easier to use. Table 4.2 (p. 132) captures the process and is meant to help you reflect on the steps you might take to change a behavior. Specific examples of practices that teachers can implement that will affect their beliefs will be provided in the next section.

Table 4.2
Changing Beliefs by Changing Practices

Step 1	Identify One Educational Belief: Determine a belief about a classroom practice or policy that affects all of your students. Reflect on the reasons you believe what you believe.
Step 2	Determine the Affect of the Belief on Student Learning: Are there certain students who benefit from the practice or policy? Who are they and why? Are there some students negatively influenced by this policy or procedure? Who are they and how are they affected?
Step 3	Identify a Practice or Behavior That Could be Changed to Support Student Learning: What could you do differently that would help all of your students? Take steps to determine a policy or practice that you can change. (You may need to alert your students of the change in practice so that they are not confused by what is expected of them.)
Step 4	Implement a Change in Practice and Observe the Results: Implement an action or policy where the change supports access to learning for all of your students. Gather some action research data on the effect of the change. If the change supported learning by all students, continue the practice. Think about your change in practice and its impact on the classroom environment.

The procedure for changing beliefs described in the preceding paragraph might seem prescriptive, but it is meant to describe one possible pathway we can use to work on attitudes and beliefs that influence learning. Our point is that beliefs can be changed gradually by new information. When we are open to behaving in new ways and see improvements in students' performance as a result of new behavior, our beliefs will change based on that new information.

Exploring the Strategy

Research studies have found that teachers make hundreds of decisions every day and decisions that teachers make about students are sometimes made unconsciously. The goal is to be self-aware and to make our unconscious thinking conscious so that we can determine why we expect what we expect. From there, we can be more aware of our input and output to our students, focus on practices that build relationships with students, and use this positive energy to create a classroom climate that supports student learning. Read through the information contained in Figure 4.2, which asks, "Are you a good judge of character?" and begin to reflect on your beliefs and the kinds of judgments teachers make all the time.

Figure 4.2
Are You a Good Judge of Character?

Do you feel like you are a reasonably good judge of character? If you have years of teaching experience under your belt, you probably feel that, more often than not, you are able to correctly size up students. Occasionally you may be wrong, but most often you are correct. Right? Many teachers believe that they can judge ahead of time—sometimes by just a glance on the first day of school—how likely certain students are to achieve and behave.

In this activity (Tauber, 1997), what are the thoughts that come to your mind when you think about the following kinds of people? Be honest. No one but you will know what you think. Think about the students you see at your grade level.

Generally, what descriptors might you use to characterize

1. A student from a family that has strong and vocal political ties
2. A significantly overweight girl
3. A student from an affluent family who is an only child
4. A student whose two older siblings you had in class several years ago—each of whom was often a troublemaker
5. An Asian boy who is the son of a respected university math professor
6. A boy who is thin, almost frail, and very uncoordinated for his age

The beliefs and biases that are revealed in this activity are a product of the unconscious, built up over many experiences and messages from your environment. You probably don't want to hold these biases, but being unconscious, they are not subject to rational logic or suppression. Of course, that doesn't mean you shouldn't work on changing your beliefs and biases. On the contrary, by making them conscious, you take the first step to liberation.

For more about the power of unconscious thinking, see *Blink: The Power of Thinking Without Thinking* (Gladwell, 2005).

To implement this strategy, personal reflection is essential. Specifically, it is important to ask yourself, "What beliefs do I have that are *supporting* or *interfering with* my ability to create a positive learning environment for all my students? Which types of students (e.g., who that show hostility) challenge my belief that they can learn?" The scenarios that follow provide examples of teachers' beliefs that negatively impact the learning of some or all of the students in the class. As you read the scenarios, think about the beliefs behind the behaviors and how these beliefs hinder the creation of a positive learning environment.

Scenario 1: Beliefs About Homework

I think my students need to learn the discipline of good study habits, so I assign homework every night. I choose homework of various types—reading their books, answering questions, finishing up class work, doing home experiments, and so on. I'm consistently disappointed in the quality of work they do, because only a few students really do it well. And, of course, I have a few students who never do it. I just record a plus or minus in my grade book indicating whether or not they did it. I don't want to use too much class time correcting homework. I take into consideration whether or not students have shown good effort in their homework when I am deciding their final grade or mark for the class.

Scenario 2: Beliefs About Grading

I want to be fair, so I let my students drop their two lowest marks each quarter. I think this helps them stay motivated because they don't get discouraged by a bad day. Sometimes, it makes a big difference for a kid.

Scenario 3: Beliefs About Classroom Expectations

I just require that students bring materials to class—their books, paper, and pencils. I can't really stand high-control environments, and I have better things to do than spend all my time being the bad guy. I enjoy a relaxed classroom, and we have good discussions and a lot of fun. My students get to know me well because I share a lot about my past and what I do outside school. They get to know me so well that they know what I expect without my having to post a bunch of rules on the bulletin board. It works for me because I know how to relate to the kids, and they respect me for that.

Scenario 4: Beliefs About Inquiry in the Classroom

I feel a real ambivalence about incorporating inquiry into my lessons. I'm worried about covering enough material to enable my students to be well-prepared for the state assessments. On the other hand, I think investigation and working with real things is what really turns kids on to science. So I try not to let a week go by without some kind of hands-on experience. Time is another factor. First, not all investigations fit into a period. Second, I just can't kill myself with so many setups and keeping the inventory for tons of supplies. I don't even have the equipment that I need. I never get out of school until the last minute when I have to rush to pick up the kids from day care. I can only do so much.

Scenario 5: Beliefs About Laboratory Reports

I know this is a really important part of students' learning. I've tried different formats over the years and have found that different formats suit different investigations, so I have pretty much rejected the good old scientific-method style. At the first of the year, I give students written directions with a data sheet to fill out and guiding questions toward the conclusion. I always let them discuss with one another if they want or need to do that—the important thing is that they learn. Then, as the year goes on, I teach them different ways of reporting their data, and the importance of making conclusions based on evidence. Then I can be less supportive with their write-ups and can expect them to apply what I've taught. I "grade" the write-ups by writing comments on them, which takes me about three days. Plus I give a 1 for incomplete or poor, a 2 for complete, or a 3 for impressive. If students want to, they can improve their write-ups by addressing my comments and turning them in again. When I get an "impressive" one, I show it to the class or post a copy.

Figure 4.3 (pp. 136–7) captures these teacher beliefs and the impact of their actions on student success. One recommendation that might improve the teacher's practice is also provided for each scenario. Think about the procedures and policies you have in class. If your school or district already has policies in place for homework and late work, for example, move on to other aspects identified in the four-factor theory findings (Rosenthal 1998). Decide what choices you can make to support learning through clear policies and procedures. Clearly, if we believe that we are able to successfully implement an instructional strategy or policy that supports learning for all students, then this positive belief supports student achievement.

Planning for Classroom Implementation

Our beliefs about student learning and our behaviors toward our students are factors that affect student learning. As you plan to implement this strategy, you will want to consider whether the norms in your classroom support your beliefs about student learning. For example, if you believe that students should be able to share their ideas, reveal their misconceptions, make mistakes, obtain feedback,

Figure 4.3
Analyzing Teacher Beliefs and Actions That Support a Climate of Learning

Scenarios	Teacher Belief	Impact on Learning	Recommendation
1. Homework	The teacher believes that homework every day will develop good study habits among the students.	Since the students are assigned homework every night, it is having a negative effect on their willingness to use homework to improve learning. This negatively impacts all students.	Not all homework is the same and some homework is for practice and some is for preparation or elaboration (Marzano, Pickering, and Pollack 2001). Homework should only be assigned periodically and should be commented on to improve the effect on student learning. Create a homework policy.
2. Grading	The teacher believes that dropping the two lowest grades is fair for students and solves the problem of students with low scores or zeros.	The two lowest scores may represent significant assessments of student achievement. The low-achieving students are affected by having grades that do not adequately align with learning and instead result in grade inflation.	If receiving evidence of student learning is the goal, then devising a strategy that allows for extended time to complete work will maintain rigor and still accommodate personal student issues. Try providing two "oops" passes each marking period to extend deadlines.
3. Classroom Expectations	The teacher believes that they create a positive classroom climate by being the students' friend and sharing personal information.	Students may not be clear about classroom expectations. Trying to be a friend affects all students because the focus is not on a well-managed or learner-centered classroom.	Establishing clear classroom expectations provides order for all students. Providing procedures for students creates a sense of comfort that supports all students. Time spent on telling a personal teacher story is time away from instruction.

and revise their thinking and their work, then you will need to set and follow norms that create an environment of cooperation and camaraderie.

As you consider implementing this strategy, you might also want to examine the belief shared by many teachers that all students can learn. What does this belief look like in practice? What do we do? What do we say? To answer these questions, think about the positive characteristics and actions of the teachers and professors in whose classes you learned the most as a student. Many of us say that we learned most in classes where the teachers liked the subject and showed that they cared about us as people. We also liked teachers who made the learning interesting and even fun sometimes. These teachers gave us chances to think about what we were learning and they didn't give up on us. They were also fair, which means they met

Figure 4.3 (cont.)
Analyzing Teacher Beliefs and Actions That Support a Climate of Learning

Scenarios	Teacher Belief	Impact on Learning	Recommendation
4. Inquiry	The teacher believes that inquiry instruction may be an important strategy, but it just takes too much time to prepare and accomplish in class.	All students are affected by a lack of inquiry instruction in a science class. The first feature of inquiry is to engage students with scientific questions that cause them to think about the concept and their own ideas.	Scientific inquiry refers to the diverse ways in which scientists study the natural work and propose explanations based on evidence. Plan to include inquiries on a regular basis, but share the prep work with other teachers or create a student schedule for set-ups and taking-down of materials.
5. Lab Reports	The teacher believes that laboratory write-ups are important as illustrations of student learning, but any responses from students are accepted and evaluated on a three-point scale.	This affects all students because the criterion for success is not clear for students. There is no way to know if they are progressing or if they understood the concepts unless the comments provide formative feedback.	Provide a rubric for the laboratory write up that includes criteria for proficient work. Provide exemplars for students to refer to and give them opportunities to revise their work based on the teacher comments.

not only our needs but the needs of the other students. Think about the ways in which you demonstrate your belief that all students can learn. What do you think your students would say you do to show that you believe in their ability to learn? Are your responses similar to your students' responses? Self-fulfilling prophecies work both ways: Our performance can reflect our students' beliefs about us just as their performance can reflect what we believe about them.

What Works in Science Classrooms: Implications for Teaching

Recommendation 1: The research on self-fulfilling prophecies shows that if we believe students can learn, then they probably will. When asked, teachers will, of course, say they believe that all students can learn. When probed further, though, there are a number of conditions. All students can learn if they come to school prepared, have the ability, have the opportunities, apply themselves, and so on. Each student should have the opportunity to learn with the support of teachers who believe they *can* learn. Examine your beliefs about student learning and how you demonstrate those beliefs through your actions and classroom policies. Determine if there are students whose learning would improve with a change in those practices or policies. To carry out this recommendation, you can discuss your beliefs with other teachers, plan for a change in practice, or survey other teachers about their effective policies and practices.

Recommendation 2: Take a systematic approach to changing your beliefs. The first step is to accept that it is possible to change your beliefs. Next, acknowledge existing beliefs, identify which of your practices demonstrate beliefs that are interfering with student learning, implement changes in those practices, and see the results of the new practices. As you implement this recommendation, you will benefit from planning how you will interact with students to show them that you believe they can learn science. Add notes to your lesson planner about behaviors you want to try or students you want to specifically interact with to build a positive relationship. Track your results and revise your behaviors as needed.

Recommendation 3: Create a positive climate that fosters camaraderie and collaboration in the classroom by attending to both procedures and interactions. We begin to create a positive climate by teaching procedures that foster student questioning, risk-taking, collaboration, and a mutual focus on learning. Remember, to teach procedures effectively, teachers must teach the steps of the procedure, model them, provide opportunities for students to practice them, and reinforce them. To foster collaboration, encourage interactions that are supportive rather than competitive. Doing so will help you and your students develop a shared belief that everyone in the class can learn. Reviewing the research on collaborative learning and the current research on science teacher beliefs and attitudes can help you incorporate this recommendation into your classroom practices. A summary of the historical and current research on these topics can be found in the *Handbook of Research on Science Education* (Abell and Lederman 2007). From the research, it is becoming clear that our belief systems are embedded in the larger sociocultural environment, which includes students, teachers, parents, administrators, the community, and the political and cultural environment.

Environment Strategy 2: Think Scientifically

The Issue

Understanding the world from a science perspective is different from understanding it from other perspectives. Students may be taught a unit about the nature of science, which addresses thinking and working like a scientist, but these units often do not provide specifics about the daily practices of scientists. In other

Table 4.1
Creating a Positive Learning Environment

Strategy 1: Believe 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: Think Scientifically Teach students to think scientifically.	
Strategy 3: Develop Positive Attitudes and Motivation Develop positive student attitudes and motivation to learn science.	
Strategy 4: Provide Feedback Give timely and criterion-referenced feedback.	
Strategy 5: Reinforce Progress and Effort Keep students focused on learning by reinforcing progress and effort.	
Strategy 6: Teach Students to Be Metacognitive Involve students in thinking about their ideas and assessing their own progress.	

words, students are not taught *how* scientists go about their work and how they reach scientific conclusions. Students often have misconceptions about scientists. They might think of them only as men in white coats who work in chemical laboratories. As a result, students rarely equate their learning in science classrooms to the work of scientists.

The DESI Approach

From the very first day of class, students should be actively engaged in learning to view the world scientifically. This means they need to have opportunities to ask questions, collect data, and discuss their findings. Every science lesson should provide opportunities for students to share their ideas, ask their classmates to defend their ideas using evidence, communicate data, be creative, critique evidence, and make scientifically based predictions. As students gain experience in working like scientists, they will be able to design and conduct investigations, first with teacher assistance, and then on their own. Ultimately, students should be able to evaluate their own explanations in light of alternative explanations, including those that reflect scientific understanding. The strategy of promoting scientific thinking is critical to establishing a collaborative classroom climate where students can discuss their ideas safely and where challenging each others' ideas is the accepted behavior because it is consistent with the way that scientists work.

Selected Research Related to the Issue

1. "We teach according to how we understand the nature of what we are teaching and according to how we understand the nature of learning…. Science is a major area of human mental and practical activity which generates knowledge that can be the basis of important technological applications as well as of intellectual satisfaction. It is an important part of the education of all, not just of scientists, to be aware of the status and nature of scientific knowledge; how it is created and how dependable it is." (Harlan 1992, p. 2)
2. "Simply telling students what scientists have discovered, for example, is not sufficient to support change in their existing preconceptions about important scientific phenomena. Similarly, simply asking students to follow the steps of 'the scientific method' is not sufficient to help them develop the knowledge, skills, and attitudes that will enable them to understand what it means to 'do science' and participate in a larger scientific community." (Donovan and Bransford 2005, p. 398)
3. "In the long run, no scientist, however famous or highly placed, is empowered to decide for other scientists what is true, for none are believed by other scientists to have special access to the truth. There are no pre-established conclusions that scientists must reach on the basis of their investigations." (AAAS 1990, p. 7)
4. "There can be no future for the human experiment unless a critical mass of involved people understands that the laws of nature constrain our activities and that our solutions to these problems must be based on knowledge and not blind adherence to fads." (Moore 1993, p. viii.)

What Is the Strategy?

Why do we want students to learn to think scientifically? Will learning to do so improve the quality of the science classroom environment? To answer these questions, we have to first define "thinking scientifically." At the simplest level, this means thinking like a scientist thinks. To be able to think like a scientist, students must have a working understanding of the nature of science. If we look at the major characteristics that describe the nature of science (Table 4.3), we can

Table 4.3
The Nature of Science

Scientific Inquiry Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypotheses and theories, the kinds of logic used, and much more. Nevertheless, scientists differ greatly from one another in what phenomena they investigate and in how they go about their work; in the reliance they place on historical data or on experimental findings and on qualitative or quantitative methods; in their recourse to fundamental principles; and in how much they draw on the findings of other sciences. Still, the exchange of techniques, information, and concepts goes on all the time among scientists, and there are common understandings among them about what constitutes an investigation that is scientifically valid. Scientific inquiry is not easily described apart from the context of particular investigations. There simply is no fixed set of steps that scientists always follow, no one path that leads them unerringly to scientific knowledge. There are, however, certain features of science that give it a distinctive character as a mode of inquiry. Although those features are especially characteristic of the work of professional scientists, everyone can exercise them in thinking scientifically about many matters of interest in everyday life.	
1.	**Science Demands Evidence** Sooner or later, the validity of scientific claims is settled by referring to observations of phenomena. Hence, scientists concentrate on getting accurate data. Such evidence is obtained by observations and measurements taken in situations that range from natural settings (such as a forest) to completely contrived ones (such as the laboratory). To make their observations, scientists use their own senses, instruments (such as microscopes) that enhance those senses, and instruments that tap characteristics quite different from what humans can sense (such as magnetic fields). Scientists observe passively (earthquakes, bird migrations), make collections (rocks, shells), and actively probe the world (as by boring into the earth's crust or administering experimental medicines). In some circumstances, scientists can control conditions deliberately and precisely to obtain their evidence. By varying just one condition at a time, they can hope to identify its exclusive effects on what happens, uncomplicated by changes in other conditions. Often, however, control of conditions may be impractical (as in studying stars), or unethical (as in studying people), or likely to distort the natural phenomena (as in studying wild animals in captivity). In such cases, observations have to be made over a sufficiently wide range of naturally occurring conditions to infer what the influence of various factors might be. Because of this reliance on evidence, great value is placed on the development of better instruments and techniques of observation, and the findings of any one investigator or group are usually checked by others. (Continued on pages 142 and 143)

Table 4.3 (cont.)
The Nature of Science

2.	**Science Is a Blend of Logic and Imagination** Although all sorts of imagination and thought may be used in coming up with hypotheses and theories, sooner or later scientific arguments must conform to the principles of logical reasoning—that is, to testing the validity of arguments by applying certain criteria of inference, demonstration, and common sense. Scientists may often disagree about the value of a particular piece of evidence, or about the appropriateness of particular assumptions that are made—and therefore disagree about what conclusions are justified. But they tend to agree about the principles of logical reasoning that connect evidence and assumptions with conclusions. Scientists do not work only with data and well-developed theories. Often, they have only tentative hypotheses about the way things may be. Such hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of data. In fact, the process of formulating and testing hypotheses is one of the core activities of scientists. To be useful, a hypothesis should suggest what evidence would support it and what evidence would refute it. A hypothesis that cannot in principle be put to the test of evidence may be interesting, but it is not likely to be scientifically useful. The use of logic and the close examination of evidence are necessary but not usually sufficient for the advancement of science. Scientific concepts do not emerge automatically from data or from any amount of analysis alone. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers. Sometimes discoveries in science are made unexpectedly, even by accident. But knowledge and creative insight are usually required to recognize the meaning of the unexpected. Aspects of data that have been ignored by one scientist may lead to new discoveries by another.
3.	**Science Explains and Predicts** Scientists strive to make sense of observations of phenomena by constructing explanations for them that use, or are consistent with, currently accepted scientific principles. Such explanations—theories—may be either sweeping or restricted, but they must be logically sound and incorporate a significant body of scientifically valid observations. The credibility of scientific theories often comes from their ability to show relationships among phenomena that previously seemed unrelated. The essence of science is validation by observation. But it is not enough for scientific theories to fit only the observations that are already known. Theories should also fit additional observations that were not used in formulating the theories in the first place; that is, theories should have predictive power. Demonstrating the predictive power of a theory does not necessarily require the prediction of events in the future. The predictions may be about evidence from the past that has not yet been found or studied.

Table 4.3 (cont.)
The Nature of Science

4.	**Scientists Try to Identify and Avoid Bias** When faced with a claim that something is true, scientists respond by asking what evidence supports it. But scientific evidence can be biased in how the data are interpreted, in the recording or reporting of the data, or even in the choice of what data to consider in the first place. Scientists' nationality, sex, ethnic origin, age, political convictions, and so on may incline them to look for or emphasize one or another kind of evidence or interpretation. Bias attributable to the investigator, the sample, the method, or the instrument may not be completely avoidable in every instance, but scientists want to know the possible sources of bias and how bias is likely to influence evidence. Scientists want, and are expected, to be as alert to possible bias in their own work as in that of other scientists, although such objectivity is not always achieved. One safeguard against undetected bias in an area of study is to have many different investigators or groups of investigators working in it.
5.	**Science Is Not Authoritarian** It is appropriate in science, as elsewhere, to turn to knowledgeable sources of information and opinion, usually people who specialize in relevant disciplines. But esteemed authorities have been wrong many times in the history of science. In the long run, no scientist, however famous or highly placed, is empowered to decide for other scientists what is true, for none are believed by other scientists to have special access to the truth. There are no pre-established conclusions that scientists must reach on the basis of their investigations. In the short run, new ideas that do not mesh well with mainstream ideas may encounter vigorous criticism, and scientists investigating such ideas may have difficulty obtaining support for their research. Indeed, challenges to new ideas are the legitimate business of science in building valid knowledge. Even the most prestigious scientists have occasionally refused to accept new theories despite there being enough accumulated evidence to convince others. In the long run, however, theories are judged by their results: When someone comes up with a new or improved version that explains more phenomena or answers more important questions than the previous version, the new one eventually takes its place.

American Association for the Advancement of Science (AAAS). 2007. *Science for all Americans*. New York: Oxford University Press. Reprinted with permission.

develop a working definition of what it means to "think scientifically" and an understanding of how a scientific way of knowing and scientific thinking influence science teaching.

Looking at some of the main ideas included in Table 4.3, we see that scientists seek to explain and make predictions that avoid bias. Using logic and imagination they seek to make sense of evidence. There are no predetermined conclusions when developing explanations, and new data contribute to scientific thinking and understanding. Scientists study the natural world by making observations, experimenting, confirming evidence, and thinking about and critiquing other scientists' explanations. They do not rely on beliefs, cultural stories, ethical norms, or social expectations.

What does thinking scientifically look like in the classroom? First and foremost, science is about asking questions, so science instruction that promotes thinking scientifically includes many opportunities for students to ask and answer questions that can be investigated through science. When students act like scientists, they exhibit the following behaviors:

- Using and testing of hypotheses and theories and developing logical explanations
- Thinking creatively and using their imaginations when developing conclusions based on evidence
- Interpreting data and checking for biases in their explanations
- Working on the same problem as other student scientists because having multiple scientists work on the same problem reduces bias
- Recognizing that even with significant amounts of data, scientists and scientific conclusions can be wrong
- Discussing their ideas with other student scientists (because scientists do not always agree, conclusions should be subject to vigorous criticism as explanations are challenged and defended)

If we keep these ideas in mind, then teaching students to think and act like scientists means we need to provide some specific kinds of experiences in the classroom. According to research studies on teaching and learning the nature of science, students need to understand that

1. there is a distinction between hypotheses, facts, and theories, and between laws and theories;

2. scientific data are not the same as scientific evidence;
3. explanations are developed from a combination of collected data and what is already known;
4. scientific thinking includes human imagination and creativity;
5. scientific knowledge is subjective and based upon a scientist's interpretation; and
6. scientific knowledge is never absolute or certain but is subject to change as new evidence makes it possible to advance or modify laws and theories (Lederman 2007, pp. 833–835).

Classroom behaviors that help develop these understandings include asking scientific questions, gathering data and making observations to develop evidence, giving priority to the evidence to develop scientific explanations, communicating and discussing findings with others, and justifying proposed explanations. To help our students get comfortable, we need to model, reinforce, and practice these behaviors every day. You don't need to focus on all of these behaviors at once. Select one to get started, and systematically teach it to your students. Then you can emphasize each of the behaviors in turn until your students become skilled at thinking scientifically.

Exploring the Strategy

We began this section by reviewing information about the nature of science and what scientists do when they conduct scientific investigations. Next, we presented some ideas about what it means to think scientifically and identified some classroom experiences that help students develop their abilities to "think scientifically." Now that we've generated some ideas about the qualities of thinking scientifically, we can address how to create an environment that supports and exemplifies those qualities, while keeping in mind what's really important: learning for all.

One way to start promoting scientific thinking is to use effective questions. Practice using probing questions that require students to think about their thinking to respond. It often is difficult to come up with good probing questions on the spot; preparing some questions ahead of time is one way to be sure that your questions promote thinking. You might start by asking open-ended questions about the investigations your students are conducting. Examples of these types of questions, which were included in Chapter 3, follow.

Questions that help students build confidence and rely on their own thinking and understanding

- How did you reach that conclusion?
- Does that make sense?
- What is the evidence that supports your explanation?

Questions that help students learn to reason scientifically

- What assumptions are you making?
- How would you verify or prove that?
- Would your results hold true for all cases? Explain why.
- Can you think of an alternate procedure?

Questions that help students collectively think about explanations or make sense of science

- What do you think about what ____ said?
- Do the rest of you agree? Why or why not?
- Did anyone get the same data but explain them in a different way?
- Does _________ explanation make sense? Why or why not?

Questions that encourage reflective thinking

- How would you justify your explanation?
- Do your data seem reasonable? Why or why not?
- Can you explain why you got the evidence that you did?
- What additional observations could you make?
- What have you learned or discovered today?

Planning for Classroom Implementation

As you plan to implement this strategy, remember that science provides a way to explain the natural world. In other words, science helps us answer questions about the natural world. As a result, teaching science means helping students understand the difference between questions in general and scientific questions. It also means helping them think about observations to infer, hypothesize, and critique explanations using evidence.

To prepare to use the strategy of promoting scientific thinking, reflect on what you know about the nature of science and ask yourself if you are clear about what makes a question a scientific question. If you have not had many opportunities to think deeply about the nature of science or to develop your own scientific investigations, think about what you would like to learn first to help your students in these areas. To develop your own knowledge and skills, you might read some of the recent studies, many of which relate to elementary teachers and students, designed to test the impact of Nature of Science (NOS) instruction. One finding from these studies is that students' reactions to conflicting evidence are at least partially related to their views on NOS (Sadler, Chambers, and Zeidler 2004).

Improving the quality of your classroom environment by promoting scientific thinking will occur gradually. The strategy will be more effective if we teach our students the procedures involved in thinking scientifically, model those procedures, and provide opportunities for students to use them. In this section, we will investigate two aspects of thinking scientifically: (1) knowing the difference between facts, hypotheses, and beliefs, and (2) using imagination and creativity. You may already have a procedure that you use to help your students with these aspects of thinking scientifically, but we invite you to look at the following ideas as you plan for classroom implementation.

Figure 4.4 (p. 148) explains the difference between fact, theory, law, hypothesis, and belief, and includes a questionnaire for testing understanding of these definitions. To help elementary students understand the differences among these terms, simplify these examples and provide students with opportunities to think about, discuss, and reach consensus on them. These terms also are used in general conversation, so it is particularly important to include explicit vocabulary instruction about the terms and reinforce their correct use throughout the year. In addition, be sure to use the correct terminology yourself to avoid student confusion.

Scientific thinking also requires imagination and creativity. Some ideas to consider as you think about promoting scientific thinking include sponsoring invention conventions or science fairs. With these approaches, once a need or a problem has been identified, students are directed to use problem-solving and creative-thinking skills to invent a product or process to solve or overcome the problem. Communication and research skills are emphasized throughout the invention convention or science fair experience. Another idea is to provide a discrepant event for which the outcome of the inquiry or demonstration is contrary to the students'

Figure 4.4
Definitions and Practice Questionnaire

Belief:	An idea that is accepted as being true based on an observation, opinion, faith (trust), or reason (logic). Beliefs do not require evidence or proof but are frequently passed along from generation to generation and may be part of a person's religious, social, or cultural background.
Facts:	The results of experiments made under carefully controlled conditions. Facts are observations and experimental evidence relating to a question or problem. In science, facts are often referred to as the data or knowledge that is known. The facts that are gathered from direct or indirect observations provide consistent data every time the experiment is conducted.
Hypothesis:	An educated prediction that can be tested and is based on prior observations that can be used as a basis for reasoning or for planning experiments to gather more information. These are frequently written in "If... then..." statements. A tested hypothesis is accepted until and unless it has been disproved.
Theory:	A well-tested model and explanation that makes sense of a great variety of related phenomena and scientific observations and is supported by consistent and extensive evidence. Theories organize knowledge in a field, fit existing data (facts), explain how events or processes are thought to occur, and often predict future discoveries and events.
Law:	A well-established, descriptive generalization that has a history of reliability. Laws state what, under certain conditions, will happen. Scientific laws can change or not hold under some conditions. Theories explain laws and facts.

Is It a Theory, Hypothesis, Fact, or Belief (practice)	
1. ________________________	The Earth is a sphere.
2. ________________________	An understanding of Earth's magnetic field and animals' migration flight patterns, and finding magnetic materials in some animals' brains, suggest that honeybees, homing pigeons, salmon, and dolphins use Earth's magnetic field to guide them on their migration routes.
3. ________________________	If pesticide use continues at its present rate, cancer will increase by 50% within the next 10 years.
4. ________________________	Humans should be vegetarians.

prediction. As a result, students need to create a new explanation using their imagination and creativity. Providing time for students to test their ideas and discuss their thinking will help them learn and practice this aspect of scientific thinking. A wide variety of discrepant events can be found using online resources. Tik Liem's book *Invitations to Science Inquiry* (1987) includes 400 discrepant events that will engage your students in creative thinking. One classic example of a discrepant event follows:

> Stand straight up with your heels against a wall and your feet together. Have someone place a dollar bill about a foot in front of your feet. Can you pick it up without bending your knees?

Students invariably predict that yes, they can. In fact, due to our center of gravity, it is **not** possible without bending our knees. The goal of discrepant events is to get students to think about the scientific explanations related to the event (i.e., to think like a scientist). Since the results do not match student predictions, students immediately start to ask questions and to think about alternative ideas.

Planning for implementation of this strategy means understanding all of the aspects of scientific thinking and creating ways to engage your students in learning about science concepts using scientific thinking. Begin by developing your students' skills in one or two aspects of scientific thinking. As time progresses, you can focus on additional aspects.

What Works in Science Classrooms: Implications for Teaching

Recommendation 1: Teach students what a scientific question is and give students opportunities to convert their questions into scientific questions that can be answered based on background research or observations. Scientific thinking involves answering scientific questions. As science teachers, we teach students that answering a scientific question involves developing explanations that cite evidence, sharing ideas about what the evidence means, and critiquing the evidence to see if the conclusions are valid or if further evidence is needed. For example, if you ask someone to answer the question "Is there global warming?" a nonscientific answer would be based on what that person believes from what they have read or heard from others. Scientific thinking, however, requires examining the evidence, discussing and critiquing the evidence, and generating an answer to the question based on existing science knowledge along with all the current evidence from scientifically designed studies. One way to begin to implement this recommendation is by generating or finding examples of science questions that might be of interest to your students.

Recommendation 2: Leverage the aspects of scientific thinking to create a positive learning environment. For example, one of our challenges is to develop a "safe" classroom environment where students can openly share their ideas and their thinking about science concepts. Class sessions where ideas are shared should not be opportunities to embarrass students or leave them open to ridicule from their peers. One way to ensure that these sessions are positive experiences is to teach students that scientists are most effective when they consider all possibilities, no matter how "outside the box" those possibilities might seem. Many scientific discoveries have resulted from experiments that did not work as planned, and there are a number of examples of when we have learned from unusual findings and creative explanations. For example, Post-Its are the result of an experiment with unexpected findings. To address this recommendation, you can construct a chart that identifies what you would be seen and heard doing with regard to the various aspects of scientific thinking and the expected student responses. There is a template in the Chapter 4 appendix (Environment Strategy 2: Thinking Scientifically) that can be used to capture this information. Use this planning template to record your scripted questions, the procedures you will be teaching your students, or the ways that you will incorporate the features of thinking scientifically into your lesson.

Environment Strategy 3: Develop Positive Attitudes and Motivation

The Issue

When student and teacher attitudes and perceptions about learning science are negative, learning suffers. Conversely, when attitudes and perceptions are positive, learning is enhanced. We all know from personal experiences that different people are motivated by different things. What motivates one student may not motivate another. A number of factors can influence what motivates a person. For example, elementary students usually want to please their teacher, which serves as an external motivator. Middle and high school students, on the other hand, often want to please their peers, which can provide negative motivation to complete in-class work or homework assignments. At any age, attitudes, like beliefs, can persist, even when the conditions that precipitated the negative attitudes no longer exist.

Table 4.1
Creating a Positive Learning Environment

Strategy 1: Believe 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: Think Scientifically Teach students to think scientifically.	
Strategy 3: Develop Positive Attitudes and Motivation Develop positive student attitudes and motivation to learn science.	
Strategy 4: Provide Feedback Give timely and criterion-referenced feedback.	
Strategy 5: Reinforce Progress and Effort Keep students focused on learning by reinforcing progress and effort.	
Strategy 6: Teach Students to Be Metacognitive Involve students in thinking about their ideas and assessing their own progress.	

The DESI Approach

Our goal is to create a classroom environment conducive to learning, where students feel accepted by teachers and peers. Effective teachers are able to assess a student's comfort level and attitudes in ways that enable the student to take risks and share ideas in class. Helping students develop positive attitudes is a two-part process: First, you must help students view the class as worthwhile, and second, you must help students feel confident about their abilities to succeed in the class. You can help students develop positive attitudes in part by engaging them in ways that make learning relevant to their lives. Providing students with tasks that are both valuable and interesting encourages intrinsic motivation for learning. We also can draw upon external motivators, such as grades or group competitions, in ways that support learning.

Selected Research Related to the Issue

1. People are influenced by other people's attitudes and perceptions about their abilities. "In our society, there is a pervasive tendency to equate accomplishment with human value, or put simply, individuals are thought to be only as worthy as their achievements. Because of this, it is understandable that students often confuse ability with worth. For those stu-

dents who are already insecure, tying a sense of worth to ability is a risky step because schools can threaten their ability. This is true because schools typically provide insufficient rewards for all students to strive for success. Instead, too many children must struggle simply to avoid failure." (Covington 1992, p. 74)

"Self-worth theory adds still another perspective to classroom motivation. If the criterion for self-acceptance in the classroom is high academic accomplishment relative to others, then, by definition, only a few high-performing students can obtain a sense of self-worth." (Marzano 2003, pp. 146–147)

2. People are influenced by their own perceptions of their abilities. Attribution theory postulates that how students perceive the causes of their prior successes and failures is a better determinant of motivation and persistence than is a learned success or failure avoidance orientation. In general, there are four causes to which individuals attribute their success: ability, effort, luck, and task difficulty. Of these, effort is the most useful, as the cause of success can translate into a willingness to engage in complex tasks and persist over time. (Marzano 2003, p. 146)
3. Motivation can be awakened in safe and trusting environments where people have the support they need to take risks. The Motivational Framework for Culturally Responsive Teaching includes the following:
   - *Establishing inclusion* refers to employing principles and practices that contribute to a learning environment in which students and teachers feel respected by and connected to one another.
   - *Developing a positive attitude* refers to employing principles and practices that contribute to, through personal and cultural relevance and through choice, a favorable disposition toward learning.
   - *Enhancing meaning* refers to bringing about challenging and engaging learning. It expands and strengthens learning in ways that matter to students and have social merit.
   - *Engendering competence* refers to employing principles and practices that help students authentically identify that they are effectively learning something they value (Ginsberg and Wlodkowski 2000, p. 45).
4. Motivation can be intrinsic or extrinsic and needs to "hook" students into wanting to learn. "Extrinsic motivators include deadlines for research projects, classroom competitions, and tests and quizzes affecting students'

grades. Intrinsic motivation, in contrast, usually stems from intellectual curiosity and a desire to learn. There is some evidence that extrinsic motivation may actually be detrimental, impeding students' intrinsic desire to learn. For example, students doing a research project might focus primarily on completing the task rather than learning the concepts (Moje et al. 2001; Nuthall 1999; 2001). Similarly, a laboratory activity performed only to confirm a previously presented idea is unlikely to deepen students' understanding of that idea; students will likely focus more on finding the 'right' answer than on understanding the underlying concepts." (Banilower et al. 2008, p.6)

What Is the Strategy?

Only two large-scale research studies in recent years have examined teaching inside science classrooms and, in both, attitudes and motivation were key elements. According to the recently released synthesis report on effective science instruction (Banilower et al. 2008), *Teaching Science in Five Countries: Results From the TIMSS 1999 Video Study* (Roth et al. 2006) reported that in eighth-grade classrooms, 32% of instructional time was spent motivating students, and the *Looking Inside the Classroom* (2003) study found that about 40% of lessons included a motivational element. If you talk to most teachers, they will identify motivating students to be one of their biggest and most important challenges. Our ability to motivate students is linked to their attitudes about the class and about the work in the classroom. Thus, this strategy focuses on developing student attitudes and motivation.

Marzano and Pickering (1997) provide guidance on how to address student attitudes and motivation by outlining actions that teachers can take to help students develop positive attitudes and perceptions about classroom climate and classroom tasks. They also address actions for developing students' intrinsic and extrinsic motivation to learn. These actions include the following:

Classroom Climate

- Providing instruction that helps students feel accepted by the teacher and peers
- Establishing classroom procedures and policies that allow all students to experience a sense of comfort and order

Classroom Tasks

- Providing students with tasks that are interesting and relevant to their lives
- Helping students believe that they have the ability and resources to complete tasks
- Helping students understand and be clear about the work they are being asked to complete

Motivation

- Developing intrinsic motivation by using hands-on, inquiry activities, discrepant events, and science mysteries and providing opportunities for students to ask questions and wonder "how" and "why" through investigations and problem-solving activities
- Developing extrinsic motivation through completion of work, grades, and assessments

Restricting motivators to extrinsic types can contribute to negative classroom attitudes. That is why it is important to consider actions that address both intrinsic and extrinsic motivation. Considering both types helps you engage different students in different ways. Clearly, using motivation as a strategy to develop a supportive classroom environment requires reflection and careful planning.

Exploring the Strategy

An important factor in developing positive attitudes and motivation in the classroom is establishing relationships with each student in the class. When students feel accepted, it boosts their confidence, and therefore, they work harder and learn more. Where can you start? Think about this: What do students say about a "good" teacher and a "bad" teacher ~~to~~ the teacher, to their peers, to their parents, or to themselves? What do they say about learning science? Consider what you have personally experienced as a student as well. Figure 4.5 includes common student responses to the question about good and bad teachers.

As a result of these negative attitudes and feelings, students might withdraw, disengage, misbehave, or skip class. To turn these negative attitudes around, we have to think about our own attitudes and reactions. Consider how developing student motivation fits into your perception of your role as a teacher. Do you plan for developing student motivation in your lessons? Also consider how you tend to respond to different student attitudes. What student actions or words "push your

Figure 4.5
Attitudes of Students About Teachers

"Good" Teachers	"Bad" Teachers
• Care about my well-being	• Don't know their subject matter
• Are interested in my progress	• Have expectations that are wretchedly, boringly low
• Provide clear expectations	• Don't care about us or whether we learn
• Treat everyone fairly	• Spend all their time worrying about rules
• Love their subject and love teaching	• Have favorites and don't treat us equally
• Are available outside of class and are there to help us	• Lecture all the time
• Make learning interesting and fun	• Won't help me

buttons"? Think about how you can interact with students in positive ways and what you will say to convey positive expectations.

Positive relationships don't develop by magic—they must be built. There are many ways to establish positive relationships and build mutual respect, including the following (Combs 1982):

- Greet students at the door individually and welcome them to class. Make a personal comment when possible.
- Talk informally with students before, during, and after class about their interests. Whenever you have had a negative interaction with a student, such as asking them why they didn't get their homework turned in or why they did so poorly on a test, it will take seven positive or neutral interactions with that student to rebuild their trust so that they believe you really care about them again.
- Be aware of important events in your students' lives and comment on them (e.g., sports, performing arts, extracurricular activities).
- Include students in classroom planning. Find out what learning experiences they have already had, what they think is important when it comes to rubrics, what expertise they may have, and what questions they would like to have answered as part of the unit.
- Call students by name and do not refer to their siblings. It is important to learn first names as soon as possible and be careful not to mispronounce their name.

- Have students complete a science "autobiography" of themselves or an interest survey related to science and then use that information throughout the school year to connect to student interests.
- Be available to assist and support students both in and out of the classroom. Let them know that you are there to help them.

These examples of how to build relationships with students may not be new to you. Consider them as reminders that can refocus us as we work with all students. Deliberately taking these actions to connect with students on a personal level may seem artificial, but building and rebuilding trust takes time, persistence, and practice.

In addition to building relationships with our students, are there additional ways we can help students develop positive attitudes and perceptions about learning? One action you can take is to provide students with choices about how they demonstrate their learning. This practice acknowledges that not all students have the same needs or react in the same ways. It also provides opportunities for students to use their strengths and interests. For example, you might offer students the option of acting out the science concepts, or writing a poem, or creating an interactive game to provide evidence of their conceptual understanding.

Positive attitudes and perceptions are more likely to develop in an environment where students have the chance to get to know and accept one another. You can create such an environment in your classroom by including structured "working together" activities that encourage students to collaborate. Establishing classroom norms that students discuss and agree upon will provide opportunities for the entire class to practice positive behaviors. Modeling and reinforcing common courtesy and respect also will encourage the development of positive attitudes and perceptions about the classroom and learning.

Planning for Classroom Implementation

There are many different ideas you can consider as you determine what you should implement to help students develop positive attitudes and perceptions. After reading the following ideas and explanations, you can use the tool provided in this chapter's appendix (Environment Strategy 3: Develop Positive Attitudes and Motivation) to plan for implementation in your classroom.

Improve students' sense of comfort and order in your classroom:

- *Use policies and procedures that support a collaborative classroom culture*. Policies and procedures related to turning in work, late assignments, starting and ending class, discussions, leaving class, independent and collaborative work, grading and homework, and laboratory work are ones that will be used again and again. As a result, we need to teach the steps of each procedure, model it, provide time for students to practice it, and reinforce it. Be sure your expectations for how well students will carry out these procedures are realistic when students are first learning them. Depending on the complexity of the procedure and individual student characteristics, students may need as many as 20–24 experiences with the procedure before they master it (Marzano 1992). Developing policies that are schoolwide and consistently enforced by all teachers makes it more likely that students will follow the procedures. To learn more about this approach, see *The First Days of School*, by Harry and Rosemary Wong (2004).
- *Improve your management skills.* The secret to behavior management is having students fully engaged in the learning process and keeping the rules to a minimum. One resource on specific techniques is *Tools for Teaching* (Jones 2000), which is extremely detailed and full of concrete directions.

Make it your responsibility to help students feel accepted by you and their peers:

- *Collect information on preferences that you can use when creating cooperative groups.*
- *Reach out seven times to establish neutral or positive relationships with students.*
- *Learn recommended strategies for high-needs students.* There are many reasons why a student might be designated as "high-needs." Some are designated as high-needs because they are difficult to teach. These students fall into one of the following categories: passive, aggressive, attention problems, perfectionist, or socially inept (Marzano 2003). For more information about these categories, see *What Works in Schools: Translating Research Into Action* (Marzano 2003, pp. 104–105) or *Classroom Management That Works: Research-Based Strategies for Every Teacher*

(Marzano, Pickering, and Pollock 2003). These resources emphasize that the most successful classroom managers employ different strategies for different types of students. Secondary students might have difficulty accepting this concept. To help them understand the concept, explicitly provide examples that illustrate how providing for individual student needs is, indeed, fair. For elementary students, use specific techniques to help students understand the rules and your expectation that they follow them.

Develop students' positive attitudes about classroom tasks:

- *Teach the relationship between effort and achievement*. You might be surprised to learn that not all students realize the importance of believing that effort can lead to achievement (Marzano, Pickering, and Pollock 2001). Fortunately, in their review of the research on instruction, Marzano and his colleagues also found that students can change their beliefs about the role of effort in achievement. Teachers can provide examples from sports, performing arts, and other student activities that illustrate the relationship between effort and achievement. Such examples show students that practice improves performance and that hard work pays off in learning just as it does in other activities.
- *Attend to safety and choice issues that specifically apply to science.* Some students have fears about science—fire, animals, dissection, smells, and such. Many of these fears can be addressed, even on the first day of school, through safety information. Resources for this strategy include the NSTA position statements on safety (*www.nsta.org/about/positions/safety.aspx*) and dissection (*www.nsta.org/pdfs/PositionStatement_LiveAnimalsAndDissection.pdf*). Flinn Scientific provides student safety contracts and other resources that address safety in the science classroom on their website (*www.flinnsci.com/Sections/Safety/safety_contracts.asp*).

As you think about implementing actions to develop students' intrinsic motivation, remember that students are motivated by events that contradict their expectations or that stimulate their curiosity and give them opportunities to solve a mystery. As you plan for implementation, think about discrepant events, mysteries that can be solved through application of science principles, and questions that might be relevant to your students' lives and of interest to them.

Return to thinking about ways that you currently support positive classroom attitudes. Refer to Figure 4.6, Developing Positive Student Attitudes, to decide

Figure 4.6
Developing Positive Student Attitudes

Attitudes and Perceptions	Suggestions to Improve the Classroom Environment
Does each student feel accepted by teachers and peers?	• Establish a relationship with each student in the class. For difficult-to-reach students, aim for one neutral/positive interaction for seven days in a row. • Monitor your own attitudes. Don't hold grudges. • Assist students in gaining acceptance of their peers. • Use cooperative learning strategies in which roles for members of a group are identified, including process observers. • Positively and thoughtfully respond to students' incorrect responses. • Recognize effort and risk-taking in each student's learning.
Does each student experience a sense of comfort and order?	• Focus on creating an environment that is centered around learning—then teach, model, and insist on meeting standards. • Engage students in setting classroom standards. • Establish and communicate classroom rules and procedures. • Establish clear policies about the physical safety of students. • Be proactive about addressing social/emotional issues (e.g., bullying, sexual harassment, racism). • Defuse situations before they become problems.
Does each student perceive tasks as valuable and interesting?	• Communicate learning goals as concepts, and tie them into "real life" situations (e.g., personal decisions, social issues, intriguing questions that don't have one right answer). • Make connections between the knowledge and skills students are learning and the "big ideas" for which they are developing understanding, as well as connections between big ideas. • Involve students in setting goals for their learning, and when possible, link tasks to their personal interests. • Plan an exploratory experience to activate and evaluate prior knowledge on each new topic. • Search for and use hands-on activities that allow students of varied levels of understanding to participate meaningfully.
Does each student believe they have the ability and resources to complete tasks?	• Establish a "we're all here to learn" environment, offer your confidence and assistance, and broker peer support. • Provide examples of good student work, rubrics of proficiency, samples of work products. • Keep learning logs in which students can record what they have learned as well as their ongoing questions. • Support struggling readers by teaching methods of comprehending nonfiction text materials. • Establish timelines and calendars for students to record progress toward learning goals. • Teach students to use positive self-talk.
Does each student understand the tasks?	• Communicate learning goals and descriptions of proficiency for each unit. • Break complex tasks into small steps or parts. • Support English language learners, as well as varied learning styles, by having both oral and written directions, and using consistent carefully chosen vocabulary. • Teach students how and when to ask for help, so they can advocate for themselves.

Adapted from Marzano, R., and D. Pickering. 1997. *Dimensions of learning trainer's manual*. Alexandria, VA: Association for Supervision and Curriculum Development.

where to focus your planning related to student attitudes. Begin by scanning the left-hand column to assess your current challenges. Think about particular students and the kinds of outcomes you would like to see. Scan the suggestions column for strategies to address your desired outcomes. Use the planning template provided in the appendix of this chapter (Environment Strategy 3. Develop Positive Attitudes and Motivation) to describe how you will incorporate these ideas in your lesson plans.

What Works in Science Classrooms: Implications for Teaching

Recommendation 1: Analyze your own attitudes about students and check your perception of your ability to create a positive classroom climate. Research suggests that the goal is not only to identify your own attitudes related to learning but also to help students identify theirs. In addition, it is important to determine what students need to feel comfortable and have a sense of order in the classroom. By working together and building relationships with and among students, you can set the stage for positive classroom behavior that will result in improved learning.

Recommendation 2: Create classroom tasks that relate to students' interests and help them meet the learning goals. When tasks are perceived as too easy, students get bored and disengage. When they perceive tasks as too difficult, they frequently give up. Tasks must be both rigorous and relevant to keep students on track and help them succeed (NASSP 1996). As you address this recommendation, keep in mind that, as teachers, we are also responsible for helping students understand that we will support them by providing the tools and resources they need to complete tasks successfully.

Recommendation 3: "Hook" students with the learning and find ways to engage them intellectually with the content. Think about the many ways to use the wonder, mystery, and investigations that are part of science to develop students' intrinsic motivation. Too often, teachers complain that their students aren't motivated by anything but grades; that if they don't grade everything, students won't do any work. That response may stem, in part, from students' perceptions that the work is uninteresting and has nothing to do with them and their lives. We can change that.

Environment Strategy 4: Provide Feedback

The Issue

For many students, particularly those who learned little or no science in elementary school, science seems like a foreign language, because their science experiences were neither rooted in the ways of science nor focused on developing understanding. This lack of experience with "doing science" is compounded by superficial exposure to an abundance of science topics. Generally, students do not receive the type of feedback that would help them understand the extent of their science knowledge and skills or make progress in learning science. The result is frustration for students and teachers.

Table 4.1
Creating a Positive Learning Environment

Strategy 1: Believe 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: Think Scientifically Teach students to think scientifically.	
Strategy 3: Develop Positive Attitudes and Motivation Develop positive student attitudes and motivation to learn science.	
Strategy 4: Provide Feedback Give timely and criterion-referenced feedback.	
Strategy 5: Reinforce Progress and Effort Keep students focused on learning by reinforcing progress and effort.	
Strategy 6: Teach Students to Be Metacognitive Involve students in thinking about their ideas and assessing their own progress.	

The DESI Approach

Providing meaningful feedback to students is essential in helping students understand science concepts. The DESI approach focuses on planning for and providing feedback that is corrective, timely, criterion-referenced, and clear. In other words, feedback goes beyond grading assignments using a "right/wrong" or "minus-one-point-for-each-error" model. Feedback needs to be corrective so that students can learn from their work. The feedback must be timely to provide the best opportunity for students to assimilate the information into their learning framework. And, the feedback needs to be criterion-referenced and communicated clearly so that students know what high-quality work looks like, what they have done correctly, and what they still need to learn.

Selected Research Related to the Issue

1. Feedback that is formative in nature supports learning. "Effective feedback should help the learners know where they are and where they should go next: the focus is improvement.... Comments are the most common way for the teacher to have a dialogue with everyone in the class.... In many cases, an effective comment relates back to the success criteria or descriptions of quality that have been shared with or devised by the students before they attempt a task. In this way, students work towards success or quality by considering the criteria as their work progresses. The feedback is then the teacher's judgment, which can be matched against the student's own judgment of quality." (Black and Harrison 2004, pp. 11–12)
2. One of the most general strategies a teacher can use is to provide students with feedback relative to how well they are doing. In fact, feedback seems to work well in so many situations that it led researcher John Hattie (1992) to make the following comment after analyzing almost 8,000 studies: The most powerful single modification that enhances achievement is feedback. The simplest prescription for improving education must be "dollops of feedback."
3. Marzano, Pickering, and Pollock's (2001) meta-analysis of K–12 instruction revealed nine categories of instructional strategies with the highest expected student achievement gains. These categories include "Setting Objectives" and "Providing Feedback." Additional information about this research will be provided in the following "What Is the Strategy?" section.

What is the Strategy?

First, let's look at the recommendations regarding feedback provided in *Classroom Instruction That Works* (Marzano, Pickering, and Pollock 2001). As you read the research summary on "Providing Feedback," note the information that speaks specifically to what a teacher should do and the numerical information in the charts that indicates a relatively strong likelihood for a positive effect on students' achievement. Findings from some of the studies that have synthesized research on the general effects of feedback are reported in Figure 4.7 (p. 164). Perhaps one of the more interesting findings regarding feedback was reported by Bangert-Drowns et al. (1991). They report an overall effect size of only .26. However, it is important to note that their study focused on feedback that takes the form of a test or, as they prefer, “test-like events.” Their findings are reported in Figure 4.8 (p. 165), which highlights research that emphasizes the points that feedback should be corrective in nature and timely.

Summarizing from the research, this strategy suggests that you provide feedback to students after assessments of learning (i.e., summative assessments such as tests, laboratory write-ups, and projects). For these student products the feedback must be timely, criterion-referenced, clear, and corrective in nature. Providing feedback one day after a test is more effective than after each item, or immediately after the test. Additionally, providing right or wrong answers is not as effective as providing opportunities for students to correct their answers. A combination of verification and elaboration is most effective so that students have an idea of what they need to do next (Shute 2008). The complexity of the elaboration is best determined by the teacher in each teachable moment. Since the effectiveness of feedback depends on its utility for a particular student with a particular learning goal, teachers need to be mindful about what information each student needs and when, as each of their students makes progress in learning science.

As long as the feedback is not perceived as an interruption by students, feedback can be provided in the moment, at predetermined junctures in the learning, or whenever you need to check whether students are ready to move forward and need help with what to work on next. As described in Chapter 3 (Understanding), feedback on formative assessment is most effective if provided after a period of learning, using descriptive comments that probe a students’ thinking to reveal what they are doing well and what they should do to progress. When providing formative assessment feedback, using only points (“marks”) or points plus comments doesn’t seem to help students (Butler 1987) and is a waste of our time. This practice is not effective because students tend to look only at the score and ignore the comments. Using points to provide feedback can have negative effects on low achievers’ motivation and, at the same time, it fails to challenge high achievers to improve. Using descriptive comments seems to motivate low achievers because they receive information about how to improve (Black and Wiliam 1998). Research also suggests that teachers provide opportunities for students to self-assess and provide some of their own feedback. Student self-assessment can be guided by use of goal-setting, rubrics, checklists and/or self-monitoring questions, allowing

Figure 4.7
Research Results for Providing Feedback

Synthesis Study	Focus	Number of Effect Sizes	Average ES	Percentile Gain [b]
Lysakowski & Walberg, 1982 [a]	General effects of feedback	22	.92	32
		7	.69	25
		3	.83	30
		9	.71	26
Lysakowski & Walberg, 1981 [a]	General effects of feedback	39	1.15	37
		19	.49	19
		49	.55	21
		11	.19	7
Walberg, 1999	General effects of feedback	20	.94	33
Tennebaum & Goldring, 1989 [a]	General effects of feedback	15	.66	25
		7	.80	29
		3	.52	20
		3	.51	19
		2	.67	25
Bloom, 1976	General effects of feedback	7	.54	21
Haller, Child, & Walberg, 1988	General effects of feedback	20	.71	26
Bangert-Drowns, Kulik, Kulik, & Morgan (1991)	General effects of feedback	58	.26	10

[a] Multiple effect sizes are listed because of the manner in which they were reported. Readers should consult those studies for more details.

[b] These are the maximum gains possible for students currently at the 50th percentile.

Note that some of the effect sizes reported are .90 and even higher.
Generally, feedback that produces these large effect sizes are “corrective” in nature.

From Marzano, R., D. Pickering, and J. Pollock. 2001. *Classroom instruction that works: Research-based strategies for increasing student achievement*. Alexandria, VA: Association for Supervision and Curriculum Development. Copyright 2001 by McREL. Reprinted with permission.

Figure 4.8
Feedback Study Results

Synthesis Study	Focus	Number of Effect Sizes	Average ES	Percentile Gain [a]
Type of Feedback	Right/wrong answer	6	-.08	-3
	Correct answer	39	.22	9
	Repeat until correct	4	.53	20
	Explanation	9	.53	20
Timing of Feedback	Immediately after item	49	.19	7
	Immediately after test	2	.72	26
	Delayed after test	8	.56	21
Timing of Test	Immediately	37	.17	6
	One day	2	.74	27
	One week	12	.53	20
	Longer	4	.26	10

[a] These are the maximum gains possible for students currently at the 50th percentile.

From Marzano, R., D. Pickering, and J. Pollock. 2001. *Classroom instruction that works: Research-based strategies for increasing student achievement*. Alexandria, VA: Association for Supervision and Curriculum Development. Copyright 2001 by McREL. Reprinted with permission.

students to compare their performances with their own or another's expectations (Bangert-Drowns et al. 1991).

When it comes to feedback on summative assessments, the advice is also clear. From the research, we know that this type of feedback must be provided in a timely fashion and be based on clear criteria. In addition, it must provide students with information about what they have done correctly in relation to those criteria. Providing feedback after students complete projects, laboratory write-ups, or any other summative assessment is yet another strategy that contributes to increased student achievement.

Exploring the Strategy

Criterion-referenced feedback, which provides students with feedback in terms of specific levels of performance relative to the learning objectives, is better than feedback in the form of percentage scores. Providing criterion-referenced feedback involves

- using well-developed rubrics that are based on quality of performance, not quantity of work. Remember that rubrics should be specific to the project and that levels of performance should be written in clear language that students can understand;
- using exemplars to help students know what quality work looks like and how their work compares to high-quality work. Numerous online and print resources are available to help identify the characteristics of high-quality science work;
- informing students whether their work is proficient and what advanced work looks like.

Teachers should provide students with feedback throughout a unit of instruction and **as soon after individual assessment events as possible**. The more delayed the feedback, the less improvement there is in achievement. If it takes a month to evaluate laboratory write-ups and get them back to students, the feedback will not support students' achievement. Make this aspect of providing feedback a priority by providing formative feedback for projects, performance assessments, laboratory write-ups, and other classroom assignments along the way. This will help students improve the quality of their work throughout the unit. As a result, you will need to spend less time reviewing final student work. This means you can return students' work quickly and students can connect the feedback they have received to improved understanding.

Simply telling students their answer is right or wrong has a negative effect on achievement. The best feedback involves an **explanation** of what is correct and incorrect about the response. If teachers provide students with this type of feedback, and ask them to keep working on a task until they succeed, they will achieve at higher levels. To practice this aspect of providing feedback, ask students to work in pairs or teams to research the correct answers to an assessment you have given them and to explain why those answers are correct. Also ask them to explain why the incorrect answers are wrong. This approach works even with multiple-choice questions.

Students benefit from participating in **peer and self-assessment.** Engaging students in peer and self-assessments develops students' abilities to recognize quality and gaps in their work and the work of others. As they get better at comparing their level of work, and the work of others, to the criteria for quality work, they can discuss strengths and weaknesses of a sample of work with clarity. As with any procedure, you need to help students learn how to be effective self-assessors and peer-assessors. You may want to start by having students assess their own work using the criteria for success and then add some descriptive comments yourself to their self-assessments. After students have practiced assessing the quality of their own work, you can ask them to assess the work of their peers. The practice with self-assessment is important because it provides students with some knowledge of what to look for and how to provide constructive comments. To help students overcome their tendency to provide only positive comments to their peers, show them how providing constructive comments helps them and their peers improve their learning.

Planning for Classroom Implementation

The appendix for Chapter 4 (Environment Strategy 4) provides a template on which you can record reminders as you plan ways to implement the "Providing Feedback" strategy. Start by selecting an aspect of this strategy that you consider as your top priority. As you think about using this strategy, remember that the purpose of feedback is to advance learning and that there are many ways to provide feedback to students. Some teachers rely on teacher-student conferencing and others provide written comments to let students know what to focus on next in their learning. In either case, including probing questions in your feedback will prompt students to think and encourage them to act on the information about what they should do next.

What Works in Science Classrooms: Implications for Teaching

Recommendation 1: Establish feedback systems that work. There is rigorous research evidence that providing students with feedback promotes student achievement. Remember, students have to do their own learning; we can't do it for them. Our job is to make the learning targets clear and then help students understand and meet the criteria for quality work. An effective feedback system provides students with information about their performance that helps them progress in their learning. Without feedback, learning won't progress.

Recommendation 2: Use both formative and summative feedback, relative to established criteria for quality work, to help students progress. "Grading" every assignment teaches a student how to get points, not how to learn and demonstrate learning of science concepts. Grades and points should be given only on work that is summative in nature. Formative feedback should replace points or grades on some of the assignments that lead up to the summative assessment. To ensure that feedback on summative work supports increased student learning, clearly identify the criteria for success, share these criteria with students, and base feedback on those criteria.

Environment Strategy 5: Reinforcing Progress and Effort

The Issue

Some students don't succeed in science because they don't put enough effort into learning. This lack of effort occurs for a variety of reasons. For example, some students feel that they are just not "good at science" so they stop trying to learn. Other students don't exert effort to learn because there is an atmosphere of competition in the classroom. In these classrooms, it seems that students are pitted against one another and challenged to be the first to come up with an answer or solution. Students know, if they just bide their time, someone else will provide the answer and they won't have to exert any effort to learn. They know that as soon as the "right" answer is found and shared with the class, the teacher will move on. In other cases,

Table 4.1
Creating a Positive Learning Environment

<table>
<tr><td>Strategy 1: Believe All Students Can Learn
Show through your actions that you believe all students have the ability to learn.</td><td rowspan="6">What's really important?

How do I create a positive learning environment?</td></tr>
<tr><td>Strategy 2: Think Scientifically
Teach students to think scientifically.</td></tr>
<tr><td>Strategy 3: Develop Positive Attitudes and Motivation
Develop positive student attitudes and motivation to learn science.</td></tr>
<tr><td>Strategy 4: Provide Feedback
Give timely and criterion-referenced feedback.</td></tr>
<tr><td>Strategy 5: Reinforce Progress and Effort
Keep students focused on learning by reinforcing progress and effort.</td></tr>
<tr><td>Strategy 6: Teach Students to Be Metacognitive
Involve students in thinking about their ideas and assessing their own progress.</td></tr>
</table>

students do not have adequate time to put in the effort required to learn. We need to consider all of the reasons why students do not exert effort and help students understand the importance of effort.

The DESI Approach

Students often do not realize the impact of effort on learning (Marzano, Pickering, and Pollock 2001). They try once to complete activities, and if they are not successful, they often give up rather than keep trying. To address this problem, teachers need to develop strategies to reinforce effort. Reinforcing effort does not mean telling students the "right" answers; rather, it means teaching students how to practice and struggle to make sense of what they are learning.

Selected Research Related to the Issue

1. "[P]eople generally attribute success at any given task to one of four causes: ability, effort, other people, or luck (Covington 1983; Harter 1980). On the surface, a belief in ability seems relatively useful—if you believe you have ability, you can tackle anything. However, regardless of how much ability you think you have, there inevitably will be tasks for which you do not believe you have the requisite ability. In fact, Covington's research (1983; 1985) indicates that a belief on the part of students that they do not possess the necessary ability to succeed at a task will cause them not to even try to succeed at the task. Belief that other people are the primary cause of success also has drawbacks, particularly when an individual finds himself or herself alone. Belief in luck has obvious disadvantages—what if your luck runs out? Belief in effort is clearly the most useful attribution." (Marzano, Pickering, and Pollock 2001)
2. One study found that students who were taught about the relationship between effort and achievement increased their achievement more than students who were taught techniques for time management and comprehension of new material (Van Overwalle and De Metsenaere 1990).
3. A number of researchers have synthesized the studies on the effects on student achievement of reinforcing effort. As explained in *A Different Kind of Classroom: Teaching With Dimensions of Learning* (Marzano 1992) and *Classroom Instruction That Works* (Marzano, Pickering, and Pollock 2001), studies have shown that simply teaching students that added effort will pay off in terms of enhanced achievement actually increases student achievement. The results from some of those syntheses are reported in Figure 4.9 (p. 170).

Figure 4.9
Synthesis Results

Synthesis Study	Number of Effect Sizes	Average ES	Percentile Gain [c]
Schunk & Cox, 1986	3	.93	32
Stipek & Weisz, 1981 [a]	98	.25	10
Hattie, Biggs, & Purdie, 1996 [b]	8	1.42	42
	2	.57	22
	2	2.14	48

[a] These studies also dealt with students' sense of control.

[b] Multiple categories of effect sizes are listed for the Hattie, Biggs, and Purdie study because of the manner in which effect size was reported. Readers should consult that study for more details.

[c] These are the maximum gains possible for students currently at the 50th percentile.

From Marzano, R., D. Pickering, and J. Pollock. 2001. *Classroom instruction that works: Research-based strategies for increasing student achievement*. Alexandria, VA: Association for Supervision and Curriculum Development. Copyright 2001 by McREL. Reprinted with permission.

What Is the Strategy?

Given that some students might not understand the importance of a belief in the power of effort, we need to provide them with basic information about the effects of effort. One way to do this is by sharing examples. You might challenge students to think of people, especially scientists, who persevered despite great challenges. Bob Ballard, for example, conducted a 12-year search for the wreck of the *Titanic* and developed state-of-the-art visual imaging technology, in addition to using geologic, oceanographic, and historic information, before his dream was realized in 1985. You can also personalize examples by giving your own story of perseverance or by asking students to recall times when they completed a project or achieved a personal goal because of persistence and hard work. In various fields—sports, music, performing arts, science—practice, with the help and support of a coach, is key to success. As teachers, we must coach students, by encouraging them and creating opportunities for them to practice what they're learning.

You might have noticed the connection between this strategy and the strategy on getting the content correct from Chapter 2. For students to make progress in their learning, teachers must identify clear learning goals and the criteria for achievement. Doing so helps students know where to direct their efforts. Effort, in and of itself, should be taught and reinforced as it is a factor that can move students from novice learners toward mastery of science concepts.

Exploring the Strategy

Rubrics are one way to provide students with the criteria for achievement; however, students often think of rubrics as checklists. When they "check off" everything on a rubric, they think they have finished learning. So, we need to create rubrics that expect high-quality performance and focus on higher cognitive demand. This means that rubrics should focus on quality indicators (e.g., students will critique the claims presented in their hypothesis by citing significant, appropriate evidence) rather than solely on quantity indicators (e.g., students will provide three pieces of supporting evidence).

It is sometimes difficult to include the criteria for all aspects of the expected learning in a rubric. One option is to couple the rubric with samples of student work that illustrate how students have met the criteria. Discussing such examples with students helps them understand why one piece is exemplary and illustrates advanced work and another is basic and indicates that more effort is needed. This strategy can be linked with the previous one on feedback. Rubrics help students understand the evidence needed to demonstrate understanding of the content and provide a way to give feedback to students. Students can use feedback on their performance to think about where they are in the learning process and where they need to exert more effort to perform at higher levels on the rubric.

Figure 4.10 (p. 172) provides a general description of the achievement characteristics of performance at five levels (including zero). Note that level three is the "acceptable" level of performance. This level is often called "proficient" performance.

In addition to using a progress (achievement) rubric, or other method to show students the criteria that must be met to master learning goals, teachers can use an effort rubric to assess students' persistence in learning. Involving your students in creating effort and achievement rubrics will make the learning goals more relevant to them. Students can gauge their level of effort by self-assessing or by receiving feedback from peers or the teacher. Depending on your grade level, helping students self-assess and peer-assess might take some practice. Younger students

Figure 4.10
Performance Rubric

4		Exemplary performance that exceeds the targeted level of performance. Students are able to apply their learning to new situations, going beyond what was taught in class and demonstrate high levels of cognitive learning.
3	**Acceptable level of Performance**	Solid performance that meets the targeted level of performance. Students are able to demonstrate conceptual understanding and demonstrate knowledge and skills based on what was presented in class. No major errors or gaps in student work products.
2		Performance that is emerging or developing toward the targeted level of performance. Students can demonstrate mastery of knowledge and skills, but their conceptual understanding of the materials is not at the depth of understanding expected.
1		Performance in which an attempt was made but there are some serious misconceptions or errors. With teacher support, students can show some knowledge and skills.
0		No judgment can be made about the students' level of performance. Even with teacher support, students cannot demonstrate understanding of the science ideas.

Adapted from Marzano, R. 2006. *Classroom assessment and grading that work.* Alexandria, VA: Association for Supervision and Curriculum Development.

might have more difficulty recognizing how their work compares with expected performance levels. Middle school students often perceive that completion demonstrates competency. And peer assessment can be confusing for students who want to give positive feedback to their friends and will resist making recommendations for improvement. Self-assessing effort also should be discussed and practiced.

Effort scores can then be matched with the progress rubric scores or criteria to emphasize the impact of persistence and hard work. A blank effort rubric that you can use with your students when you discuss the characteristics of effort is provided in this chapter's appendix for Environment Strategy 5.

Don't forget to post the rubric (but not individual student scores) in the classroom for students to refer to as they work or when they provide feedback to peers.

A new tracking sheet can be used each quarter (marking period) or for each unit, whichever works for you and your students. You can keep track of the performance of the class as a whole and illustrate this graphically for the class to see. For elementary students, you might want to complete a tracking form each day. Once middle and high school students learn about the impact of effort, it might not be necessary to have every student complete a self-assessment. Some teachers use this method on a student-by-student basis. You may want these students to record their effort for each unit and then set goals for themselves for the next unit. Because teachers and students have different perceptions of the learning environment and their effort, feedback from students about the classroom and their participation should be collected. We can then use that data as we strive to create productive, positive learning environments that are more cohesive and goal oriented and where there is less overall friction.

Planning for Classroom Implementation

Reinforcing effort and progress in the classroom takes time. Just telling students that they can succeed is not enough. Asking them to work harder is also not a strategy that yields achievement gains. Teaching about effort, practicing it, monitoring it, and reflecting on the results that are achieved with effort are all proactive ways that we can help students as we address this strategy.

Reflect on the following ideas for your practice:

1. Teach students about the research on effort to make them self-aware.
2. Help students believe that they can succeed by providing the resources they need (including time), encouraging and reinforcing their efforts, and providing support so they can complete tasks (this doesn't mean telling them the answer).
3. Ask students to set goals for both effort and achievement and track their effort compared to achievement.
4. Engage the class in group goal setting around effort that supports learning. At the completion of difficult learning experiences, discuss with students what they learned about effort as they participated in the learning activities.

As mentioned earlier, a powerful way to exemplify the impact of effort is to implement a system by which students track their effort in relationship to achievement. Students can track their own effort and achievement using record sheets. Then, students can plot the relationship between their effort and achievement in

Figure 4.11
Sample Tracking Sheet

Student ______________________________

Date(s) of Work	Assignment	Due Date	Effort Rubric	Achievement Rubric
October 6—7	Design an experiment	October 7	2	2
October 8—9	Conduct the experiment	October 9	3	3
October 10—13	Develop explanations and communicate to the class	October 13	3	3
October 15	Laboratory write-up completed	October 15	4	3.5

Adapted from 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.

a chart or graph so that they can visualize the relationship. A student example is provided in Figure 4.11, which shows a tracking sheet for students to record their assignments, when it was assigned, their effort score, and their achievement progress score from the rubric designed with class input.

In addition to charting the relationship between the two variables (effort and achievement), students might be asked to tell us what they learned from the experience. For example, teachers might periodically ask students to describe what they noticed about the relationship between the effort they put into a project or task and their achievement. Reflecting on their experiences in this way helps students heighten their awareness of the power of effort.

To build students' confidence in their learning abilities, we have to help them set reasonable, attainable goals. Figure 4.12 provides a self-assessment tool that can be used by students to determine their effort and what they want to work to improve. Conferencing with students one-on-one will give you a chance to see what each student needs. This may sound impractical if you have 150 plus students, but targeting a few students each day while they are working on other learning experiences can make this approach work. Conferencing provides opportunities to discuss with students what they believe about themselves and how those beliefs align with the behaviors you observe in class. Students are generally very honest in their self-assessments so the conference provides a chance to promote positive improvement in behaviors. When students develop positive work habits their behavior contributes to the overall positive classroom climate.

Figure 4.12
Student Self-Assessment and Goal Setting Template

Put an X on the scale to indicate your self-assessment.
Write a sentence below the scale to explain your response.

1. I always listen to the teacher in class and follow instructions.

Never Sometimes Always

2. I contribute to class discussions and readily share my ideas about the science concepts.

Never Sometimes Always

3. I turn in my assignments when they are due.

Never Sometimes Always

4. My work is always done to the best of my ability.

Never Sometimes Always

5. I get help when I need it from both my teacher and my classmates.

Never Sometimes Always

6. I contribute fully during group work and help the others in my group with the learning.

Never Sometimes Always

7. I use class time wisely and make sure that I clearly know what is expected of my work.

Never Sometimes Always

8. I contribute to a positive classroom environment through both participation and supporting the efforts of others.

Never Sometimes Always

Goals that will help me improve:

What Works in Science Classrooms: Implications for Teaching

Recommendation 1: Teach students about the relationship between effort and achievement. Effort is a key characteristic of people who succeed. Just like the Little Engine That Could ("I think I can, I think I can, I think I can"), when students believe that they can succeed, they are more likely to persevere and push the limits of their cognitive abilities. Learning about the research that supports effort helps students realize that their capabilities are linked to their motivation to learn, the effort they put into the process, and the belief that their teachers will scaffold the learning to close their gaps in understanding.

Recommendation 2: Ask students to track their progress with learning. Tracking their progress is the simplest way for students to know if they are learning. To track their progress, students must be clear about the learning goals, where they are in relation to those goals at the beginning of a unit of study, and the learning progression that will take them from where they are to the learning goals. You can help students determine their starting point in the learning progression by eliciting their existing thinking about concepts in the unit. Next, explain the learning progression (how ideas within the unit are linked) and share the criteria for success and examples of quality work that provides evidence of learning. It is important to help students develop the belief that with effort and support, they can master the next step in the learning progression. To help students develop this belief, break the learning targets into manageable next steps. Doing so helps students believe that the bigger learning goal is attainable. Without this assistance, students might give up, thinking that the learning goal is just too hard to achieve.

Environment Strategy 6: Teach Students to Be Metacognitive

The Issue

In their efforts to address the vast array of content included in most science curricula, teachers often use a direct teaching approach rather than an inquiry approach. As a result, student learning is frequently limited to knowing definitions and a few facts or details. This race through the curriculum also means that students rarely have opportunities to think about what they are learning. Lack of processing time results in few opportunities for students to make sense of the science concepts embedded in the learning experiences or to learn the information at a deep level. If we want students to think about their thinking, then we need to teach them the processes associated with metacognition and provide time for them to put those processes to use.

Table 4.1
Creating a Positive Learning Environment

Strategy 1: Believe 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: Think Scientifically Teach students to think scientifically.	
Strategy 3: Develop Positive Attitudes and Motivation Develop positive student attitudes and motivation to learn science.	
Strategy 4: Provide Feedback Give timely and criterion-referenced feedback.	
Strategy 5; Reinforce Progress and Effort Keep students focused on learning by reinforcing progress and effort.	
Strategy 6: Teach Students to Be Metacognitive Involve students in thinking about their ideas and assessing their own progress.	

The DESI Approach

To develop deep understanding of science concepts, students need to think critically and creatively, reason scientifically, and monitor their own thinking and progress with achieving learning goals. In other words, students need to use mental procedures associated with metacognition. It is important for science students, in particular, to be able to use metacognitive processes; these processes are useful as students process information from their observations, analyze their data, and develop conclusions based on their scientific evidence. Teachers can help students develop skills for metacognition by modeling metacognitive strategies, providing opportunities for students to practice those strategies, and reinforcing students' use of them. The DESI approach is to ensure that students have skills and opportunities to think about their thinking so that they can identify what they understand about the science concepts in their units of study, what they think they might understand but aren't sure, what they clearly don't understand, and what they will do to learn what they don't understand.

Selected Research Related to the Issue

1. "Students need to be able to self-assess. This is not a simple task as it requires the student to have a sufficiently clear picture of the targets in the learning trajectory ahead of them and a means of moving forward to close the learning gap. In some classrooms, students do not have this clear picture and respond to lessons as a set of exercises to be completed. In this scenario, the students are not engaged with the learning and are not aware of the rationale behind specific tasks…. Peer assessment helps students develop and hone their self-assessment skills. Students have the ability to recognize both quality and inadequacies in others students' work even if the level of competence that they themselves are performing at is different from the level of work that they are reading." (Black and Harrison 2004, pp. 15–16)

2. "The habits of mind identified in the Dimensions of Learning model fall into three general categories: critical thinking, creative thinking, and self-regulated thinking.

   If you have mental habits that exemplify *critical thinking,* you tend to

   • Be accurate and seek accuracy

   • Be clear and seek clarity

   • Maintain an open mind

- Restrain impulsivity
- Take a position when the situation warrants it
- Respond appropriately to others' feelings and level of knowledge

If you have mental habits that exemplify *creative thinking,* you tend to

- Persevere
- Push the limits of your knowledge and abilities
- Generate, trust, and maintain your own standards of evaluation
- Generate new ways of viewing a situation that are outside the boundaries of standard conventions

If you have mental habits that exemplify *self-regulated thinking,* you tend to

- Monitor your own thinking
- Plan appropriately
- Identify and use necessary resources
- Respond appropriately to feedback
- Evaluate the effectiveness of your actions" (Marzano and Pickering 1997)

3. "The metacognitive system [of thought] includes processes that address goal specification, process monitoring, and disposition monitoring." (Marzano, Pickering, and Pollock 2001, p. 56)

   Objectives for metacognition include the following:

   - Goal Specification: The student can set a plan for goals relative to the knowledge.
   - Process Monitoring: The student can monitor the execution of the knowledge.
   - Monitoring Clarity: The student can determine the extent to which he or she has clarity about the knowledge.
   - Monitoring Accuracy: The student can determine the extent to which he or she is accurate about the knowledge. (Marzano, Pickering, and Pollock 2001, p.57)

4. "A 'metacognitive' approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them." (Donovan, Bransford, and Pellegrino 1999, p. 13)

What Is the Strategy?

There are two ideas for you to think about in this strategy. The first idea is related to assessment: Teach students to peer-assess and self-assess. Such involvement in assessment will help students recognize, based on the criteria for achievement, what they are uncertain about or not understanding in relation to the learning goals. As a result, they will know what they need to do next to make progress toward the learning goal. The second idea is related to habits of mind: Teach students the habits of mind that encourage the development and use of critical thinking, creative thinking, and self-regulated thinking aspects of metacognition. Connecting the habits of mind with peer assessment helps students develop the thinking they need to objectively self-assess.

These two ideas form our metacognition strategy. This strategy contributes to the development of a positive classroom climate because it builds relationships among students and sets expectations that students will support one another's learning and use habits of mind—such as seeking accuracy and clarity, keeping an open mind, responding appropriately to others' feelings and level of knowledge—that make students feel accepted and capable in the classroom.

The first step in using peer assessment is to teach students the steps in the peer assessment process. For this instruction to be effective, it must help students understand how to recognize quality work and how to provide feedback that highlights both accomplishments and deficiencies demonstrated by the work. We need to explain to students what they should look for in samples of student work and model the process of examining work for evidence of those indicators. We also need to guide discussions of samples of work that include formative feedback to help students learn what to look for as evidence of learning and how to provide comments that will help their peers take the steps they need to improve their work. Finally, we need to help students learn how to discuss their work with one another in class. Discussion allows students to share their ideas and reveal their thinking. This two-way sharing can help students clarify their own ideas and, occasionally, lead them to revise their thinking to include the viewpoints of others.

The first step in using habits of mind is to call explicit attention to these skills, define them, and explain how they relate to learning. In addition, teachers should discuss how the habit of mind is associated with specific behaviors that help students be more metacognitive. You can explain to students that metacognition is sometimes described as having an internal conversation with yourself about what you are doing and how well you are doing it. To use ideas about metacognition and habits of mind in the classroom, teach students how to predict outcomes (critical thinking), activate their background knowledge, plan ahead, note when their thinking does not lead to comprehension, and explain to themselves how to improve their understanding of the content (all of which are aspects of self-regulated thinking). Students and teachers need to discuss and practice the actions associated with habits of mind to learn how to use them. With practice, students—even very young ones—should be able to monitor their own thinking and comprehension without teacher support.

Exploring the Strategy

To develop their abilities to assess their peers, students need examples of significant work that is intellectually engaging. Examples of such work result from engaging students in inquiries in which they explore a scientific question. Inquiries, whether guided or open-ended, involve students with gathering and analyzing data, formulating explanations from the evidence, connecting their explanations with scientific knowledge, and communicating and justifying their explanations. In most classrooms, students gather this information in science notebooks. Some teachers ask the students to place their work into portfolios.

One way to start using peer assessment is to ask the students to trade science notebooks or portfolios and simply check one another's work, looking for specific indicators of performance. For example, are charts and graphs labeled? Do the measurements use the correct units? Are the key vocabulary words included? Do the explanations make sense on the first read and does the student cite evidence? After checking for these indicators, students can practice writing comments that point out one thing that was done well and provide one suggestion for what to look out for in future work. Many students do not want others, including the teacher, to write directly on their work; ask students to provide their comments on sticky notes or a comment sheet where comments can be added each time there is a peer review opportunity. Peer assessment can be used even with young students. They can review pictures and diagrams and ask about the meaning of various parts of the representations.

The feedback from peer review is only valuable if students use the feedback they receive. Small groups or the whole class can discuss the comments they received to determine if they agree with the feedback or not. If there is consensus, then students need to respond to the feedback by writing a summary of what they will do to improve the quality of their work. Through repeated experiences with the peer-assessment process, students will become more objective about the feedback they receive, which will help them be better self-assessors.

There are many approaches to teaching the habits of mind, which include critical thinking, creative thinking, and self-regulated thinking (Marzano and Pickering 1997). One simple approach is to model the process, using an appropriate example. To help students consciously think about these metacognitive processes, you will want to provide multiple opportunities for them to practice using the habits of mind. For example, to help students think critically, you can ask them to conduct an error analysis when the results of their investigations don't match their predictions. Asking students to be accurate and clear about their findings when they present and discuss their evidence provides another opportunity to think critically. They also practice thinking critically when they keep an open mind to others' ideas and proposed explanations as they seek clarity about what happened.

Another way to ask students to think critically in science class is to ask them to debate a science issue related to the concepts in a particular unit. For example, should we use antibacterial soap? Some say this is creating resistant bacteria that hospitals can't fight. Or try discussing the question "Which is better, tap water or bottled water and why?" These kinds of debates ask students to provide evidence to support their claims and use evidence to critique the claims and predictions of others (Banilower et al. 2008). You can teach formal debate procedures or use a simple "fish bowl" format. In the "fish bowl" format, several students sit in a small circle in the middle of the room with the rest of the students in chairs outside of the circle. There are a few empty chairs in the inner circle that provide space for students outside the circle to join the discussion on a short-term basis. The students seated in the circle are asked to take a position on a question and use evidence to support their claims. The students outside the circle listen to the discussion and join in if they have points to add to the conversation. Those in the circle can similarly cycle out to the perimeter. Some students will need to remain in the circle to carry on the discussion. These students should be designated ahead of time or, at some point, there may not be a sufficient number of students inside the fish bowl to sustain the discussion. Designated students on the outside of the circle could serve as process observers, noting when students in the circle demonstrated the attributes of critical, creative, or self-regulated thinking. At the end of the debate, ask these students to give feedback on the metacognitive practices that were demonstrated.

Planning for Classroom Implementation

Implementation of this strategy requires that you plan how you will provide students with the criteria for quality work. It is important to provide these criteria so that students become aware of what success looks like. That will enable them to recognize and articulate problem areas in their own work and the work of others. Be sure you understand, and can explain to students and parents, the benefits of peer assessment. Peer assessment helps students learn about the characteristics of quality work and use this information to improve their own work. Consider how you will provide opportunities for students to verbalize their own thinking. Doing so will help them monitor their understanding. The more they do this, the more they will be able to understand whether new information is consistent with what they already understand. At the same time, they will become adept at identifying what they don't understand conceptually.

Habits of mind refer to mental processes that students use consciously, not behaviors that student do without thought. Our goal is that students apply these mental processes when they are learning science or any other content. In the science classroom, critical thinking includes analyzing errors and weighing evidence to be used in decision making. Thinking creatively in science class involves thinking abstractly and being inventive. To encourage the development and use of habits of mind in your classroom, you will need to present students with activities that require them to analyze errors and weigh evidence (critical thinking), wrestle with abstract concepts and be inventive (creative thinking), and master the art of self-assessment with the help of feedback (self-regulated thinking). Planning for implementation of habits of mind includes determining how and when you will model these habits, provide students with opportunities to practice using them, and reinforce their use.

To plan lessons that support teaching and learning about the habits of mind, think about upcoming learning activities that you might do with your students. Determine what kinds of outcomes you would like students to achieve as a result of these activities and determine how those outcomes relate to the habits of mind. Scan the characteristics for critical, creative, and self-regulated thinking. Use the suggested methods contained in Figure 4.13 (p. 184) to find strategies that will address your desired outcomes.

Figure 4.13
Habits of Mind

Habits of Mind	Methods
Critical Thinking • Be accurate and seek accuracy. • Be clear and seek clarity. • Maintain an open mind. • Restrain impulsivity. • Take a position when the situation warrants it. • Respond appropriately to others' feelings and level of knowledge.	**Help students understand productive habits of mind.** • Facilitate classroom discussion. • Use examples from literature and current events of people who are using the habits in different situations. • Share personal anecdotes. • Notice and label student behavior that demonstrates a habit. • Ask students to identify personal heroes or mentors and describe the extent to which they exemplify specific habits of mind. • Have students create posters that illustrate their understanding of the habits.
Creative Thinking • Persevere. • Push the limits of your knowledge and abilities. • Generate trust, and maintain your own standards of evaluation. • Generate new ways of viewing a situation that are outside the boundaries of standard conventions.	**Help students identify and develop strategies related to the habits of mind.** • Use think-aloud to demonstrate specific strategies. • Ask students to share their own strategies. • Encourage students to find examples of strategies mentioned in literature and current events. • Ask students to interview others to identify strategies. • Each quarter or semester, ask students to identify and focus on a habit of mind they would like to develop.
Self-Regulated Thinking • Monitor your own thinking. • Plan appropriately. • Identify and use necessary resources. • Respond appropriately to feedback. • Evaluate the effectiveness of your actions.	**Create a culture in the classroom and the school that encourages the development and use of the habits of mind.** • Model the habits. • Integrate the habits into the daily routines and activities of the classroom. • Develop and display posters, icons, and other visual representations to express the importance of productive habits of mind. • When appropriate, cue students to focus on specific mental habits or ask them to identify habits that would help them while working on difficult tasks.
	Provide positive reinforcement to students who exhibit the habits of mind. • Appoint "process observers," students who watch for positive examples of other students who are demonstrating the habits. • Ask students to self-assess their use of specific habits. • Give students feedback on a report card or progress report.

Adapted from Marzano, R., and D. Pickering. 1997. *Dimensions of learning trainer's manual*. Alexandria, VA: Association for Supervision and Curriculum Development.

Determine how you will teach, model, practice, and emphasize the type of thinking (critical, creative, self-regulated) that will support your learning goals. Remember, if we want students to be metacognitive, we must first model and teach metacognitive strategies. Then students need opportunities to practice and discuss the strategies. With time, students will develop their self-regulation skills and be able to have productive internal conversations with themselves without teacher support.

What Works in Classrooms: Implications for Teaching

Recommendation 1: Teach students how to engage in peer and self-assessment. Teaching students to peer and self-assess helps them recognize what quality work looks like. For these processes to contribute to student learning, the tasks you assign must be robust enough to reveal student progress toward conceptual understanding. Your role in these processes is to ensure that students know how to write appropriate comments and discuss work with peers and to facilitate discussions about how to examine work against a set of criteria. These practices will help students become more aware of the quality of their own work, when they are on track with their learning, and when they need help and feedback to move forward.

Recommendation 2: Teach students metacognitive strategies that help them construct new knowledge, monitor their own progress, and contribute to the positive climate in the classroom. Students construct new understandings based upon their current knowledge and how that knowledge is connected to new experiences. Given that, one of the first tasks you will want to accomplish when introducing new content is to make visible students' current thinking about the content. Metacognitive strategies that help students engage in creative, critical, and self-regulated thinking prompt learners to elaborate on their existing ideas by incorporating new learning into a set of coherent ideas. To ensure that students are able to use such strategies, model the strategies and provide opportunities for students to practice them and receive feedback on how well they are using them. As part of implementing this recommendation, involve students in collaborative learning experiences that provide opportunities for them to share and clarify their understanding of content.